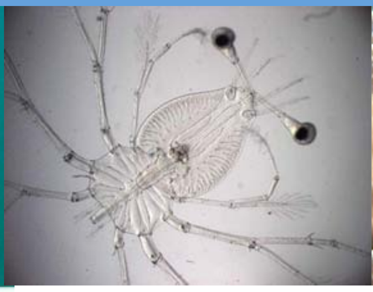
Implications of climate change impacts on fisheries resources of northern Australia

Part 2: Species profiles



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Background

The species profiles herein are a selection of 23 of the some of the most important fishery species of northern Australia. Although there are many others that could have been included, the species were selected to be representative of the regions, fishery sectors and taxa, while also being identified as high priority species during consultations with stakeholders. As a companion report to *Part 1: Vulnerability assessment and adaptation options,* the information compiled here for each species provided the necessary baseline information for this project: (i) carry out further species sensitivity data analyses, (ii) conduct the species-based vulnerability assessments, and (iii) identify appropriate adaptation options and barriers. Each species profile covered the following aspects: fisheries, biology, ecology and life cycle, and environmental sensitivity and resilience in a climate change context. This content followed the template set by the similar project conducted in south-eastern Australia (Pecl et al. 2011) thereby ensuring consistency across projects.

Each profile involved comprehensive literature reviews so as to provide the most up-to-date, and therefore relevant, information to inform the major tasks of the project. Firstly, identifying the known sensitivity of each species to key environmental (climate) variables helped us to set up hypotheses for testing for the data analyses conducted for some species, determined the information gaps, and informed the development and scoring for the vulnerability assessments. Documenting the biology, ecology and life history also informed the development of the hypotheses as well as the vulnerability assessments. Information about the fisheries, including their management and operational characteristics, was important also in informing the vulnerability assessments, and particularly in identifying adaptation options for fisheries.

This report should represent a useful and interesting stand-alone resource for any fishing stakeholder group in northern Australia.

Reference:

Pecl GT, Doubleday Z, Ward T, Clarke S, Day J, Dixon C, Frusher S, Gibbs P, Hobday A, Hutchinson N, Jennings S, Jones K, Li X, Spooner D, and Stoklosa R (2011). Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia. Part 2: Species profiles. Fisheries and Aquaculture Risk Assessment. Fisheries Research and Development Corporation, Project 2009/070.

INVERTEBRATES

1. Banana prawn, *Penaeus merguiensis*

Authors: Julie Robins and David Vance

Banana prawns belong to the family *Penaeidae*. Over 50 different species of penaid prawns occur in Australian waters, with about 10 species of major economic importance. Despite all belonging to the same family, commercially important prawns in northern Australia have distinct differences in their distribution, habitat preferences, seasonality, recruitment dynamics and migratory abilities. These differences suggest that Australian penaeid prawn species are likely to have different sensitivities and resilience to any changes in environmental conditions resulting from long-term global climate change.

The fishery

Key points:

- The two key fisheries for banana prawns can be divided into the Queensland east coast (river and estuarine beam trawl fishery, and the offshore otter trawl fishery) and the Northern Prawn fishery, which operates from the Gulf of Carpentaria to Cape Londonderry in Western Australia.
- It is estimated that the Northern Prawn Fishery harvests ~90% of the annual banana prawn population.
- In northern regions catch is influenced by SOI and rainfall/riverflow, while temperature is likely to play a more significant role in southern regions.

<u>Queensland east coast</u>

Banana prawns are taken by commercial and recreational fishers on the Queensland east coast. Commercial fisheries include the river and estuarine beam trawl fishery, which harvests regional sub-stocks of juvenile and sub-adult banana prawns, and offshore otter trawls, which harvest schools of sub-adult and adult banana prawns. Offshore schools of banana prawns are generally associated with major river systems and can be geographically grouped into the following sub-stocks (Tanimoto et al. 2006): Cooktown, Cairns, Tully, Townsville, Mackay, Fitzroy, Gladstone, Burnett, and Moreton. The annual harvest of banana prawns in the otter trawl fishery is variable, ranging from 230 t to 978 t, with an average of ~500 t. The annual harvest in the beam trawl fishery is more stable, ranging from 71 t to 235 t, with an average of 133 t. There is also a relatively small commercial stripe net fishery for banana prawns in the Burnett and Mary River systems. Recreational fishers also harvest bananas prawns via cast netting in estuaries and near shore areas adjacent to major population centres. The recreational harvest varies between years and regionally, but is thought to be in the order of ~100 t (Tanimoto et al. 2006) .

The multi-species Queensland East Coast Otter Trawl Fishery occurs from the border between Queensland and New South Wales northwards to the Torres Strait. This fishery is managed by input controls including limited entry, net and mesh size regulations, individual effort limits, vessel restrictions, and spatial and temporal closures. However, there are no specific input controls for banana prawns. Banana prawns are predominantly harvested during daylight and are different to others species captured within the fishery in that a significant amount of the fishing effort is spent "searching" for aggregations of banana prawns.

Northern Prawn Fishery

Banana prawns are a commercial only harvest in the Northern Prawn Fishery, a commonwealth managed fishery between Cape Londonderry (Western Australia) and the western tip of Cape York (Queensland). Two species of banana prawns are caught in the fishery. The common banana prawn, *Penaeus merguiensis*, is caught throughout much of the fishery while the Indian banana prawn, *P. indicus,* is caught in two locations; in Joseph Bonaparte Gulf and in a small area just north of Melville Island. Banana prawns are harvested over a tightly controlled season beginning in April and which can last between 6 and 14 weeks, depending on the banana prawn abundance and subsequent catch rates. The catch of banana prawns in the Northern Prawn Fishery is variable, with catches around ~5,800 tones for 2008, 2009 and 2010; ~7,100 tonnes in 2011 and ~4,900 tonnes in 2012 (AFMA 2013). The fleet of the Northern Prawn Fishery is thought to harvest around 90% of the annual banana prawn population. Although two species of prawns are caught in the fishery, they both have similar estuarine habitat requirements as juveniles and their responses to climate change will probably be similar.

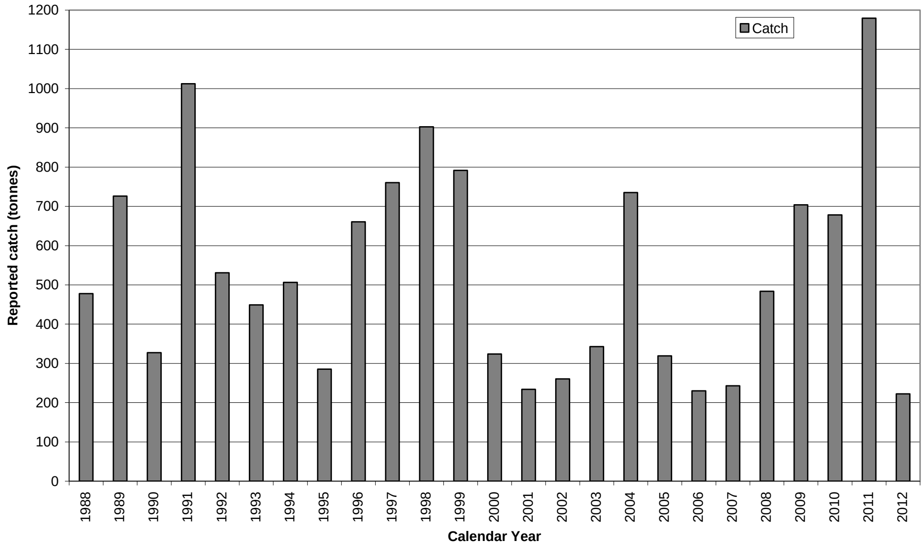

Figure 1.1. Reported catch of banana prawns for Queensland East Coast Otter Trawl Fishery.

Life history

Key points:

- Banana prawns appear to be able to adapt to local environmental conditions, with Indian banana prawns from the Red Sea adapted to the high salinity conditions.
- Recruitment is spatially variable, and probably linked to rainfall and riverflow.
- Sub-stocks exist along the Queensland east coast and the Gulf of Carpentaria with limited exchange between sub-stocks.

Life cycle, age, growth and environmental variation

Banana prawns are an estuarine and coastal species, and as adults are associated with waters up to 20 km from the coast and up to 45 m depth (Grey et al. 1983). Banana prawns have a typical type-2 penaeid life cycle (Dall et al. 1990). Adolescent banana prawns migrate downstream from estuarine habitats to marine waters. Here, they mature and spawn eggs which are demersal for less than a day, before becoming pelagic larvae. Larvae and post-larvae migrate from offshore waters into estuaries using tidal currents, and settle as post-larvae in mangrove-lined estuarine nursery habitats. Juvenile banana prawns remain in the estuary for several months, before migrating out of the estuary to coastal marine waters.

Banana prawns can spawn throughout the year if water temperatures are appropriate. In northern Australia, there are usually peaks of population spawning in autumn, when individuals spawned in the previous spring mature into adults, and also in spring, when water temperatures warm up after winter. Spring-spawned individuals migrate into nursery habitats between November and March and it is likely that they contribute most to the autumn commercial fishery for banana prawns in coastal and offshore waters of both the NPF and the Queensland ECOTF.

Banana prawns are thought to have a one-year life cycle although some older prawns are caught in commercial catches. A complicating factor is the report by Dredge (1985) of the recruitment of juvenile banana prawns (>10mm carapace length, CL) into the Burnett River in southeastern Queensland from December to March as well as May to June. Large banana prawns have been recorded in the estuaries of central and southern Queensland during winter and there is some speculation that this is indicative that banana prawns in this area may have a six-month life-cycle with two generations per year (Dredge 1985).

Haywood and Staples (1993) used length-frequency analysis and modal progression to derive growth rates for banana prawns during the estuarine phase of their life cycle. They found that growth rates ranged from 0.63 to 1.65 mm carapace length per week, and that a linear model could describe the relationship between growth, water temperature (a positive effect) and prawn density (a negative effect). Previously, Staples (1980b) used polymodal frequency analysis (assuming negligible effects of size-selective mortality within a cohort) to derive the mean carapace length of different cohorts at weekly intervals and then estimated growth rates. Staples (1980b) noted sexual dimorphism in size occurred at >10mm carapace length, although slight differences in growth rates between females and males was not of sufficient magnitude to include in growth equations.

Temperature, as in all crustaceans, affects various aspects of the life cycle of banana prawns. Spawning of adult prawns in the Gulf of Carpentaria occurs over a wide range of water temperatures but seems to be particularly stimulated by increasing temperature during spring time (Crocos and Kerr 1983). They also found that the maximum proportion of females spawning in the north eastern Gulf occurred in January when water temperatures were around 30°C. It is not known what maximum temperature would prevent banana prawns from spawning at all.

Nauplia, protozoeal and mysis stages of *P. merguiensis* spawned from adult prawns caught in Pakistan had the highest survival in 30 to 35 ppt salinity (Nisa and Ahmed 2000), while in India, the best hatching rate of eggs was found at 33ºC and salinity of 35 ppt (Zacharia and Kakati 2004). They also found that survival rates after hatching were higher at 33ºC and salinity of 35 ppt.

There is no evidence of temperature affecting the migration of banana prawn postlarvae into estuarine nursery grounds but low estuarine salinities do seem to prevent the immigration of postlarvae to estuaries in the Gulf of Carpentaria (Staples 1980a; Vance et al. 1998a).

Haywood and Staples (1993) reported that salinity had no detectable effect on growth rates of juvenile banana prawns. However, in a laboratory experiment, juvenile banana prawns were found to have optimal food consumption and production at 20 ppt salinity, while at higher salinities there was a considerable decrease in growth and food consumption (Vinod et al. 1996). In contrast, Saldanha and Achuthankutty (2000) report that growth of juvenile banana prawns increased with salinity (up to 40 ppt). Staples and Heales (1991b) reported that the optimum temperature and salinity for the growth in length of juvenile banana prawns (i.e., shortest intermolt period and largest moult increment) was 31ºC and 30 ppt salinity (resulting in a weekly growth rate of ~1mm/week). However, taking into account survival, the optimum temperature and salinity for the greatest increase in biomass and production were 28ºC and 25 ppt salinity. Staples and Heales (1991b) concluded that deviations from the optimum temperature had a greater effect on productivity than changes in salinity. Based on their experimental work, Staples and Heales (1991b) predicted that in an estuary, postlarval prawns would grow quickly but suffer high mortality when temperature and salinity were high, but would grow slowly and remain in nursery areas if the salinity of the estuary fell below 20 ppt**.**

One of the most interesting studies was by Kumlu and Jones (1995). They examined the growth and survival of *P. indicus* using postlarvae reared in the laboratory from brood stock that originated in India. They used the same experimental protocol as had been used by Bukhari *et al.* (1994) who studied *P. indicus* bred from adults caught in the Red Sea. Water temperatures were between 29 and 31ºC and salinities tested ranged from 10 to 50 ppt. Kumlu and Jones (1995) found that these hatchery-reared postlarvae of *P. indicus* tolerated a wide range of salinities. For the smaller postlarvae, up to about PL20, the lower salinities produced the best growth and survival. However, from PL20 to PL60, the growth and survival of the Indian postlarvae was highest at salinities of 20 and 30 ppt, whereas for the Red Sea postlarvae, the highest growth and survival was at salinities of 35 ppt and higher with maximum yield at 50 ppt.

It would appear that there are two distinct strains of *P. indicus;* the Indian laboratory postlarvae behaved similarly to wild-caught Indian postlarvae while the Red Sea postlarvae seemed to be adapted to the much higher salinities that occur naturally in the waters of the Red Sea. The results suggest that banana prawns have the capacity to adapt to different environmental conditions. Emigration of juvenile and adolescent banana prawns from estuaries occurs mostly during the wet season and is highest immediately following high rainfall (Staples and Vance 1986; Vance et al. 1998a). This response is probably mediated by a physiological response of the prawns to low salinity (Dall 1981).

Commercial catches of banana prawns in some regions of the Northern Prawn Fishery are highly correlated with rainfall during the previous wet season (Vance *et al*. 1985; Vance *et al*. 2003). This high correlation is a consequence of the increased emigration of prawns from estuaries during periods of high rainfall (see previous paragraph). Vance *et al*. (1985) also noted a negative correlation between wet season temperatures and the annual commercial banana prawn catch, but this should not be interpreted as a direct effect of temperature on prawn catches. It is simply a result of the negative relationship between rainfall and temperature; high rainfall during the wet season results in lower air temperatures.

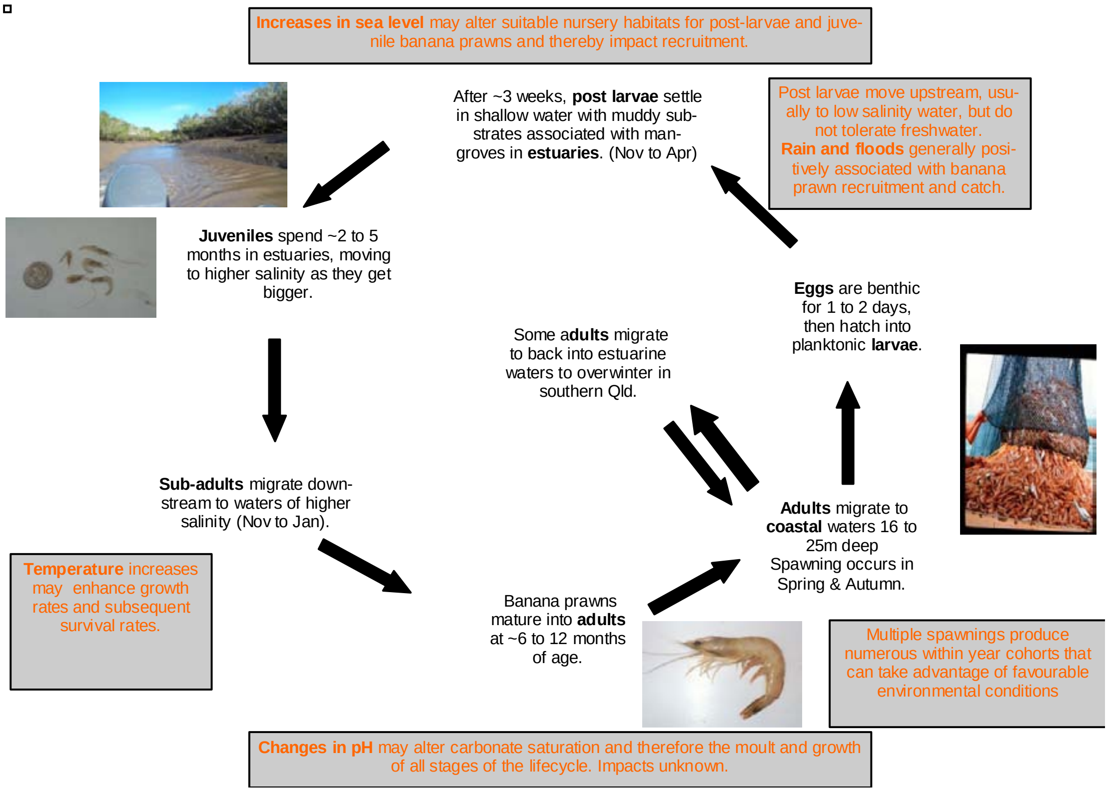

Figure 1.2. Generalised life cycle of the banana prawn. (Images sourced from QDAFF).

Distribution, habitat and environmental preferences

Banana prawns are distributed in tropical and sub-tropical areas from Shark Bay (Western Australia) to Northern New South Wales (Figure 1.3). The benthic post larvae and juveniles are usually associated with estuaries that have mangrove-lined muddy banks and freshwater influences. Banana prawns are very rarely found in locations in estuaries where there are no mangroves. The small prawns move into mangrove forests as the water level rises on high tide and then move out into the open rivers and creeks as the water level falls towards low tide. Vance *et al.* (2002) sampled inside mangrove forests over several years and concluded that, in general, the fringing parts of the mangrove forests were used more by the banana prawns when they were inside the mangroves at high tide.

Juvenile and sub-adult banana prawns gradually migrate downstream as they increase in size and emigrate from the estuaries to coastal waters in summer and autumn at times of high seasonal rainfall and decreases in estuarine water salinity (Staples and Vance 1986; Meager et al. 2003b; Halliday and Robins 2007). Adults are trawled offshore in schools at depths between 16 and 25 m (Tanimoto et al. 2006).

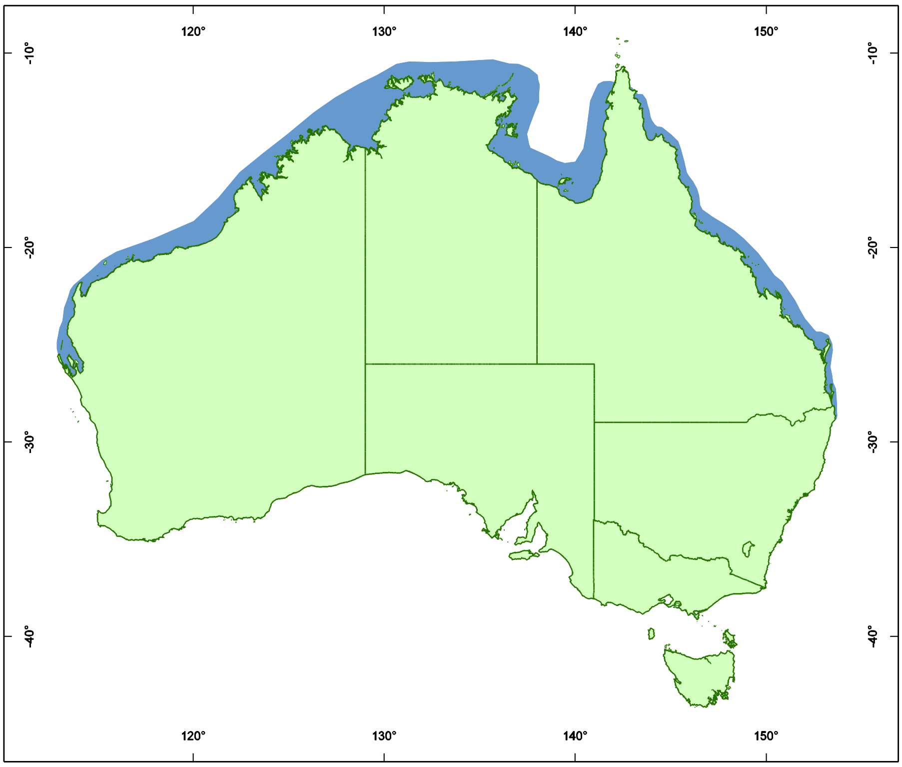

Figure 1.3. Australian distribution of the banana prawn, *P. merguiensis.*

<u>Predators and prey</u>

Banana prawns are an important part of the food chain and are eaten by many species of fish, including some of commercial value. Salini *et al.* (1990) and Salini *et al.* (1998) found that juvenile *P. merguiensis* were important prey of many fish species in two estuaries in the Gulf of Carpentaria. In the northeastern Gulf of Carpentaria, banana prawns were eaten by ten out of the 26 predators that were caught in good numbers in the estuary, including the highly valuable barramundi, *Lates calcarifer*. Salini *et al.* (1998) also found that fish seemed to target banana prawns at times when the prawns were more abundant. Robertson (1988) also found that juvenile *P. merguiensis* were eaten by several fish, including young barramundi. Other studies didn't identify prawns to species but also identified that penaeid prawns were an important part of the diet of some fish in estuaries in the Northern Territory (Davis 1985) and on the Queensland east coast (Russell and Garrett 1983). Adult banana prawns on the commercial fishing grounds of Albatross Bay in the Gulf of Carpentaria were a significant component of fish diets. Brewer et al. (1991) estimated that predators of banana prawns (i.e., fish) consume about 3x as many banana prawns as are harvested by the Northern Prawn Fishery.

Whilst in estuaries, juvenile banana prawns are carnivorous detritivores, consuming a wide range of organisms and organic detritus (Chong and Sasekumar 1981). Gut-content studies report unidentified debris as well as live benthic and pelagic animals such as polychaetes, copepods, amphipods, isopods, mysids, carids, sergestids, foraminifera, molluscs, gastropods, nematodes, insects, diatoms, algae, bacteria, epiphytes (Wassenberg and Hill 1993). Banana prawns feed while inside mangrove forests as well as in the shallows of creeks and rivers when the water levels are below the mangroves (Logan River – Sue Pillans, personal communication). Newly arrived pelagic post-larvae are carnivorous, feeding mostly on calanoid copepods, while epibenthic post-larvae and juveniles are carnivorous detritivores feeding on detritus, foraminiferans (Rhotallidae), copepods (calanoid and harpacticoid), larval bivalves, diatoms and brachyuran larvae (Chong and Sasekumar 1981). Subadults are detritivorous carnivores feeding on large crustaceans such as *Acetes* and mysids, with lesser amounts of detritus. Adults are detritivorous carnivores feeding on detritus and animals (e.g., large crustaceans *Acetes*, molluscs and fishes) in equal amounts. Plant material consumed by juveniles (in small but consistent amounts) included pieces of mangrove, filamentous algae (*Trichodesmium* and *Microcoleus* spp), and diatoms (*Coscinodiscus*, *Cyclotella*, *Pleurosigma* and *Gyrosigma* app.)

Isotope studies are suggested to give a better indication of the relative importance of dietary items because results indicate a time-integrated, objective measure of carbon assimilated by the organism (Primavera 1996). Several authors have investigated the isotopic signature of banana prawns to identify the relative importance of the various organisms in the nutrition of banana prawns. Newell *et al.* (1995) reported that juvenile banana prawns living in tidal creeks derived nutrition from mangrove sources as well as benthic microalgae, although the greater relative abundance of mangrove detritus in tidal creeks resulted in its greater consumption by juvenile banana prawns. Primavera (1996) reported that $\delta^{13}C$ of banana prawns (-18) was closer to plankton and epiphytic algae (-22.6 and –24.3 respectively) than to mangroves (-28.6). She reported a similar finding for $\delta^{15}N$, with banana prawns (<9 mm to 30 mm CL) having a signal (6.9) closer to epiphytic algae (6.0) than to decomposing mangrove leaves (3.8) or plankton (2.3). Primavera (1996) noted that the high $\delta^{15}N$ for epiphytic algae may be due to contamination by nematodes and meiofauna present in the samples. Primavera (1996) suggested that the enriched $\delta^{15}N$ signal of banana prawns suggests that prawns are two to three levels up the trophic chain from phytoplankton (assuming a 2.4% enrichment per trophic level). Primavera (1996) suggested the use of stable S to improve the understanding of plankton-penaeid shrimp connections. Loneragan *et al*. (1997) found similar results to those of Primavera (1996). Banana prawns had $\delta^{13}C$ and $\delta^{15}N$ values closer to that of macroalgae/seston. Values of $\delta^{34}S$ were between the values of a seagrass (*E. acoroides*) and a mangrove (*C. tagal*). They concluded that juvenile banana prawns were likely to obtain <10% of their nutrition from mangrove detritus.

Recruitment

Banana prawns recruit in multiple cohorts into estuaries between November and May.

Current impacts of climate change

There are no documented impacts of climate change on banana prawns, although there are documented links between harvests and river flow/rainfall.

Sensitivity to change

Key points:

- Banana prawns are highly reliant on mangrove-lined mud banks in estuarine areas for postlarval growth and survival and negative consequences on mangrove distribution due to sea level rise would result in decreased banana prawn abundance.
- Banana prawn growth and survival has been shown to be optimal at 28 °C compromised at temperatures of 35 °C. Increase in SST may impact on banana prawn abundance in far northern areas.

Many species of prawn show relationships between catch and environmental variables (see Dall et al. 1990 for review; Vance et al. 2003; Halliday and Robins 2007) but these relationships are not always consistent over time and space. Prawns also prefer optimum environmental conditions (e.g. salinity, temp) and these optimums vary between prawn species, reflecting their life-cycle preferences as classified by Dall *et al*. (1990). Banana prawns inhabit estuaries and as such, are already exposed to daily and seasonal fluctuations in many of the physical attributes of shallow waters (i.e., <5m), including water temperature, salinity, turbidity, and pH.

Potential impacts of climate change on banana prawns can be divided into two categories; direct impacts on the survival and/or growth of the prawns, and indirect impacts due to changes in habitat or other characteristics of the environment or ecology.

Direct impacts

Increase in water temperature is the factor most likely to have a direct impact on banana prawns survival and growth. Staples and Heales (1991a) found that the optimum condition for increase in biomass of juvenile prawn populations in the laboratory was at a temperature of 28°C and salinity of 25 ppt. They also found that after six weeks at 35°C and at 35 ppt, all prawns kept under those conditions died. Clearly, there is some potential for impact on banana prawn populations if water temperatures increase substantially. Rothlisberg *et al.* (1998) discussed potential impacts of climate change on banana prawns and felt that increased water temperatures of 2 to 3°C would not significantly affect spawning behaviour of the prawns.

We need to be careful when we interpret some published results on the effects of temperature. For example, Vance *et al.* (1985) found a significant negative correlation between wet season temperature and annual commercial prawn catch. However, wet season temperature is negatively correlated with the amount of wet season rainfall. In fact, it is the rainfall that is driving the catch correlation, not temperature. This is confirmed by detailed biological studies that showed that prawn emigration from the estuaries was highly correlated with rainfall events (Staples and Vance 1986; Vance *et al*. 1998b). Variation in rainfall can have significant impacts on the abundance of adult banana prawns in offshore waters. In some regions of the Gulf of Carpentaria, it would be possible to make quite good estimates of how offshore commercial catches would vary if annual rainfall increased or decreased to particular levels (Vance *et al*. 1985; Vance *et al*. 2003).

As well as variation in total rainfall, banana prawn abundances could be susceptible to changes in seasonal patterns of rainfall. The banana prawns life cycle requires medium to high salinities in the estuarine nursery grounds in spring and early summer so that postlarval prawns can migrate into the estuaries and spend two to three months growing within the estuary. Increased rainfall and lower salinities during the summer wet season and early autumn then stimulates the adolescent prawns to move offshore again. If the length of the wet season increased substantially and if salinities became low during late spring and early summer then post larval prawns might be prevented from reaching the nursery habitat and therefore not survive through to adulthood.

It is important to note that research on banana prawns in the Gulf of Carpentaria has shown strong correlations between rainfall and offshore adult banana prawn catches in some regions but not in others (Vance et al. 1985). However, more detailed biological research in the estuaries in these regions has shown that prawns in the different regions still emigrate from the estuaries in response to rainfall/low salinity (Vance et al. 1998a). The lack of correlation between rainfall and offshore catch in some regions is not because the prawns behave differently in different regions but because of other factors such as different levels of rainfall in different regions and lower variability in rainfall between years in some regions or difficulties in estimating actual abundances of prawns.

Indirect impacts

The most significant potential indirect impact on banana prawns would be an increase in Mean Sea Level (MSL), which might impact the primary estuarine nursery habitat of juvenile prawns. Juvenile banana prawns are very sensitive to the availability of mangrove-lined mud banks and are only found associated with mangrove-lined mud banks. If MSL increased so dramatically that mangroves disappeared from some areas, then banana prawn abundance would also decrease.

Resilience to change

Key points:

- Banana prawns are likely to be resilient to increases in temperature projected for northern Australia over at least the medium-term (~50 years).
- Populations of banana prawns are likely to perpetuate in the face of reduced riverflow, however, future fishery harvest levels of banana prawn may decrease in some of these regions.

Temperature

From laboratory experiments, juvenile banana prawns are unlikely to survive extended periods living in water temperatures of 35°C or greater (Staples and Heales 1991b). During the 1970's to the 1990's, water temperatures at Karumba and at Weipa in the northern Gulf of Carpentaria reached just over 30°C at times (D. Vance personal observation). If water temperatures in northern Australia consistently reach 35°C then it would appear that banana prawn abundances would almost certainly decrease in some areas. However, we must use some caution in extrapolating the results of Staples and Heales (1991b) to banana prawns in far northern Australia. Their laboratory experiments used post larval and juvenile prawns caught from Emu Park, near Rockhampton, central Queensland east coast. It is possible that prawns that have been born and bred in warmer northern waters might survive water hotter than 35°C. Research on banana prawns in other parts of the world has certainly shown that prawns from different regions have different levels of growth and survival when subjected to the same conditions of temperature and salinity (Kumlu and Jones 1995).

If changes in water temperature occur gradually, as we would expect, it is quite likely that prawn populations may be able to adapt to higher temperatures resulting in less change than we would expect based on the results of Staples and Heales (1991). Although increased water temperatures might cause some stress for banana prawn populations in the far north of Australia, an increase in water temperature at the southern end of the range of banana prawns in Australia would almost certainly mean that populations of banana prawns would appear further south than they currently exist. In southeastern Queensland, near the southern end of the range of banana prawns on the east coast of Australia, the seasonal variation in water temperature is higher than in tropical waters, and warm temperatures were actually associated with higher juvenile prawn catches in the Logan River (Meager et al. 2003a; Courtney et al. 2011). Therefore, although the pattern of distribution of banana prawns in Australia might change to some extent in response to temperature change, the overall abundance of prawns may not change much.

Rainfall

As noted above, substantial, decreases in rainfall will probably lead to decreased abundances of adult banana prawns in offshore waters. In some regions of northern Australia we have seen large fluctuations in annual commercial banana prawn catches in response to changes in annual summer rainfall. However, even with very low levels of rainfall and when offshore catches have dropped to near zero, enough adults have survived to reproduce and even produce large populations of banana prawns within one year when rainfall conditions have improved (Vance et al. 2003). Therefore, we believe that although local populations of banana prawns may decrease, the species is sufficiently resilient that populations will survive. If wet season rainfall levels increased then banana prawn abundances would probably increase.

Mean Sea Level and effects on mangrove habitat

It is important to note that not all parts of the mangrove forests are equally important for banana prawns. Vance e*t al.* (2002) found that at high tide, juvenile banana prawns were more frequently caught at the fringes of the mangrove forests than deep inside the forests. Loneragan *et al.* (2005) found that, in Malaysia, the abundance of juvenile banana prawns caught near narrow fringing mangrove forests, 5 to 10 m wide, was the same as the abundance near wide mangrove forests.

It is likely that, if mean seal level (MSL) does increase, the increase will be gradual. In some areas the boundaries of the mangrove forests may simply shift further back from present river or creek edges. In other areas, the mangrove forests may simply continue to trap sediments as the MSL increases and the substrate level may also increase such that there is very little actual change in the pattern of mangroves. Unless the fringing mangroves are destroyed completely by climate change then we believe that changes in MSL will not impact banana prawn abundance or distribution. However, in areas where there are barriers to mangroves moving landwards with sea level rise (eg. coastal development) there will potentially be localised reductions in banana prawn abundance.

Other authors have come to slightly different conclusions on the potential impacts of MSL rise. Morison and Pears (2012) completed an expert based vulnerability assessment of the Queensland East Coast Otter Trawl Fishery and concluded that banana prawns in Queensland had a high level of ecological vulnerability to sea level rise and changed rainfall patterns, which could result in both positive and negative effects. Morison and Pears (2012) also found that banana prawns had a medium level of ecological vulnerability to higher sea surface temperatures, with effects on the growth and survival of juveniles.

Rothlisberg *et al*. (1988) assessed the possible impact of the greenhouse effect on commercial prawns in the Gulf of Carpentaria and concluded that, if the greenhouse effect leads to higher sea levels, higher rainfall and increased cyclone activity, we could expect an increase in banana prawn catches.

Other

Key points:

- Water resource extraction and management, particularly on the Queensland east coast, is a potentially significant additional stressor of banana prawns in estuarine ecosystems.

Ecosystem level interactions

Banana prawns are a key food source for many estuarine-dependent and inshore coastal species. Changes in the distribution and abundance of banana prawns may potentially effect the distribution and abundance of their predators.

Additional (multiple) stressors

Banana prawns are an estuarine-dependent species whose production is linked to river flows. Management of water resources for human use has the potential to exacerbate climate stressors, particularly under scenarios with reduced rainfall as human demand for water resources often takes precedent over ecosystem needs.

Critical data gaps and level of uncertainty

One of the critical data gaps is how banana prawns respond to altered pH at various stages within their life cycle.

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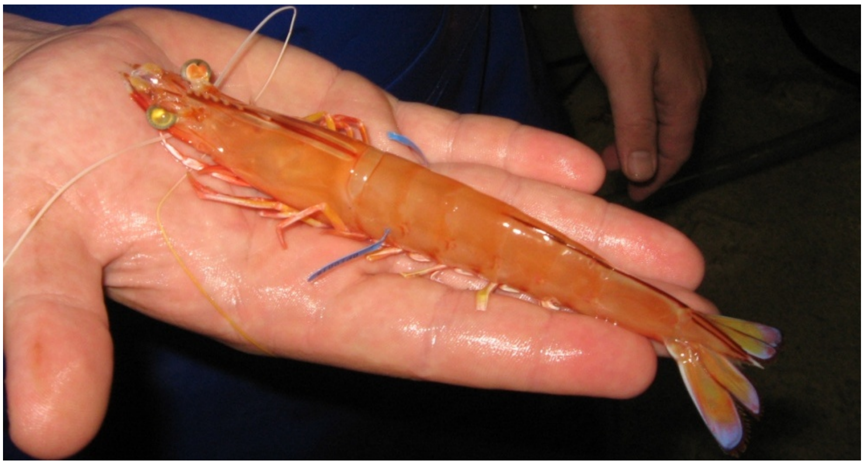
2. Eastern king prawn, *Melicertus (Penaeus) plebejus*

Authors: Julie Robins and Tony Courtney



Eastern king prawn, *Melicertus plebejus*. Photo: T.C. Courtney.

Eastern king prawns are predominately found on the east coast of Australia and are a single stock that is shared between Queensland and New South Wales. Although there are arrangements for collaborative stock assessment, the fishery is managed separately under each the state's jurisdiction.

The fishery

Key points:

- Eastern king prawns are a shared resource between Queensland and New South Wales, with Queensland producing about 80% of landings in the last five years.
- In Queensland the catch is commercial only.

Eastern king prawns are fished only by commercial trawlers in Queensland where they are taken as juveniles and adults in offshore otter trawls. Eastern king prawns form part of the multi-species East Coast Otter Trawl Fishery, which occurs from the border between Queensland and New South Wales northwards to the Torres Strait. Eastern king prawns are harvested across their distribution in Queensland, which is predominately south of 22°S. The eastern king prawn catch is worth around $32 million, based on an annual average catch of 2000 t and a price $16/kg received by fishers. The economic viability and profitability of the Queensland East Coast Otter Trawl Fishery is dependent on several factors, one of which is fuel price, and varies between sectors as there is a price differential for different species of prawn.

Management

The Queensland East Coast Otter Trawl Fishery is managed by input controls including: limited entry, net and mesh size regulation, individual effort limits, vessel restrictions, and spatial and temporal closures. However, there are no specific input controls for eastern king prawns or any other targeted species in the fishery. The fishery is managed under the Fisheries (East Coast Trawl) Management Plan 1999, with ten different endorsements for different aspects of the fishery. The fishery is also constrained by the zoning plans of the Great Barrier Reef Marine Park, Great Sandy Strait Marine Park and Moreton Bay Marine Park.

Operational characteristics

Trawl nets are used to capture prawns, scallop and several other allowed species in the fishery. Different net configurations are used in different sectors of the fishery, depending on the target species and the type of grounds fished. There are restrictions on the allowable combined head rope length and trawl net mesh sizes, with a limit of 24 fathoms head rope length in shallow-water and 50 fathoms head rope length in deep-water (O'Neill et al. 2003). Vessels targeting eastern king prawns in offshore waters generally use ‘triple rig’ gear i.e., three nets linked together in between two outer boards, and two inner sleds. This is a very stable configuration especially for trawling in waters up to about 300m deep and in strong currents. Trawling for eastern king prawn occurs at night, when this species emerges to feed from being buried in the sediment.

Vessels in the fishery have a maximum allowable size of 20 m. Around 350 trawl vessels participated in the fishery in 2008 (Anon. 2010), with not all boats participating in all sectors. Vessels vary in their characteristics that affect fishing power, i.e., technologies such as engine power, propeller nozzle, global positioning systems, plotters, and type of otter board. See O’Neill *et al.* (2003) for detailed descriptions of the fleet.

Catch and effort of eastern king prawns is recorded by fishers as part of a compulsory daily logbook program managed by Fisheries Queensland, and commenced in 1988. Eastern king prawns are also part of the Long-Term Monitoring Program by Fisheries Queensland. Fishery-independent surveys of eastern king prawn pre-recruit abundance have been conducted annually since 2006. Details of the survey can be found in Courtney *et al.* (2011).

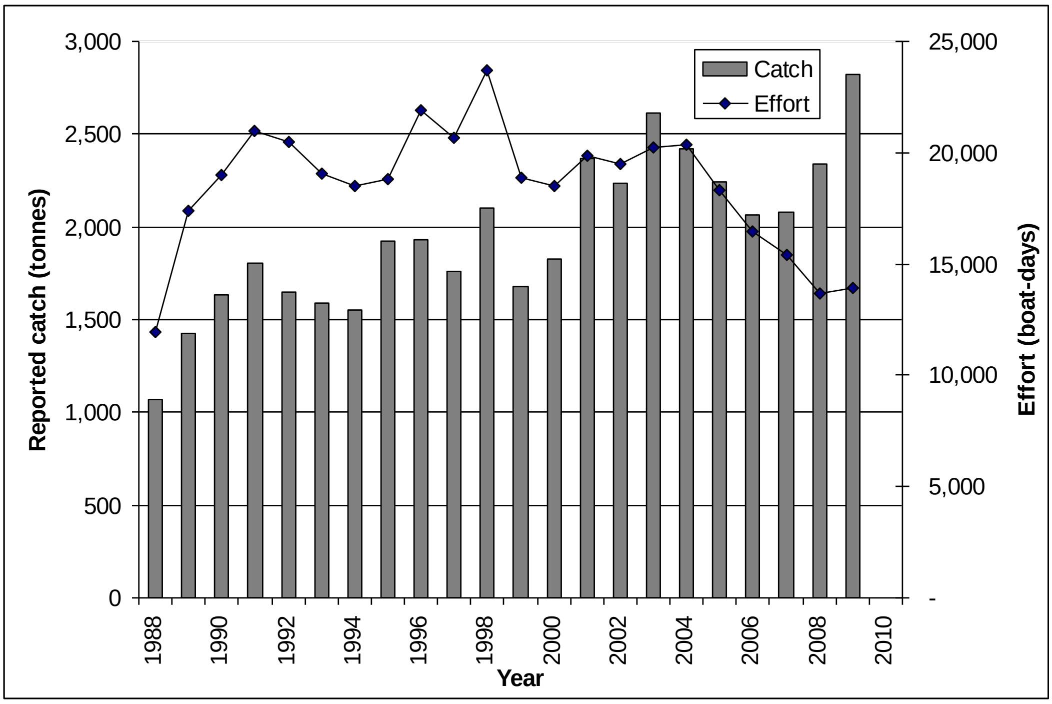


Figure 2.1. Eastern king prawn commercial catch (tonnes) and effort (boat days) by year for Queensland East Coast Otter Trawl fishery.

Life history

Key points:

- Recruits are probably sourced from a wide number of spawning locations along the Australian east coast.
- Although spawning occurs at multiple sites and times, recruitment of eastern king prawns to the fishery in Moreton Bay occurs between October and December.
- Eastern king prawns have an offshore preference as adults with early life history stages predominantly closer inshore.

Life cycle, age and growth

Eastern king prawns have a typical penaeid prawn life cycle of planktonic larvae, pelagic and then benthic postlarvae, juveniles and then adults. Adults spawn in offshore waters >90 m between January and August and spawning is thought to occur near the edge of the continental shelf (Ruello 1975; Courtney et al. 1995b; Courtney 1997c; Montgomery et al. 2007). The peak spawning season is between May and July. Eastern king prawns show extensive spatial population egg production (based on ovary weight, ovary histology, abundance of spawners) from NSW to central Queensland (Montgomery et al. 2007). There are likely to be multiple spawning grounds for eastern king prawn along the coastline of Queensland and New South Wales, with the Swains Reef Complex thought to be a major spawning ground (Courtney 1997a). Multiple spawning grounds provide this species with flexibility for inter-year variation in "effective" spawning areas i.e., areas providing recruits in any one year.

The distribution of pelagic eastern king prawn larvae into estuarine embayments (Ruello 1975; Courtney et al. 1995a; Rothlisberg et al. 1995) and the recruitment of eastern king prawn into the trawl fishery are almost certainly influenced by the south flowing East Australian Current and its eddies, as well as the predominately onshore winds between September and November in Queensland (Courtney et al. 1996). The benthic post-larvae settle on to bare substrates and seagrass (Young and Carpenter 1977). The post-larvae of eastern king prawn have an aversion to areas with freshwater influence, with fewer individuals settling in these areas and those that do only remaining at sites near river mouths for brief periods (Coles and Greenwood 1983).

Eastern king prawns spend about three months in estuarine embayments (Courtney 1997b) before migrating to ocean habitats (Lucas 1974). They mature into adults at 35 to 40 mm carapace length (CL) (Courtney et al. 1996) when they are between six to 12 months of age. Eastern king prawns can undertake extensive northerly migrations to as far north as the Swains Reef complex (Ruello 1975). Some individuals migrate more than 1300 km (Montgomery 1981).

Although eastern king prawns use embayments as nursery habitats, it is possible for their life cycle to be completed in offshore waters (Montgomery 1990), although this probably requires some type of shallow nursery habitat. Eastern king prawns have a lifespan of up to three years (Ruello 1975), but the majority of the population is thought to live for less than one year. Eastern king prawns have relatively fast growth rates (Glaister et al. 1987).

<u>Distribution, habitat and environmental preferences</u>

Eastern king prawns are found only on Australia's east coast and are distributed from Mackay to Tasmania in depths of 1 - 300 m (Courtney unpublished data). Adults have an offshore distribution, whilst juveniles are distributed throughout ocean-influenced estuaries between southern NSW and Bustard Head in central Queensland (Williams 2002), Queensland (Figure 2.3).

Courtney *et al*. (2011) investigated the influence of abiotic parameters on the standardised catch rates of eastern king prawns within Moreton Bay, Queensland. They reported that average daily flow of the Brisbane River, from one month, two months and three months prior to the catch date significantly affected the daily catch rates of eastern king prawns as did the mean daily maximum air temperature at Cape Moreton for the proceeding 60 days and the proceeding 120 to 180 days. Analyses indicated that abiotic parameters had significant but small effects on the catch rates of eastern king prawns. Flow one and two months prior and temperature in the preceding 60 days all had a positive influence on eastern king prawn catch. Flow three months prior to the catch had a negative influence on eastern king prawn catch. Temperature 121 to 180 days preceding the catch was considered to have the largest significant (negative) effect on the daily catch of eastern king prawns in Moreton Bay. This translated to warmer winter (i.e. April to August) temperatures resulting in lower than expected catch rates of eastern king prawns in October to December.

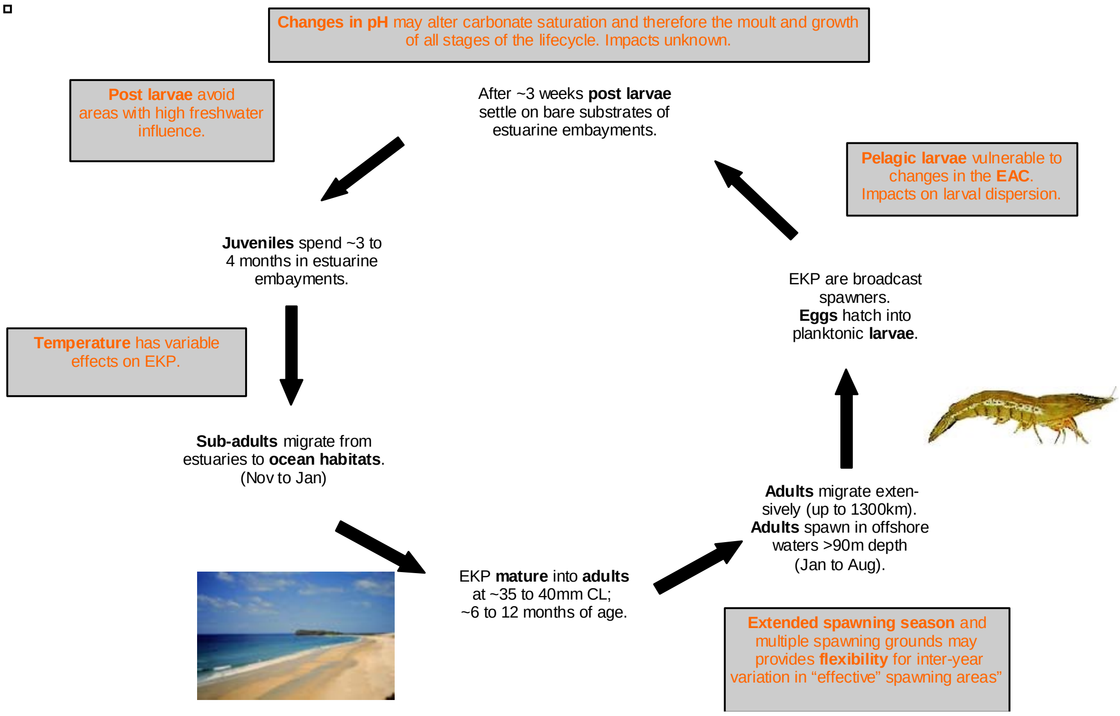


Figure 2.2. Generalised life cycle of eastern king prawn. (Images sourced from QDAFF).

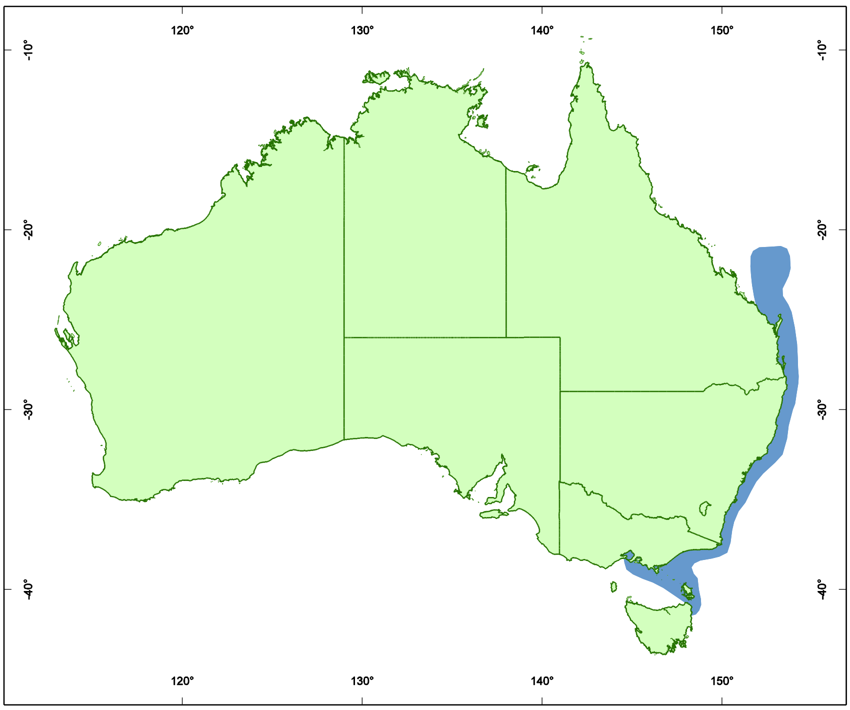


Figure 2.3. Australian distribution of the eastern king prawn.

Predators and prey

Eastern king prawns are opportunistic omnivores, whose diet includes small crustaceans, polychaetes, bivalves and protozoans (Kailola et al. 1993). Predators of eastern king prawns include marine fish.

Recruitment

Spawning of eastern king prawns occurs over many months throughout their distribution, but especially so in the northern part of their distribution, and with greater egg production at lower latitudes (Montgomery et al. 2007). However, it is likely that most egg production is wasted or ineffective due to high mortality rates of eggs, larvae and postlarvae. May to August is a key period for effective egg production and results in the recruitment of juveniles to the Moreton Bay part of the Queensland fishery that is succinct and consistent i.e., October to December (Courtney et al. 1995a).

Courtney *et al*. (1995a) also reported that catch rates of eastern king prawn recruits (< 15 mm CL) and post-recruits (> 15 mm CL) peaked with salinity, and were significantly ($P< 0.01$, $n = 216$) and positively correlated with salinity over the 2-year sampling period. This may a coincidence in timing between recruitment and the lack of rainfall (and thus high salinities). When times of peak recruitment were analysed (i.e., September to December), bottom salinity and temperature had no significant effect on the abundance of recruits or post-recruits (Courtney *et al.* 1995a).

Ruello (1975) speculated a strong causal relationship between the East Australian Current (EAC) and the distribution and abundance of eastern king prawns. Rothlisberg *et al.* (1995) challenged this speculation, instead suggesting that recruitment to inshore nursery habitats was derived from localised spawning. The role and importance of the EAC in the population dynamics, movement and distribution of eastern king prawns is still poorly understood and not quantified.

Current impacts of climate change

Key points:

- The distribution of eastern king prawns is likely to be affected by changes in the East Australian Current, water temperature, sea level rise, changed rainfall and ocean acidification.
- Exposure differs for estuarine post-larvae and juveniles to that of oceanic sub-adults and adults.

There are no documented impacts of climate change on eastern king prawns. However, Montgomery (1990) speculated that a more consistent southward flow of the EAC below 32°S may lead to less variable recruitment to southern estuaries and a range extension. Montgomery (1990) also speculated that an increase in water temperature of two to four degrees Celsius could trigger: (i) earlier emigration from inshore nursery areas (assuming that emigration is related to water temperature) which would lead to increased aggregation of individuals and to increased catch rates; (ii) earlier spawning (assuming spawning is related to water temperature and ignoring any role day-length may have in determining spawning seasons); and (iii) spawning occurring at more southerly latitudes, as overall reproductive potential is currently greatest at lower latitudes (i.e., Ballina north) in autumn (Montgomery et al. 2007).

Courtney *et al.* (2011) reported a significant negative effect of winter temperatures on the daily catch rates of eastern king prawns in the following October to December in Moreton Bay. They suggested that increasing temperatures associated with climate change may result in a decline in the abundance and/or distribution of eastern king prawns in the Moreton Bay/Southern Queensland region.

A sea level rise of 1.2 to 1.4 m was speculated to potentially increase habitats for juvenile eastern king prawns. Montgomery (1990) speculated that increases in wave action as a consequence of increased wind speed south of 36°S may increase the accessibility (and therefore habitat of eastern king prawn) of intermittently open estuaries. Increases in summer rainfall, and subsequent salinity changes and flooding frequency was speculated to not affect survival of juvenile and adult phases, but may stimulate earlier emigration (Montgomery 1990). Siltation changes that affect the substratum of eastern king prawn habitats have the potential to affect the distribution and possibly the abundance of this species.

Eastern king prawns inhabit oceanic waters along the east coast of Australia where the East Australian Current (EAC) is likely to influence their spawning, recruitment and distribution. Changes to the EAC will alter the distribution and recruitment of eastern king prawns.

Ocean acidification due to carbon dioxide dissolving into the ocean may possibly lower the pH of seawater i.e. from a current mean pH of 8.1 to 7.6 in 2100 (Bechmann et al. 2011) and alter carbonate saturation. This may have a potential impact on the moult and replacement of their exoskeleton and therefore affect growth rates. Eastern king prawns exhibited a positive calcification response pattern to elevated levels of atmospheric carbon dioxide (pCO_2) under experimental conditions (Ries et al. 2009). How this translates to responses of the population in the wild remains unknown.

Sensitivity to change

Key points:

- Eastern king prawns have a life cycle that is timed to exploit inshore areas as juveniles when these areas are most stable, i.e., between June and October prior to the onset of major rainfall and flood events.

Gibbs (2011) suggested that eastern king prawns were most sensitive to change during their estuarine phases of their life cycle. Montgomery (1990) argued that the period of highest eastern king prawn post-larval abundance is at a time when summer rainfall would be expected to have the least effect upon salinity and therefore the survival of larvae. This is also true of eastern king prawns in Queensland, who utilise estuarine inshore areas between June and October, which is prior to the onset of major rainfall and flood events.

Resilience to change

Key points:

- There are conflicting opinions about the resilience of eastern king prawn to climate change.

Gibbs (2011) concluded that eastern king prawns in New South Wales were resilient to climate change. However, Morison and Pears (2012) completed an expert based vulnerability assessment of the Queensland East Coast Otter Trawl Fishery and concluded that eastern king prawns in Queensland had a high level of ecological vulnerability to altered ocean circulation and a medium level of ecological vulnerability to higher sea surface temperature, increased tropical storm intensity and flooding, and climate variability driven by El Nino Southern Oscillation.

Other

Key points:

- The effect of changes in the East Australian Current and associated eddies along with increasing acidification on banana prawn populations is poorly understood.

Ecosystem level interactions

Eastern king prawns utilise sandy oceanic habitats that are possibly at less risk of change than habitats associated with other penaeids species (e.g. seagrasss or mangroves).

Additional (multiple) stressors

The eastern king prawn stock is a shared resource between Queensland and New South Wales. Changes in fishery dynamics in Queensland are likely to impact upon eastern king prawn resources in New South Wales.

Critical data gaps and level of uncertainty

The role and importance of the East Australian Current in the population dynamics, movement and distribution of eastern king prawns is still poorly understood and not quantified. It is uncertain if changes in the East Australian Current will result in changes to the thermocline, eddies and other physical oceanographic features along the east coast of Australia and how these may affect eastern king prawns and their fishery.

It is uncertain as to whether changes in ocean pH will have impacts on the calcification and moulting of prawns. There is conflicting speculation as to whether prawns will (Raven et al. 2005) or won't (Cooley and Doney 2009) be affected. There is also the possibility that as prawns inhabit estuaries where pH is probably variable, they may be able to tolerate changes in ocean pH.

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3. Red spot king prawn, *Penaeus longistylus*

Authors: Julie Robins

There are over 50 species of penaeid prawn in Australian waters, of which 10 are of major commercial importance. The red spot king prawn, *Melicertus (Penaeus) longistylus,* has a distinctive (often circular) patch of red on its third abdominal segment. The red spot king prawn is distributed throughout the Indo-West Pacific and South China Sea to Malaysia. It often occurs with the blue legged king prawn *M. latisulcatus*. Both species have similar life histories and distributions and are harvested by trawl fisheries throughout northern Australia.

The fishery

Key points:

- Red spot king prawns are the main target of a regionally important fishery in central to north Queensland that trawls inter-reef habitats.
- They are a specific target sector in the Queensland east coast otter trawl fishery and are a minor species in the Torres Strait and Northern Prawn Fisheries.

Queensland east coast

The red spot king prawn forms part of the multi-species East Coast Otter Trawl Fishery, which occurs from the border between Queensland and New South Wales, northwards to the Torres Strait. This fishery is managed by input controls including: limited entry, net and mesh size regulation, individual effort limits, vessel restrictions, spatial and temporal closures. However, there are no specific input controls for red spot king prawns prawns. Although red spot king prawns and blue leg king prawns can be caught along the length of the Queensland east coast, the majority of the harvest is taken between 18°S and 21°S (i.e., Bowen to Lucinda) within the lagoon and inter-reef areas of the Great Barrier Reef in water depths of 40 to 60 m (Kailola et al. 1993; Williams 2002). King prawn landings north of ~21ºS are predominantly red spot kings (70%). Separation of king prawns into the various species (i.e., eastern king, red spot and blue-legged) in the compulsory commercial logbook of the Queensland east coast otter trawl fishery has only occurred since 2003 (http://www.dpi.qld.gov.au/28_18391.htm accessed November 2011). Fishing effort for northern king prawn has declined since 1996, and catch rates have increased. The current catch rate is in the upper range of historical catch rates (http://www.dpi.qld.gov.au/28_18391.htm accessed November 2011).

Torres Strait Prawn Fishery

Red spot king prawns are also harvested by the Torres Strait Prawn Fishery, although this species comprises a minor component of the overall prawn harvest i.e., ~7% (Flood et al. 2010). Recruitment of red spot king prawns to the Torres Strait fishery peaks in December (Somers et al. 1987).

Northern Prawn Fishery

Mostly associated with reefal areas throughout northern Australia (Grey et al. 1983), red spot king prawns are rarely caught in the Northern Prawn Fishery (Barwick 2010).

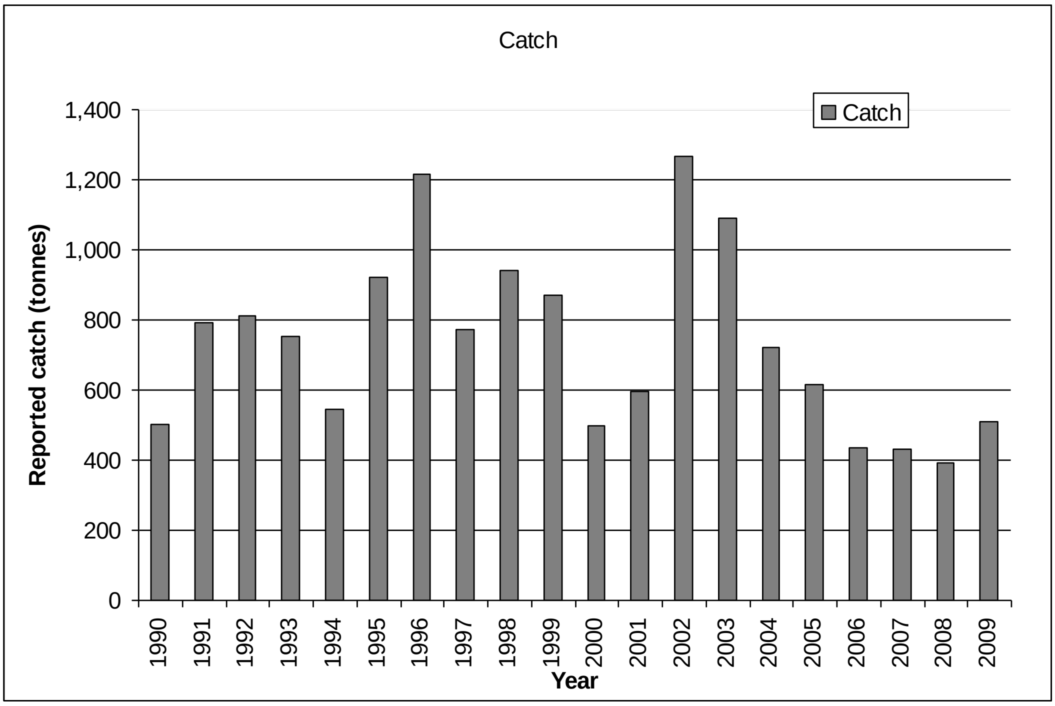

Figure 3.1. Red spot king prawn commercial catch (tonnes) in the northern region of the Queensland East Coast Otter Trawl Fishery (data sourced from Fisheries Queensland).

Life history

Key points:

- Only limited information is known about the biology and environmental requirements of red spot king prawns.
- Differ from other key prawn species in that their life cycle is completely offshore and associated with reef lagoon areas (juveniles) and inter-reef areas (adults).
- Have an extended spawning season (May to October) throughout their northern Australian range.

Life cycle, age and growth

The red spot king prawn has a type-3 penaeid prawn life cycle (Dall et al. 1990), but are atypical in that they are not associated with estuarine or coastal environments. Adults are sedentary and live in inter-reef areas and the lagoon of the Great Barrier Reef on coralline sandy sediments up to 60 m deep. Red spot king prawns have an extended spawning season (May to October), with peak spawning thought to occur between July and August (Courtney and Dredge 1988). Courtney and Dredge (1988) also suggested that there is little geographic variation in spawning periodicity between populations of red spot king prawns that occur in the Gulf of Carpentaria and the central Queensland east coast.

Larvae are pelagic and benthic post-larvae settle between September and May in shallow coralline sandy sediments, often associated with lagoons of coral reefs. Juveniles spend four to six months on reef-tops before emigrating to inter-reef areas. Lunar period does not affect the availability of red spot king prawns to trawl nets unlike other prawn species (Williams 2002).

Like other penaeid species in northern Australia, red spot king prawns are thought to have high natural mortality rates, such that most prawns live for less than two years and a life cycle that is completed within 12 months. Dredge (1990) reported that red spot king prawns have a slower growth rate than eastern king prawns, although this could be a reflection of the timing (i.e., winter) of the study. Growth parameters were also found to vary between males and females and between years.

Distribution, habitat and environmental preferences

Red spot king prawns are distributed in the tropics (Figure 3.3) and use the coralline sand sediment of coral reef lagoons as nursery areas for benthic post-larvae and juveniles. Juveniles migrate from coral reef tops to inter-reef areas in late summer to autumn. Recorded bottom sea-water temperatures during research trawling for red spot king prawns ranged from 23.6°C in September 1985 to 28.5°C in March 1986 (Courtney and Dredge 1988).

Predators and prey

No specific studies on the predators and prey of red spot king prawns are available. However, it would be expected that predators of red spot king prawns would include carnivorous reef fish and that red spot king prawns would be omnivorous eating a variety of bivalves, gastropods, ophiuroids, crustaceans and polychaetes (Wassenberg and Hill 1987).

Recruitment

Recruitment of benthic post-larvae to the lagoons of coral reefs within the Great Barrier Reef occurs between September and May. Juvenile red spot king prawns remain on reefs tops for four to six months, exposing them to the impacts of the Queensland cyclone season i.e., January to April. Regional fishers have expressed concern that the recruitment of red spot kings can be negatively impacted by cyclones (Morison and Pears 2012) but a general dearth of research on this species makes speculation difficult. As red spot king prawns inhabit coral reefs, it may be interesting to investigate whether localised coral bleaching has any impact on localised recruitment and subsequent catch rates of this species.

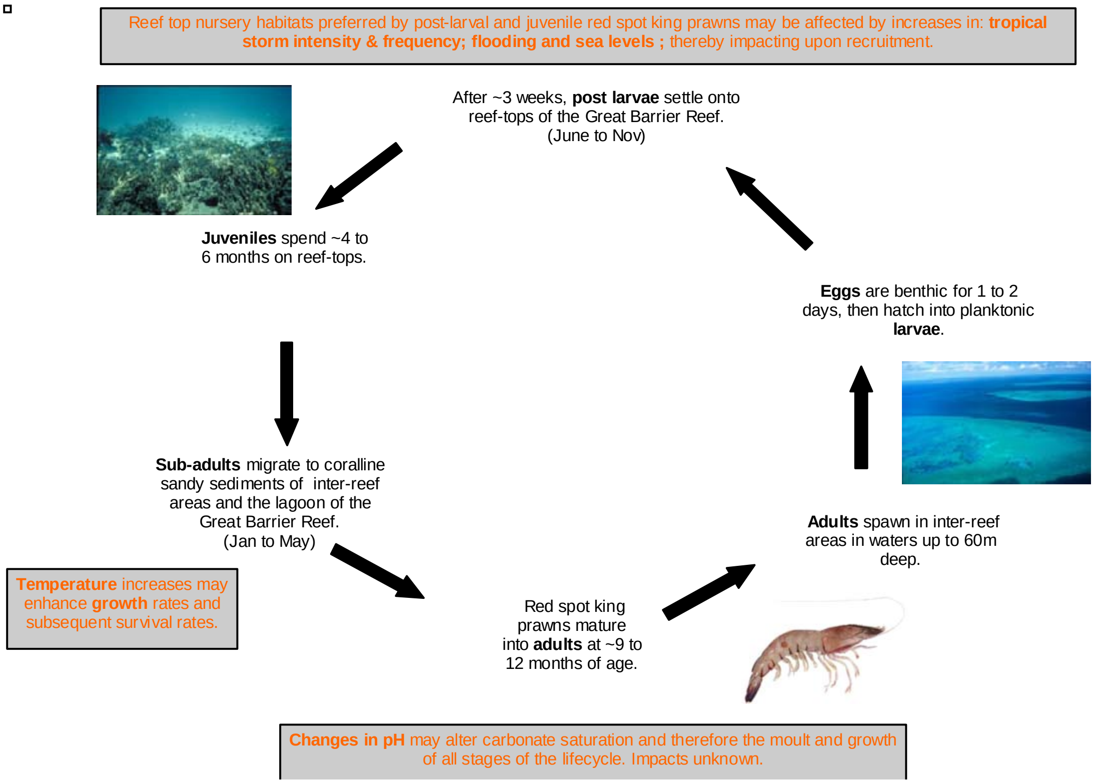

Figure 3.2. Generalised life cycle of the red spot king prawn. (Reef images courtesy of GBRMPA).

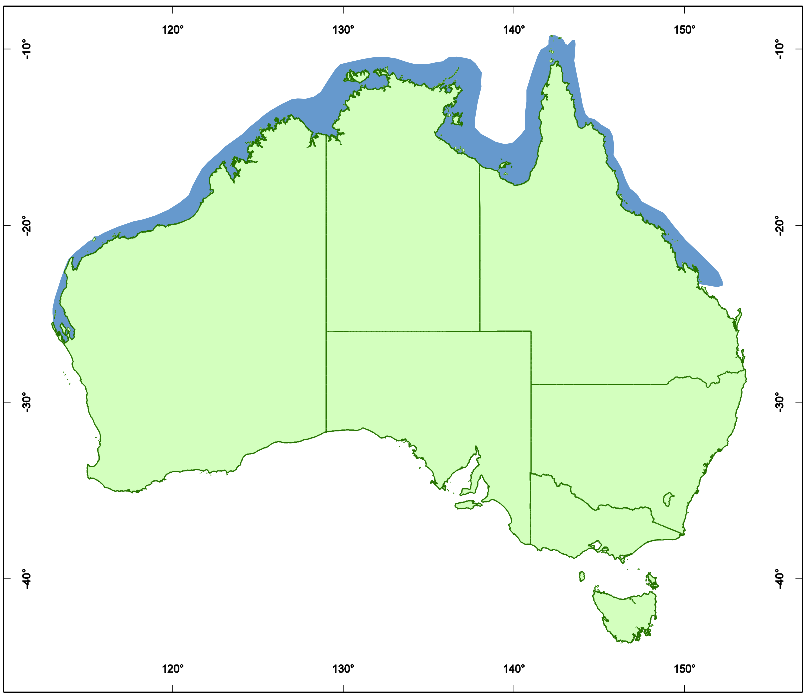

Figure 3.3. Australian distribution of red-spot king prawn.

Current impacts of climate change

There are no documented impacts of climate change on red spot king prawns.

Sensitivity to change

Key points:

- Potentially sensitive due to specific habitat requirements.
- Anecdotal reports suggest recruitment of red spot king prawns may be affected by cyclones.
- As SST rises, there is potential for the distribution of red-spot kings to move southwards, should habitats permit.

Red spot king prawns have specialised habitat requirements as juveniles, potentially making them sensitive to change. An extended spawning season may allow this species to take advantage or cope with changes in some environmental cues such as water temperature.

Resilience to change

Key points:

- Extended spawning season may allow some flexibility in recruitment.

Morison and Pears (2012) completed an expert based vulnerability assessment of the Queensland East Coast Otter Trawl Fishery and concluded that red spot king prawns in Queensland had a medium level of ecological vulnerability to increased tropical storm activity and flooding which could critically impact on the juvenile reef top habitats. Red spot king prawns also had a medium level of ecological vulnerability to higher sea surface temperature, sea level rise, and ocean acidification.

Other

Key points:

- Red spot king prawns are the least studied of all the commercial prawn species in Australia.
- Red spot king prawns are known to have an association with coral reef habitats which are predicted to be degraded under future climate change scenarios.

Ecosystem level interactions

In Queensland, red spot king prawns are associated with coralline sandy habitats, often associated with coral reefs. Degradation of reefs under climate change may impact on habitat quality and or food supply of red spot king prawns.

Additional (multiple) stressors

No specific additional stressors are known.

Critical data gaps and level of uncertainty

Red spot king prawns are the least researched of the main commercial penaeid species of northern Australia. Critical aspects of their biology and possible environmental drivers are unknown.

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4. Brown tiger prawn, *Penaeus esculentus*, and grooved tiger prawn, *P. semisulcatus*

Authors: Julie Robins and Clive Turnbull

Brown tiger prawn, *Penaeus esculentus.* Image from QDAFF.

Two species of tiger prawn are harvested in northern Australia: *Penaeus esculentus,* the brown tiger prawn, and *Penaeus semisulcatus*, the grooved or green tiger prawn. Tiger prawns have similar life histories with both species using seagrass or algal beds as juveniles, but have slightly different distributions as adults. Brown tiger prawns prefer coarse sediments, while the grooved tiger prawn prefers sandy or muddy sediments (Grey et al. 1983; Kailola et al. 1993). Both are harvested by trawl fisheries in northern Australia.

The fishery

Key points:

- Tiger prawns are a very important component of trawl fisheries in northern Australia with high economic value.

Queensland east coast

Brown and grooved tiger prawns form part of the multi-species East Coast Otter Trawl Fishery, which occurs from the border between Queensland and New South Wales northwards to the Torres Strait. The fishery is managed by input controls including: limited entry, net and mesh size regulation, individual effort limits, vessel restrictions, and spatial and temporal closures. However, there are no input controls for specific to tiger prawns. Although tiger prawns are caught along the length of the Queensland east coast, the majority of the catch is taken north of 21°S in inshore coastal waters (i.e., <30 nm offshore).

Torres Strait Prawn Fishery

The Torres Strait Prawn Fishery (TSPF) is a separate and distinct fishery from both the Northern Prawn Fishery and the Queensland East Coast Trawl Fishery. Most vessels in the Torres Strait Prawn fishery hold a Queensland east coast trawl endorsement, and some also hold a Northern Prawn Fishery endorsement. The Torres Strait Prawn Fishery is managed by input controls, including: limited entry, gear and vessel restrictions, individual effort limits, seasonal and area closures. The fleet is highly mobile and most vessels operate in this fishery on a part-time basis. Sixty-one vessels are licensed to fish the Torres Strait Prawn Fishery with up to 6,867 fishing days. In 2011, only ~1,300 days of fishing effort was recorded (Torres Strait Prawn Handbook 2012). Patterns of fishing effort in the Torres Strait Prawn Fishery have changed in recent years as a consequence of fuel costs and market prices for target species. Currently, brown tiger prawns dominate the catch (197 t), followed by blue endeavour prawns (72 t) and red-spot king prawns (4 t). This differs from average catches between 1991 and 2003, when endeavour prawns dominated the catch.

Relative abundance data since 1980 has been used in stock assessments, management strategy evaluations and fishery assessments for the Torres Strait Prawn Fishery (O'Neil and Turnbull 2006; Turnbull *et al.* 2009). As a result of the very low level of fishing effort in recent years, the annual catches of both tiger and endeavour prawns are now well below both the historic catch levels and the estimated Maximum Sustainable Yield (MSY) for tiger and endeavour prawns (Torres Strait Prawn Handbook 2012). The increase in tiger prawn catch per unit effort since 2000 is probably a consequence of the combined effect of fishers targeting tiger prawns in preference to endeavour prawns and a higher abundance of tiger prawns on the seabed. This is supported by the stock assessments conducted in 2004 and 2006, which are based on the monthly catch and standardised catch rates of tiger prawns since 1980. These assessments indicate that from 2002 to 2006 the tiger prawn biomass was increasing and higher than during the 1990's and the stock level required for maximum stock productivity (B_{msy}) (Torres Strait Prawn Handbook 2012).

Northern Prawn Fishery

The Northern Prawn Fishery extends from Cape Londonderry (Western Australia) eastwards to Cape York (Queensland). The Northern Prawn Fishery targets six different species of penaeid prawn, with brown and grooved tiger prawns a major sector of the fishery (Barwick 2010). The Northern Prawn Fishery is managed by the Australian Fisheries Management Authority through a combination of input controls including: limited entry (52 vessels), seasonal closures, permanent area closures, gear restrictions, and operational controls, which are all implemented under a Management Plan. In 2010, the banana prawn season commenced on the 31st March and concluded on the 10th June i.e., ten weeks, while the tiger prawn season commenced on the 1st August and concluded on the 29th November i.e., 17 weeks (Barwick 2010). In 2010, 52 vessels landed 1,628t of tiger prawns using 4,898 days of fishing effort. Annual monitoring surveys have occurred since 2002, in January and July, to provide independent data for recruitment and spawning indices.

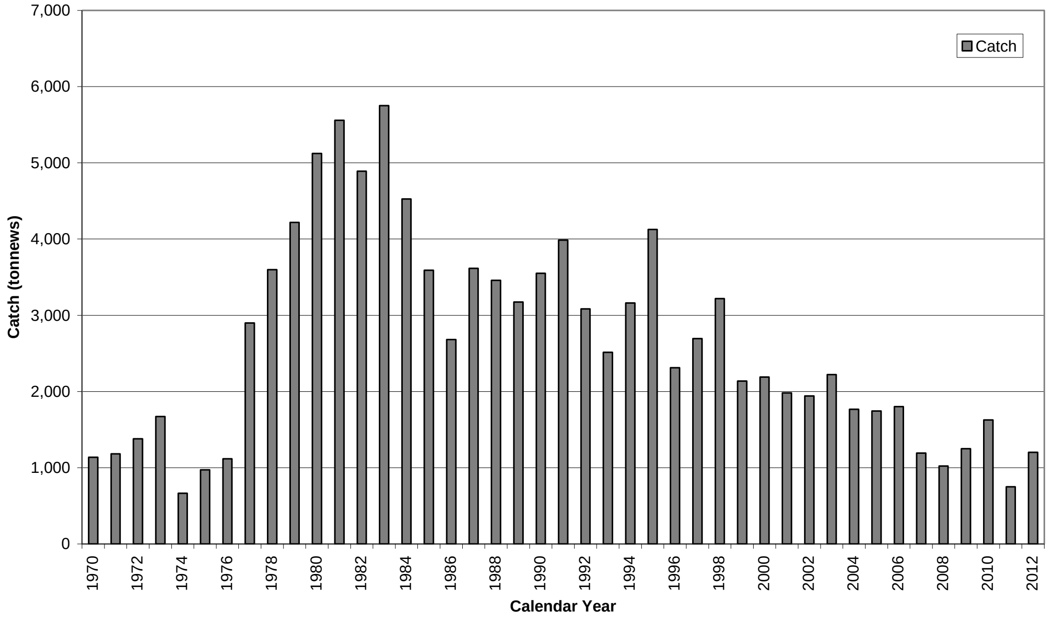

Figure 4.1. Tiger prawn commercial catch (tonnes) by year for the Northern Prawn Fishery (data from Barwick (2010) and AFMA (2013).

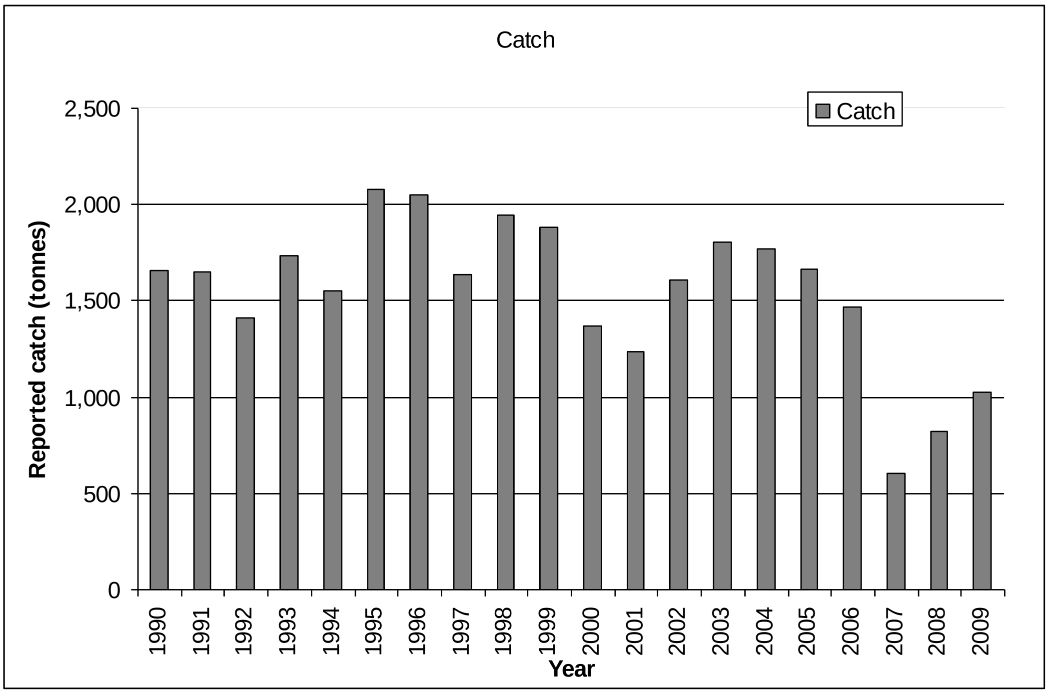

Figure 4.2. Tiger prawn commercial catch (tonnes) by year for the northern region of the Queensland East Coast Otter Trawl Fishery (data sourced from Fisheries Queensland).

Life history

Key points:

- Recruitment is probably affected by environmental factors but this has not been quantified.
- Juveniles are reliant on sea grass habitats as their primary habitat.

Life cycle, age and growth

Tiger prawns have a typical type-3 penaeid prawn life cycle (Dall et al. 1990), preferring relatively high salinity, sheltered inshore waters. Adults prefer habitats where sediments have a high (50-80%) mud content (Somers 1987a; Somers et al. 1987). Tiger prawns spawn in coastal waters up to 50m depth. The brown tiger prawn (*P. esculentus*) has variable spawning times and the spawning between August and October (i.e., Winter/Spring) provides the main source of recruits in the Torres Strait and Queensland east coast. However, in the Torres Strait, brown tiger prawns spawn throughout the year, with a second peak in spawning in summer that contributes a second (smaller) pulse of recruits that contribute to the Torres Strait Prawn Fishery. The grooved tiger prawn (*P. semisulcatus*) is thought to have two spawning periods, one in early summer and the other in autumn. Maturation and spawning of unablated female brown tiger prawns was favoured by conditions of warm temperature (26°C) and long days (14.5 h), whereas ovarian maturation did not occur at lower temperatures (20°C) and short days (12 h) (Crocos and Kerr 1983).

Pelagic larvae occur in high salinity water i.e., 30 to 35 ppt (Rothlisberg and Jackson 1987). Benthic post-larvae and juveniles have a strong association with seagrass habitats and algal beds (Young and Carpenter 1977; Young 1978; Coles and Lee Long 1985; Staples et al. 1985; Coles et al. 1987; Loneragan et al. 1994; O'Brien 1994a). In Torres Strait, juvenile tiger prawns are found on the tops of coral reef platforms, where they remain until they migrate into inter-reef areas as sub-adults. Tag-recapture studies in the Gulf of Carpentaria, Torres Strait, and Queensland east coast report movements by tiger prawns of generally less than 50 km (Kirkwood and Somers 1984; Somers and Kirkwood 1984); (Derbyshire et al. 1990; Watson and Turnbull 1993). This suggests that tiger prawns undertake limited migration between juvenile seagrass habitats and adjacent adult habitats.

Prawns are thought to have salinity and temperature optimums for biological processes such as growth and mortality e.g., (Saldanha and Achuthankutty 2000; Staples and Heales 1991), but these are likely to differ between species as a consequence of fundamental differences in their life history preferences (Dall et al. 1990). Laboratory studies on the brown tiger prawn (*P. esculentus*) found that after 50 days, juveniles could survive a wide range of temperature and salinity combinations (O'Brien 1994b). For example, survival of juvenile tiger prawns was >60% when water temperature was between 15 and 30°C and salinity was between 15 and 45 ppt. However, combinations of extreme temperature with extreme salinity were lethal. Fastest growth was estimated to occur at 30°C and a salinity of 30 ppt. O'Brien (1994b) concluded that juvenile brown tiger prawns were relatively euryhaline (i.e., able to tolerate a wide range of salinities) but were less tolerant of wide ranges in temperature, having impacts on growth rates, survival and distribution.

For grooved tiger prawns (*P. semisulcatus*), Xu *et al.* (1995) reported that salinity was negatively correlated with natural mortality estimates of a wild population in Kuwait waters i.e., the grooved tiger prawn had high mortality when salinity was low, due to flooding of the Shatt Al-Arab River.

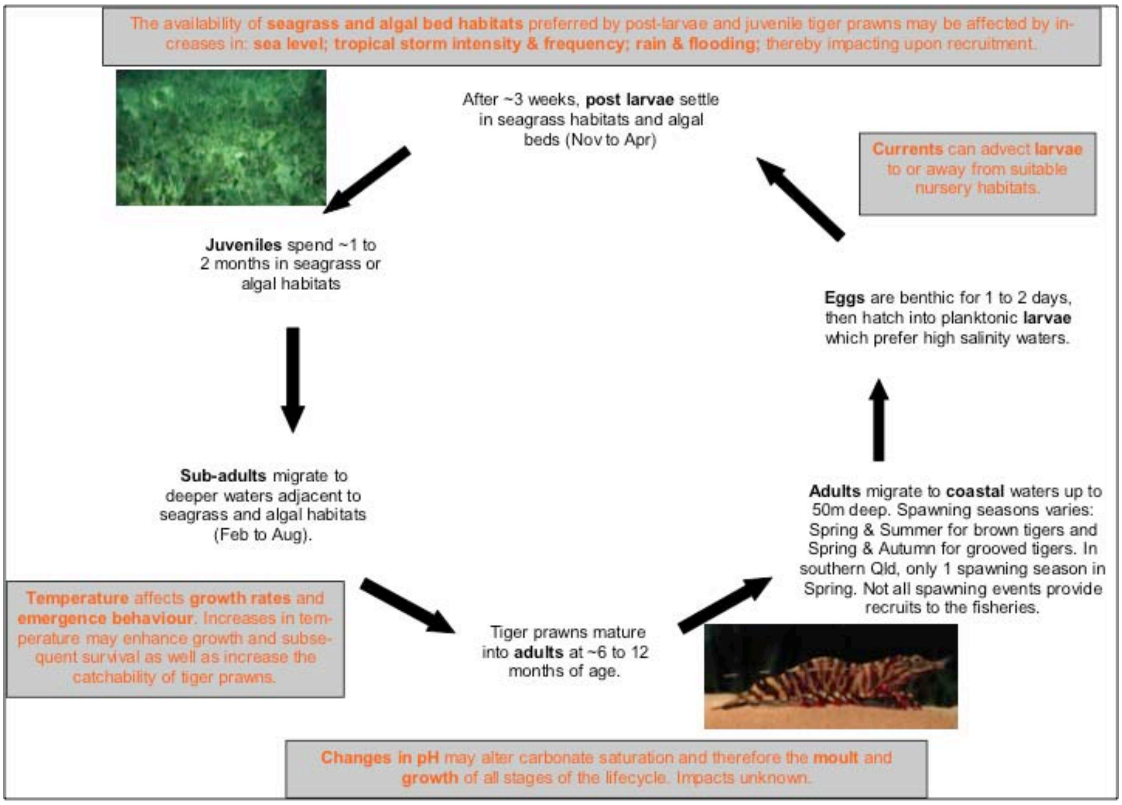

Figure 4.3. Generalised life cycle of tiger prawns. (Images sourced from QDAFF).

Distribution, habitat and environmental preferences

The brown tiger prawn (*P. esculentus*) is endemic to coastal waters of tropical and sub-tropical Australia, and can be found in waters up to 50 m deep (Kirkegaard and Walker 1969; Racek and Dall 1965). It is likely that there are separate stocks of brown tiger prawns on the east and west coast of Australia (Courtney 1997).

The grooved tiger prawn (*P. semisulcatus*) is a tropical species and is more widespread in its distribution than the brown tiger prawn, occurring in coastal waters of the Indian and western Pacific oceans, where it is trawled in waters up 130 m deep (Grey et al. 1983; Kailola et al. 1993). The benthic post-larvae and juveniles of both species of tiger prawn prefer seagrass and algal bed habitats. Adults of the brown tiger prefer habitats with coarse, sandy sediments, while adults of the grooved tiger prawn prefer habitats with a high (50-80%) mud content (Somers 1987b; Somers et al. 1987).

In a recent detailed study of the influence of environmental parameters on standardised catch rates of brown tiger prawns in Moreton Bay, Courtney *et al.* (2011) found that flow of the Brisbane River had a significant (but small) negative impact, as would be expected from life history information and previous studies. This is in contrast to that reported from a broadscale analysis of relationships between fisheries catch and climate parameters, where tiger prawn catches along the east coast of Cape York were positively related to rainfall and the Southern Oscillation Index (Meynecke and Lee 2011). A positive correlation between catch (adjusted for effort) and SOI suggests that increased catches occur when the SOI is positive (indicative of La Nina events and increased rainfall).

Cool water is thought to be the major factor that restricts the distribution of *Penaeus esculentus* in Australia (O'Brien 1994b).

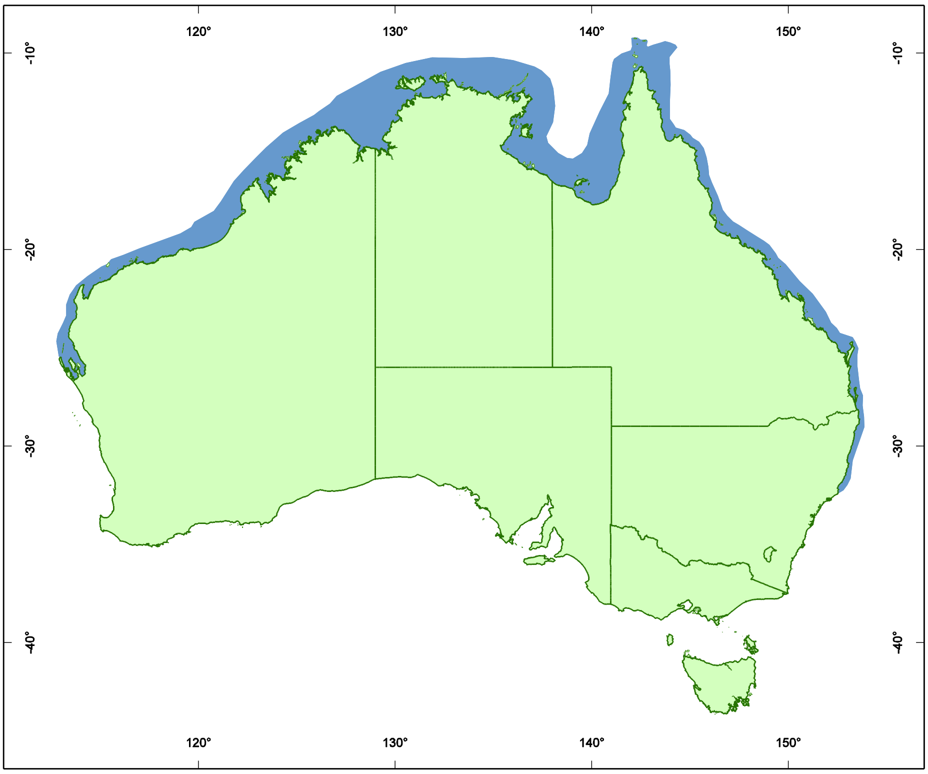

Figure 4.4. Australian distribution of tiger prawn.

Predators and prey

Tiger prawns eat a variety of organisms including bivalves, gastropods, ophiuroids, crustaceans and polychaetes (Wassenberg and Hill 1987). Tiger prawns are eaten by a variety of predatory fish.

Recruitment

Flood *et al.* (2010) stated that variable recruitment of brown tiger prawns in Torres Strait was influenced by environmental factors. Fishers operating in the Torres Strait Prawn fishery anecdotally report that a dry preceding year favours tiger prawn recruitment while a wet preceding year favours endeavour prawn recruitment (C. Turnbull pers. comm.). Recruitment was impacted by cyclones in Western Australia, with the effect depending on timing (Penn and Caputi 1986a). Cyclones and associated rainfall early in the wet season reduced salinity of near shore juvenile habitats and reduced recruitment, whilst cyclones later in the wet season increased the turbidity of water and probably reduced predation of sub-adult and adult tiger prawns that had moved away from shallow nursery habitats.

Current impacts of climate change

Key points:

- There are known links between climate factors and tiger prawn population dynamics.
- Effects are likely to vary regionally – temperature should be an important factor towards the southern limit of the distribution of brown tiger prawns.

There are no documented impacts of climate change on tiger prawns. Tiger prawns utilise inshore areas during their life cycle. These species are particularly dependent on seagrass and algal beds as nursery habitats. Primary and secondary climatic factors that impact (positively or negatively) upon the abundance, distribution and quality of these habitats will impact tiger prawns. Impacts include elevated sea surface temperatures (postulated positive effects on prawn growth and survival, emergence duration and exposure to capture and productivity of seagrass habitats); sea level rise; tropical storm activity. Tiger prawns are also exposed to changes in ocean pH, and like other species it is uncertain whether prawns in general and tiger prawns as individual species are sensitive to the anticipated change in ocean pH and its effect on calcium carbonate formation and moulting.

Meynecke and Lee (2011) report significant positive correlations between tiger prawn catch adjusted for effort in select regions of Queensland with rainfall and SOI. Relationships between tiger prawn catch (adjusted for effort) and wet season rainfall were not significant ($r<0.30$, $p>0.05$) in the five northern regional areas where the majority of tiger prawns are harvested. However, catch adjusted for effort was significantly correlated to sea surface temperature in two of the five northern regional areas that account for most of the tiger prawn catch (see Fig. 3 of Meynecke and Lee 2011).

Sensitivity to change

Key points:

- Tiger prawns are sensitive to changes in the seagrass and algal beds as these are the primary habitat of juveniles.
- Tiger prawns appear to have a wide tolerance for temperature and salinity.

Tiger prawns are dependent on seagrass and algal beds as juveniles and would be sensitive to any changes in the abundance, quality or distribution of this habitat. For example, tropical storm activity (i.e., severe cyclones) negatively impacted juvenile tiger prawn habitats in Western Australia and tiger prawn recruitment was reduced in the two years subsequent to the cyclone (Penn and Caputi 1986b).

Resilience to change

Key points:

- Tiger prawns are possibly less resilient to change than other prawn species because of their dependence on specific habitats as juveniles.

Brown *et al*. (2010) simulated the effects climate change may have on primary production in Australian marine ecosystems using the food web model Ecosim. They predicted that in the Gulf of Carpentaria, tiger prawn abundance would decline in response to high predation rates or strong competition with other functional groups.

Morison and Pears (2012) completed an expert based vulnerability assessment of the Queensland East Coast Otter Trawl Fishery and concluded that tiger prawns in Queensland had a medium level of ecological vulnerability to ocean acidification and its consequences for moult success and therefore recruitment. They also found a medium level of ecological vulnerability to higher sea surface temperature, sea level rise, changed rainfall patterns and increased tropical storm activity.

Water temperature is thought to be a major factor restricting the distribution of the brown tiger prawn (*P. esculentus*) in Australia (O'Brien 1994b). As water temperatures increase, brown tiger prawns might increase their distribution southerly (i.e., into New South Wales) and become more abundant in areas where seagrass occurs, but temperature limits the survival of brown tiger prawns.

Other

Ecosystem level interactions

Tiger prawns are a key food source for many estuarine-dependent and inshore coastal species. Changes in the distribution and abundance of tiger prawns may potentially affect the distribution and abundance of their predators. Tiger prawns are also dependent on specific habitats (sea-grass and algal beds) as juveniles. Changes in the distribution and abundance of these habitats may also affect tiger prawn populations.

Additional (multiple) stressors

Tiger prawns are exploited by trawl fishers, although the main trawl fisheries are managed such that tiger prawn stocks in northern Australia are not thought to be over-exploited (Punt et al. 2010).

Critical data gaps and level of uncertainty

Knowledge of the impact of many physical factors on the population dynamics of each species of tiger prawn is limited. Therefore, the impacts of climate change on these species are mostly speculative and uncertain.

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5. Mud crab, giant (*Scylla serrata)* and orange (*S. olivacea)*

Authors: Emily Lawson, Thor Saunders, and Julie Robins

The fishery

Key points:

- Mud crabs are harvested at substantial levels by all sectors across the majority of northern Australia.
- There is a male only harvest fishery in Queensland waters; elsewhere males and females may be harvested.
- In northern regions catch is influenced by SOI and rainfall/riverflow, while temperature is likely to play a more significant role in southern regions.

Western Australia

There is only a small developmental fishery for the orange mud crab, *Scylla olivacea*, in Western Australia. Currently annual catches are less than 5 t (Department of Fisheries 2011).

Northern Territory

The mud crab fishery is one of the key Northern Territory (NT) managed wild harvest fisheries. Approximately 400 tonnes of mud crabs were caught in the 2010 commercial wild harvest sector, down from over 1000 tonnes in 2001 (Figure 5.1). Two species of mud crabs are found in NT waters; the giant mud crab (*S. serrata*) accounts for 99% of the catch from all sectors, while *S. olivacea* constitutes the remainder (Northern Territory Government 2011). Crabbing operations are confined to coastal and estuarine areas, predominantly on mud flats, with most activity concentrated in the Gulf of Carpentaria. The estimated gross value of the catch was $8 million in 2010 (Northern Territory Government 2011).

Parallel surveys in 2000-01 highlighted the importance of the mud crab resource to recreational (including Fishing Tour Operators) and Indigenous fishers who were estimated to harvest 82,000 and 86,500 crabs, respectively, with a combined weight of about 135 tonnes, during a 12-month period (Henry and Lyle 2003).

Both male and female mud crabs can be retained in the Northern Territory. Rules and regulations apply to each fishing sector, such as minimum legal size, possession limits, gear restrictions and no harvest of berried females (i.e., with eggs attached) or newly moulted ‘soft’ crabs.

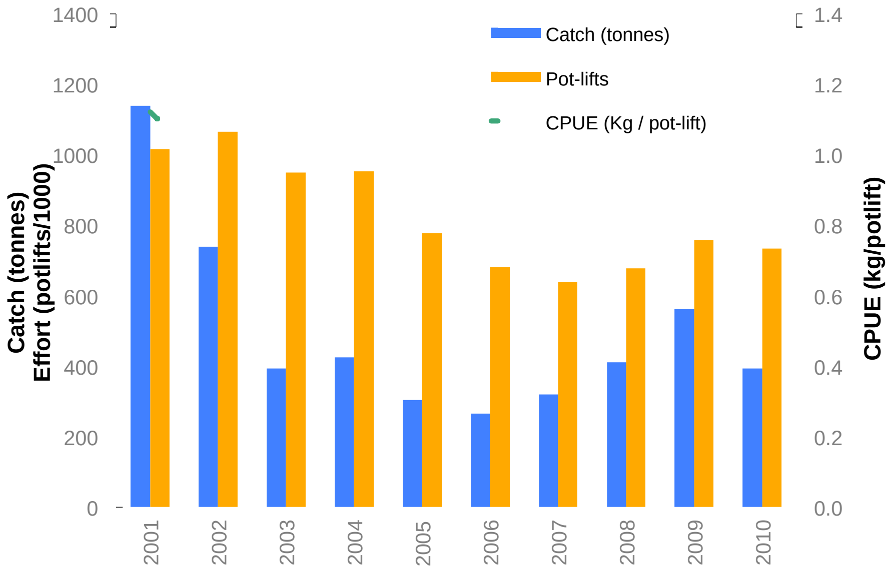

Figure 5.1. Catch per unit effort (CPUE) for the Northern Territory commercial Mud Crab Fishery from 2001 to 2010.

Queensland

The Queensland mud crab fishery primarily targets *S. serrata*, although *S. olivacea* occurs in Queensland waters and comprises a small component of the catch (Jebreen *et al*. 2002). The commercial sector accounts for ~59% of the total mud crab harvest, while the recreational sector accounts for about 40%, and the Indigenous sector <1% (Fisheries Queensland 2010). Pots and hoop dillies are the primary means of capture, with 'hooking' prohibited since 1995. Crabbing can be carried out in association with other forms of fishing, such that pots are set and left while undertaking other activities like netting (commercial) or line fishing (recreational or commercial). Mud crabs are also caught as bycatch in the Queensland set gill net fishery.

The Queensland commercial mud crab fishery is managed by input controls including: restricted commercial entry, limits on the number and types of pots (maximum 50), minimum legal size (150 mm carapace width), a male only fishery (females protected), spatial closures, and a possession limit of 10 for the recreational fishery.

In 2010, the reported commercial catch was 1,192 tonnes (Figure 5.2), with 1,015 tonnes taken from the Queensland east coast and the remainder from the Gulf of Carpentaria (Fisheries Queensland 2011). The gross value of production for the commercial fishery was in the order of $19 million, with 375 out of a possible 437 licences reporting landings of mud crab (Fisheries Queensland 2011).

Fisheries for mud crabs are associated mostly with estuaries. However, in Queensland, some of the major commercial mud crab areas are not rivers, but large sheltered areas behind islands e.g., southern Moreton Bay, Great Sandy Straits, the Narrows near Gladstone, Broadsound north of Rockhampton, and Hinchinbrook Channel north of Townsville (Fisheries Queensland 2011). The duration of the main peak fishing season increases with latitude, being eight months in north Queensland and ten months in Moreton Bay (Hill 1982). Main landings occur between December and June and are related to water temperature, as activity and feeding are reduced at temperatures below 20°C (Hill 1980).

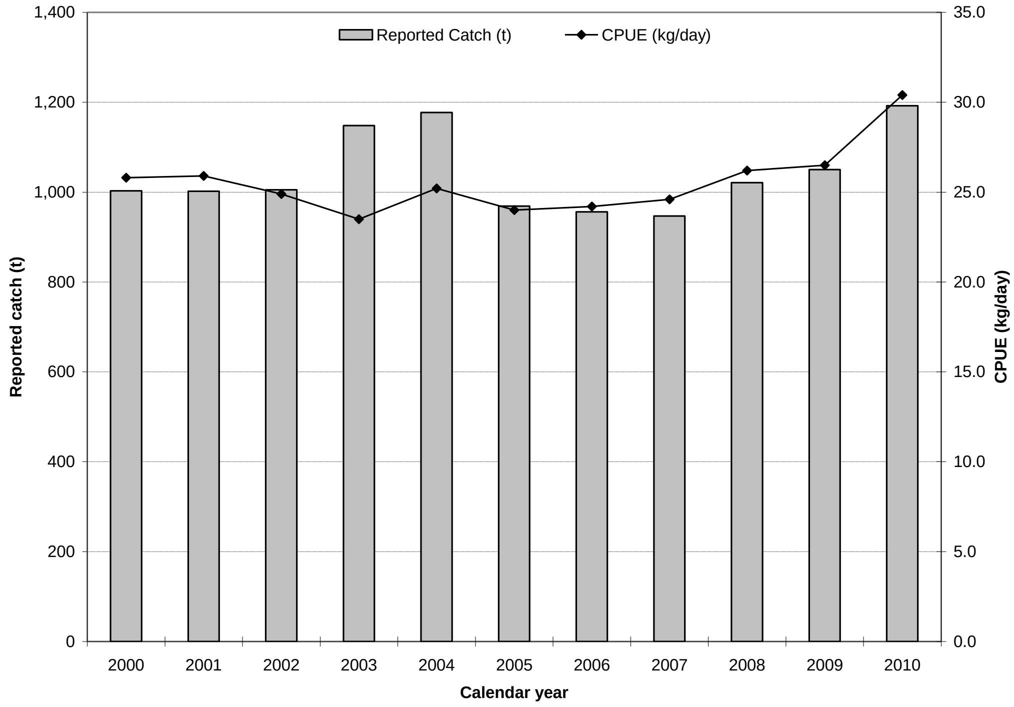

Figure 5.2. Mud crab commercial catch (tonnes) and catch per unit effort (CPUE) by year for Queensland, east coast and Gulf of Carpentaria pooled (Source: Fisheries Queensland Annual Status Report 2011 Mud Crab Fishery).

<u>Relationships between catch and environmental variables</u>

There is variable evidence as to the importance of different environmental factors on the catch rate of mud crabs (Table 5.1). Williams and Hill (1982) conducted fishery independent sampling and found that catches were not correlated with salinities (range of 24 to 35 ppt; r = 0.09, n=44), but were significantly correlated with daily water temperature (r = 0.56, n=44). Williams and Hill (1982) found that the catchability of mud crabs was (negatively) influenced by low water temperatures in winter as well as the moulting cycle. Moulting mostly occurs in October and to a lesser extent in December and January. Catchability also varied with the size and sex of mud crabs.

Helmke *et al.* (1998) reported that Queensland commercial crabbers generally believed that environmental factors were responsible for declining catches in the Gulf of Carpentaria in 1998. The crabbers believed that a drop in the number of crabs caught was a consequence of: (i) 'the long period of rain early in the year and an extended period of freshwater runoff', when adult crabs may have been flushed out into the Gulf of Carpentaria and then tried to return to successive estuaries as they moved down the coast; and (ii) recruitment failure caused by high rainfall two years' previous. Helmke *et al.* (1998) also reported a low percentage of tag-recaptures in the Weipa region during an intensive tag-recapture study and suggested that this was indicative of a high migration rate possibly linked to the long period of freshwater runoff ‘that local crabbers believe cause crabs to move’.

Loneragan and Bunn (1999) reported significant positive correlations between (fishery-dependent) mud crab catch and summer freshwater flow in the Logan River estuary (a sub-tropical estuary), while Robins *et al.* (2005) and Halliday and Robins (2007) found significant correlations between fishery-dependent mud crab catch and flow and rainfall for the Fitzroy and Port Curtis regions (near the Tropic of Capricorn). Robins *et al*. (2005) reported a positive correlation between the catch of mud crabs and summer freshwater flow. Loneragan and Bunn (1999) suggested that the downstream migration of adults as a consequence of freshwater flow may enhance the catchability of adults by moving them to fishable areas as well as enhance the survival of juveniles (i.e., a recruitment effect) by reducing competition for burrows and any cannibalism, potentially increasing the overall abundance of the species.

More recently, Meynecke *et al.* (2012) used fishery dependent catch data and reported significant regional correlations between monthly mud crab catch per unit effort, mean seasonal flow and mean summer sea surface temperature.

Life history

- Mud crabs spawn in marine waters during Spring and Summer and are highly fecund.
- Mud crabs grow quickly and attain maturity after ~18 months in the tropics but can take up to 36 months in the sub-tropics (eg. Moreton Bay, SE Queensland).
- Growth rates decrease with increasing latitude, while size-at-maturity increases with increasing latitude. These effects are likely to be temperature related.
- Currents, salinity, temperature, food supply and predation are more likely to influence recruitment than the abundance of spawning females.

Life cycle

The life cycle of the mud crab involves several stages that utilise both marine and estuarine environments (Arriola 1940). The mating process begins when a mature, hard shelled male finds a female that is ready to moult (presumably through the release of pheromones from the female). The male then carries the female with his first pair of walking legs for a period of three to four days before she moults and is subsequently inseminated (Ong 1966). The crabs remain “doubled” until such time as the females’ shell has hardened, typically about five days (Perrine 1978). The female stores the spermatophores for between two and seven months (Ong 1966), during which time up to three batches of eggs can be fertilised (Heasman *et al*. 1983). The eggs (which may number from two to 11 million; Davis, 2004) are later extruded onto the ventral surface of the females’ abdomen where they remain until hatching.

Once mated, the females can migrate up to 50 km offshore into waters 20 to 40 m deep (Hill, 1994). The peak of the spawning event (comprising both migration and hatching) in Australia, occurs from September to November in the tropics, and from October to December in the subtropics (Heasman *et al*. 1985; Knuckey 1999). The timing of the migration (i.e., before the monsoon season), suggests that migration is not triggered by low salinities in estuaries (Hill 1994), although both Quinn and

Kojis (1987) and Heasman *et al.* (1985) suggested that peak spawning in the tropics does indeed coincide with periods of high nutrient input associated with monsoonal rainfall.

The rate of egg and larval development in *Scylla* species is inversely proportional to temperature, with an optimal temperature of 29°C (Hamasaki 2003). Salinity also appears to be critically important with salinities below 20 ppt resulting in high mortality rates (Hill 1974; Quinn and Kojis 1987; Nurdiani and Zeng 2007), however, experimental aquaculture work indicates that juvenile mud crabs can be reared at salinities within 10 to 25 ppt, provided temperature is greater than 25°C (Ruscoe *et al.* 2004). Hatching occurs about 12 days post extrusion, after which the planktonic zoea pass through five discrete stages over the next 12 to 15 days (Brown 1993).

The megalopae are semi-pelagic bottom-dwelling (Fielder and Heasman 1978) and after five to 12 days metamorphose into juvenile crabs (Williams 2002). Webley and Connolly (2007) proposed that megalopae settle on the coastal shelf, possibly near river mouths and then move along the substrate as they migrate upstream towards mangrove and seagrass habitats (Webley *et al*. 2009). Stage one crabs are only about 4 mm wide and have rarely been seen in the wild, but frequent moults mean that they grow very quickly.

Age and growth

Mud crabs grow through a series of moults and (unlike fishes) do not retain hard parts suitable for ageing. Hence, estimates of mud crab age are crude and rely on cohort analysis, which infer a maximum life span of three to four years (Heasman 1980).

Mud crabs grow quickly, reaching 80 to 100 mm carapace width (CW) in their first year; 130 to 160 mm CW in their second year, and around 200 mm CW (under ideal conditions) in their third year (Heasman 1980). Both growth rates and the size at first maturity vary with latitude (Fielder and Heasman 1978). Mud crabs in Australia reach maturity in 18 months in the tropics, but can take up to 36 months to reach maturity in the sub-tropics such as Moreton Bay. The minimum size at maturity is larger in sub-tropical areas than tropical areas (Brown 1993).

Table 5.1. Summary of studies correlating mud crab catch with environmental variables

Reference and data source	Analysis	Result	Discussion points
Williams & Hill, 1982 • Fishery independent	Pearson correlation for catch *vs* salinity/daily temperature	No correlation with salinity (r = 0.09) but moderate positive correlation with daily water temperature (r = 0.56)	Catch rates related to water temperature but not salinity
Loneragan & Bunn, 1999 • Fishery dependent	Pearson correlation for Log catch *vs* Log seasonal river flow (Logan River)	Catch strongly correlated (r = 0.9) with summer river flow only	Catch rates related to summer river flow
Manson *et al*., 2005 • Fishery dependent	Multiple regression analysis of catch rates *vs* mangrove area and perimeter.	Moderate and significant positive relationship between mangrove perimeter and catch rates (r^2 = 0.53)	Catch rates related to mangrove perimeter
Robins *et al*., 2005 • Fishery dependent	Pearson correlation and all subsets regression for concurrent and lagged (*i.e.* 1 or 2 years) Log catch *vs* Log seasonal river flow/ rainfall (Fitzroy region). Two data sets used: 1960-1980 from QLD Fish Board (QFB) and 1988-2002 from Fisheries Queensland commercial logbook catch data.	Ambiguous results from analyses of QFB data – some significant positive and negative relationships. Significant positive relationship (r^2 = 0.7) in Fisheries Queensland commercial logbook catch data between Autumn catch lagged by two years and river flow. All subset regression identified several alternate models that explained between 70 and 97% of the variation in mud crab catch for the QFB and CFISH data respectively.	The QFB data was not adjusted for effort and so inferences from subsequent analyses are limited. The Fisheries Queensland commercial logbook catch was corrected for effort, with model outputs similar to those given in Loneragan & Bunn (1999).
Halliday & Robins, 2007 • Fishery dependent	Pearson correlation and all subsets regression for concurrent and lagged (*i.e.* 1 or 2 years) Log catch *vs* Log seasonal river flow/ rainfall (Port Curtis region). Two data sets	Significant correlations between QFB catch data and summer and autumn flows. Flows lagged by 1 and 2 years were also significantly (negatively) correlated with catch. Four alternate GLMs identified explaining between	Evidence of freshwater flows in autumn affecting the recruitment strength of mud crabs, concurring with the suggestion of

	used: 1960-1980 from QLD Fish Board (QFB) and 1988-2002 from Fisheries Queensland commercial logbook catch data.	60% and 66% of variability (i.e., adj. R^2) of the QFB catch. Two significant alternate models (adj. R^2 71% and 63%) for the commercial logbook catch, both containing spring flow or rain lagged by two years.	recruitment effects by Loneragan & Bunn (1999).
Meynecke and Lee 2011 • Fishery dependent	Linear regression of wet season and monthly catch adjusted for effort (CAE) against Sea Surface Temperature and Rainfall for Queensland divided into 8 regional areas.	Significant positive correlation between wet season CAE and rainfall for 2 of 8 regions. Significant GLMs explaining 43% to 68% of variation in annual CAE for 3 regions; of which 2 regions had SOI (May to Oct) and annual rainfall. Significant GLM's explaining 22% to 71% of variation in CAE lagged by two years. Temperature important in 1 region, wet season rainfall important in the other 2 regions.	Suggested significant relationships reflected reduction in the numbers of sub adult and adult crabs in river systems from increased runoff, thus enhancing survival of juveniles. Relationships variable between regions.
Meynecke *et al*. 2012 • Fishery dependent	Monthly catch and effort data (CPUE) analysed by forward linear regression of 29 catchments with 52 river systems across the Northern Territory, Queensland and New South Wales. Used multi-dimensional scaling to describe similarities in annual CPUE, rainfall, temperature and flow.	Significant relationships between seasonal rainfall lagged by one season and annual maximum SOI with NT CPUE for 4 of 7 river systems, with Qld CPUE for 6 of 14 river systems. For NSW CPUE, temperature was the most influential climate parameter. MDS showed regional groupings in all states.	Identified regional patterns in mud crab catches. SOI was a good predictor of CPUE in Qld, NT and some parts of NSW. CPUE significantly related to rainfall and or flow in many rivers examined. Monthly SST and CPUE related in some areas.

Distribution, habitat and environmental preferences

Mud crabs of the genus *Scylla* commonly occur throughout tropical to warm temperate areas of the west Pacific and Indian Oceans (Keenan 1999). Their distribution encompasses the Asian sub-continent and Japan, northern and eastern Australia and from the east coast of Africa across to Tahiti (Ryan 2003). In Australia, they inhabit regions extending from Exmouth Gulf on the coast of Western Australia, through to the Northern Territory and Queensland to the southern coast of New South Wales (Figure 5.3; Knuckey 1999).

Mud crabs usually inhabit estuarine channels, sheltered coastal habitats and shallow tidal flats associated with mangrove communities (Hill *et al*. 1982). Juveniles usually remain in the intertidal zone (amongst mangroves), whereas adults tend to be more abundant in the sub-tidal zone (Hill *et al*. 1982).

Predators and prey

Mud crabs form an important part of mud flat and mangrove food webs as they consume a variety of organisms while they are prey for large teleost fishes, rays, sharks, turtles and crocodiles (Poovachiranon 1992). Isotope studies of the stomach contents of mud crabs suggest that their diet changes with size. Small mud crabs (i.e., 60 to 99 mm CW) are omnivorous, feeding on small crabs and plant material, while medium (100 to 139 mm CW) and large mud crabs (140 to 179 mm CW) are predominately carnivorous, feeding on slow moving invertebrates such as grapsid crabs, prawns, molluscs, worms and some fish (Thimdee *et al.* 2001). Mud crabs are generally nocturnal feeders, emerging from their intertidal burrows at dusk, moving slowly over the substrate to capture prey and to scavenge before returning to a burrow by dawn (NSW DPI 2008). They have a home range of approximately 500 m, and use their larger claw for crushing while the smaller claw is used for biting, cutting and manipulating the prey (Ryan 2003). Their feeding activity depends on environmental factors such as temperature and physiological factors such as moult condition.

Recruitment

Mud crabs are highly fecund and it is likely that factors such as currents, salinity, temperature, food supply, suitable habitat and predation are more important in determining recruitment levels than the number of spawning females (Ian Brown pers. comm.). Halliday and Robins (2007) reported significant correlations between mud crab catch (adjusted for effort) and autumn or spring flows two years prior to the catch in the Fitzroy and Port Curtis regions of central Queensland. These results suggest an effect of freshwater flows on successful recruitment to the estuary and concur with the hypothesised recruitment effects by Loneragan and Bunn (1999). It is unlikely that it is the flow per se that increases recruitment, as mud crab early life stages are not tolerant of low salinity water. More likely is the effect freshwater flows have on nutrient inputs and productivity of the estuary, leading to enhanced food opportunities and faster growth rates, which may lead to greater survival of young crabs.

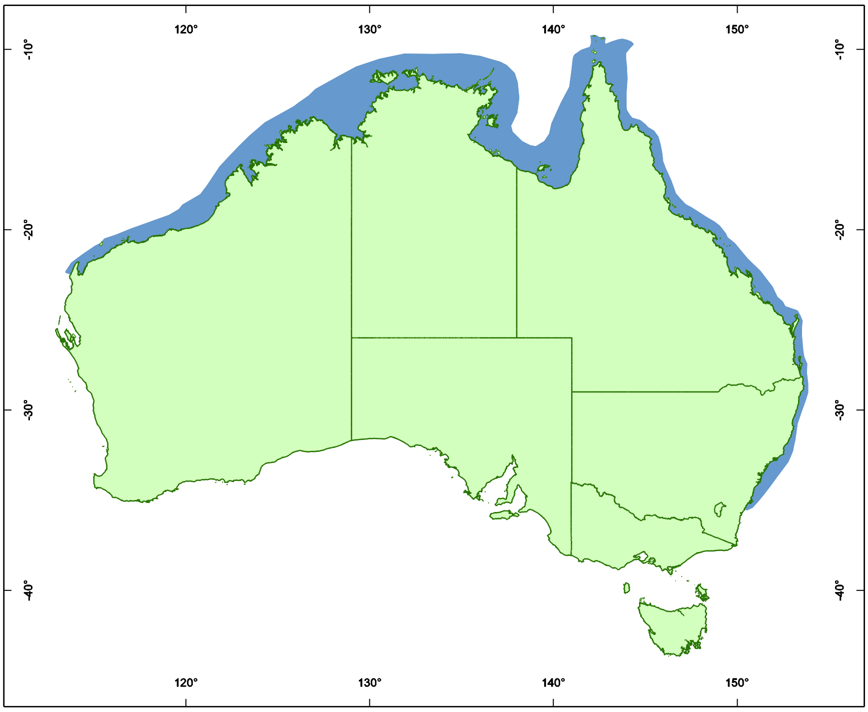

Figure 5.3. Australian distribution of mud crab

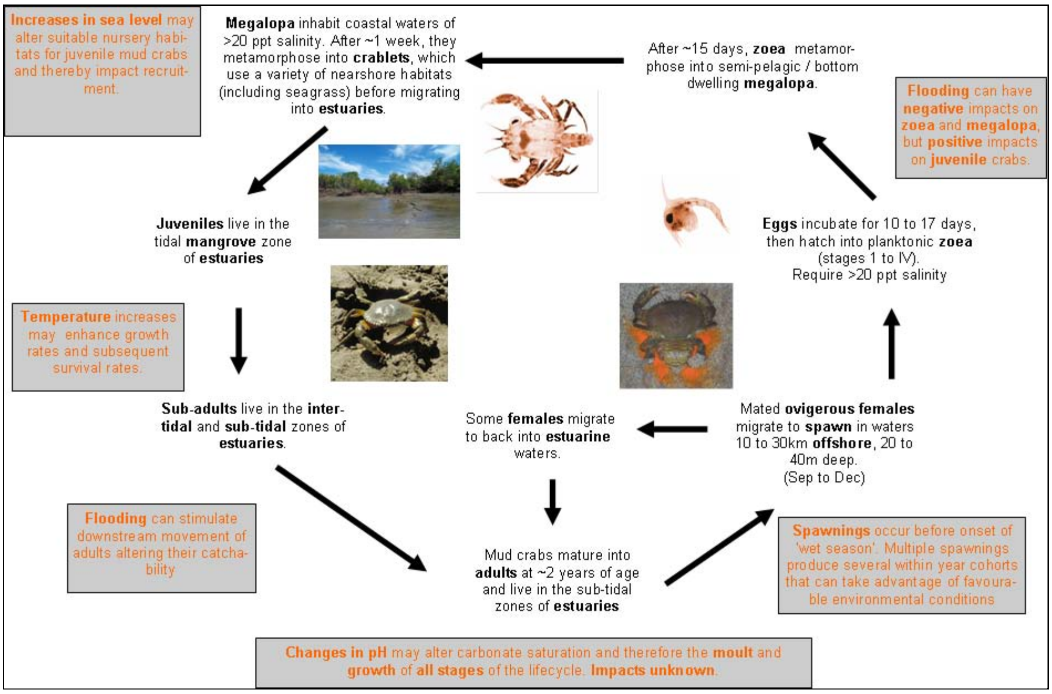

Figure 5.4. Generalised life cycle of mud crab (Images courtesy of DAFF, NTDoR and GBRMPA)

Current impacts of climate change

- There are no known current impacts on mud crabs attributable to climate change.

Rainfall and temperature are suggested to be important potential environmental drivers affecting mud crab catchability, growth rates and recruitment success. Notwithstanding this there are no current impacts on mud crabs that can be attributed to climate change.

Sensitivity to change

- Rainfall/riverflow and temperature appear to have a significant influence on mud crab catchability (and possibly juvenile survival) and growth.
- Mud crabs are likely to be sensitive to changes in the distribution of estuaries and associated wetland habitats, including mangroves and saltmarshes, with sea level rise.

Mud crabs are widely distributed throughout the tropics and sub-tropics of the west Pacific and Indian Oceans. Several aspects of the life cycle of mud crabs are sensitive to temperature, including survival and development of early life stages (Hamasaki 2003; Ruscoe *et al.* 2004), growth rates (Fielder and Heasman 1978; Brown 1993) and feeding activity (Williams and Hill 1982). To date, studies have focused on the lower temperature tolerances and no studies have examined the sensitivity of mud crabs to temperatures above 35°C. Mud crabs are also sensitivity to salinity (Ruscoe *et al.* 2004), with early life history stages requiring >20 ppt. Mud crabs utilise estuaries and associated wetland habitats, including mangroves and saltmarshes, and will be sensitive to changes in the distribution of these habitats that may occur if sea level rises significantly. In addition, mud crab abundance will be sensitive to any changes in the Southern Oscillation Index (SOI) as between 30 and 40% of the catch variability is explained by La Niña phases which are associated with increased rainfall and higher temperatures in northern Australia (Meynecke *et al*. 2010).

Other physical drivers that influence the abundance of mud crabs arecurrents, tides and wind that control dispersal and settlement during the larval stage the lunar cycle that affects the timing of moulting and migration. Additionally the mangroves and mudflats inhabited by mud crabs are often rich in organic material and microorganisms, thereby having a high biochemical oxygen demand. The shallow water of these areas with ebbing or flooding tides is likely to contain low levels of dissolved oxygen. Therefore, mud crabs may be subject to hypoxic stress (Davenport and Wong 1987), especially during high temperatures.

Resilience to change

- Mud crabs appear to be resilient to a wide range of environmental conditions throughout their life history.

The resilience of mud crabs to long-term changes in the climate regime is unknown. However, there are many aspects of the life history of mud crabs that suggest they may be resilient to change, at least in the short term (i.e., <50 years). Mud crabs have a wide geographic distribution (including a large latitudinal range), are an omnivorous detritivore capable of using a wide variety of prey items, inhabit a wide range of estuarine habitats, have extended spawning seasons, and high fecundity, with short time to maturity. Further research is needed to determine if the early life history stages of mud crabs may be critically limited by altered water pH and what is their upper temperature tolerance.

Other

- Mud crabs provide a source of food to higher-level predators.
- The effect of specific environmental factors, including water extraction, on each stage of the mud crab life cycle is poorly understood.

Ecosystem level interactions

Biological drivers can include predation by other crabs (i.e., cannibalism) or through predators like crocodiles, sharks, rays, fish, dingoes and humans. In addition, the distribution, abundance and diversity of estuarine habitats such as mangroves, mudflats and seagrasses are likely to be related to the abundance of mud crabs (Meynecke *et al.* 2007; Webley *et al*. 2009).

Additional (multiple) stressors

Both the market demand and catch rate of mud crabs have increased substantially over the past decade but there has also been large variations in catch, particularly in the Gulf of Carpentaria and the Northern Territory. Fluctuations in catch rates greater than a factor of eight were thought to be driven by climate parameters and are likely to increase further with climate change. Such variations may pose a challenge to the viability of the commercial fishery.

The years 2000 and 2001 saw record mud crab (*Scylla serrata*) catches throughout its range in Australia, presumably due to a combination of high fishing effort and favourable recruitment in the preceding years. This peak was followed by a significant decrease in catch in all relevant jurisdictions, with the magnitude of the decline greatest in the Northern Territory. These large commercial catches are occurring again in 2011 (Fisheries Queensland commercial logbook data).

Heavy rainfall events (causing major flooding) can have an associated dieback of seagrass beds. Seagrass has been proposed (but not validated) as a preferred habitat for crablet colonisation, prior to their movement into estuaries (Webley *et al*. 2009). Therefore, negative impacts of climate change on seagrass beds may subsequently impact on the recruitment success of mud crabs at their crablet stage.

Critical data gaps and level of uncertainty

More field studies to examine the linkages between specific environmental drivers, habitat mosaics and their influence on the mud crab life cycle are needed. There is little evidence of cause and effect which is an issue with most ecological/climate modelling. This includes the definition of activity and spawning trigger values, such as tide, temperature and salinity, for a number of Australian mud crab populations from the various biogeographic regions.

Despite the continued use of freshwater resources and subsequent alteration of the quantity and quality of freshwater flowing down rivers to estuaries, there is limited understanding of the impacts of such changes on estuarine flora and fauna. To understand the impact of changed flow, we need first to understand and quantify the role of freshwater on populations of estuarine-dependent species.

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6. Saucer scallop, *Amusium japonicum balloti*, and mud scallop, *A. pleuronectes*

Author: Julie Robins

Queensland saucer scallop, *Amusium japonicum balloti.* (Image sourced from QDAFF).

The fishery

Key points:

- Harvest is variable and probably linked to environmental drivers.
- The fishery is dependent on scallops that are one to two years old.

Queensland east coast

Two species of scallop are harvested along the Queensland east coast and, unlike other scallop species in southern Australia, are harvested by trawl methods rather than dredge. Scallops are harvested by trawlers in the East Coast Otter Trawl Fishery, which operates from the border between Queensland and New South Wales northwards to the Torres Strait. The saucer scallop, *Amusium japonicum balloti,* is the main species harvested in Queensland waters south of 20°S while the mud scallop, *A. pleuronectes*, is the main scallop species harvested in waters north of 20°S and is generally regarded as a by-product species (Williams 2002).

Although scallops form part of the multi-species East Coast Otter Trawl Fishery, there are specific management restrictions and gear differences that separate the scallop sector from the prawn sectors. The Queensland East Coast Otter Trawl Fishery is managed by input controls including: limited entry, individual effort limits, vessel restrictions, and spatial and temporal closures. In addition, for saucer scallops, there are minimum legal shell size limits, as well as rotational spatial closures and temporal closures that are designed to maintain broodstock levels and maximise harvest rates.

The annual harvest of Queensland saucer scallops is highly variable (Figure 6.1). Monthly catch rates of saucer scallops are also highly variable, peaking in January and November when spatial and temporal closes (respectively) are opened to fishing (Campbell *et al*. 2010).

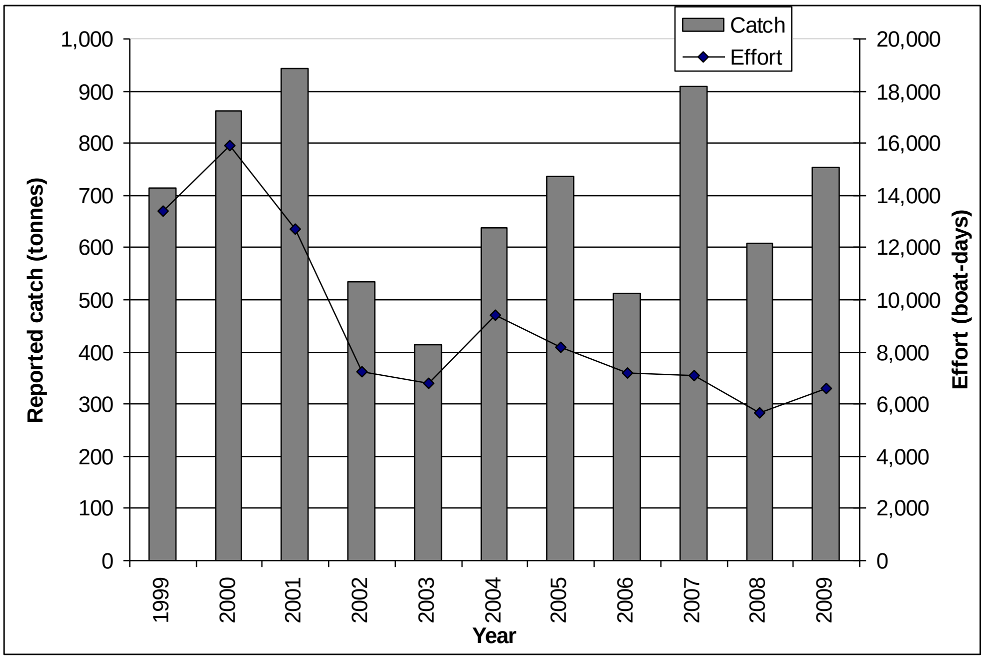

Figure 6.1. Scallop commercial catch (tonnes) and effort (boat days) by year for the Queensland East Coast otter Trawl Fishery (data source Fisheries Queensland)

Life history

Key points:

- Recruitment is highly variable in Queensland and Western Australian stocks.
- Recruitment variability in WA is linked to a weak Leeuwin Current that occurs in El Nino years.
- Recruitment in Queensland is speculated to be linked to the East Australian Current.

Life cycle, age and growth

The saucer scallop has a life history that is typical of Pectinid bivalves. Adults spawn in a single spawning season from winter to spring. Saucer scallops spawn eggs and sperm that are fertilized in the water column. After a short incubation period (<2 days), eggs hatch into a two-stage larval phase first becoming a trochophore (~28 h after fertilization), then a veliger (2 days after fertilization), both of which are pelagic (Rose et al. 1988). The pelagic larval phases last up to about three weeks (Rose et al. 1988) and during this time larvae can freely swim. Laboratory experiments have shown that saucer scallop larvae require water temperatures <25^{o}C (Cropp 1993). The distribution of pelagic larval scallops and the subsequent recruitment of scallop spat to productive seabed areas in speculated to the influenced by water currents and other hydrological features such as cyclonic eddies.

The pelagic veliger stage metamorphoses into a pediveliger stage at around 20 days, developing a ciliated foot and a distinct byssal gland that in other scallop species produces byssus threads for attaching the spat to hard surfaces. Saucer scallops have a limited byssal stage (Rose et al. 1988). . Spatfall (the settling of larval scallops to the sea floor) and survival of spat is probably important in determining the productivity of sea bed areas for adult scallops. Successful spatfall of other species of scallop requires suitable substrates for settlement and is negatively affected by shifting sands on the seafloor. Whether this is the case for saucer scallops is unknown, but their short byssal phase may make them more tolerant of shifting sands. Once settled on the seafloor, saucer scallops are thought to be relatively sedentary i.e., they do not undertake migration.

Saucer scallops have the best swimming ability of pectinid bivalves and can swim up to 20 m in one burst. Juvenile saucer scallops grow quickly, up to 2.2 mm per week (Joll 1988), reaching 90mm shell height in 33 to 42 weeks (Williams and Dredge 1981), and participate in their first spawning at between nine and 12 months of age (Dredge 1981). Saucer scallops are dioecious i.e., separate sexes. They live to about three years of age, although most do not survive to this age because of high natural mortality rates (Dredge 1985).

The development of gonads in saucer scallops starts when water temperatures have reached their peak (around 28 to 29°C) and begin to fall (Dredge 1981). However, Joll and Caputi (1995) reported no relationship between temperature and spawning for saucer scallops in Western Australia. Maximum gonad development occurred when water temperatures were near minimum (Dredge 1981). The spawning of saucer scallop can also be heat-manipulated in laboratory situations (Rose et al. 1988).. Dredge (1981) found that the fecundity and peak spawning of saucer scallops varied over relatively small distances, although *Amusium balloti* releases a lower number of eggs compared to other species of scallop such as *Pecten* (Rose et al. 1988).

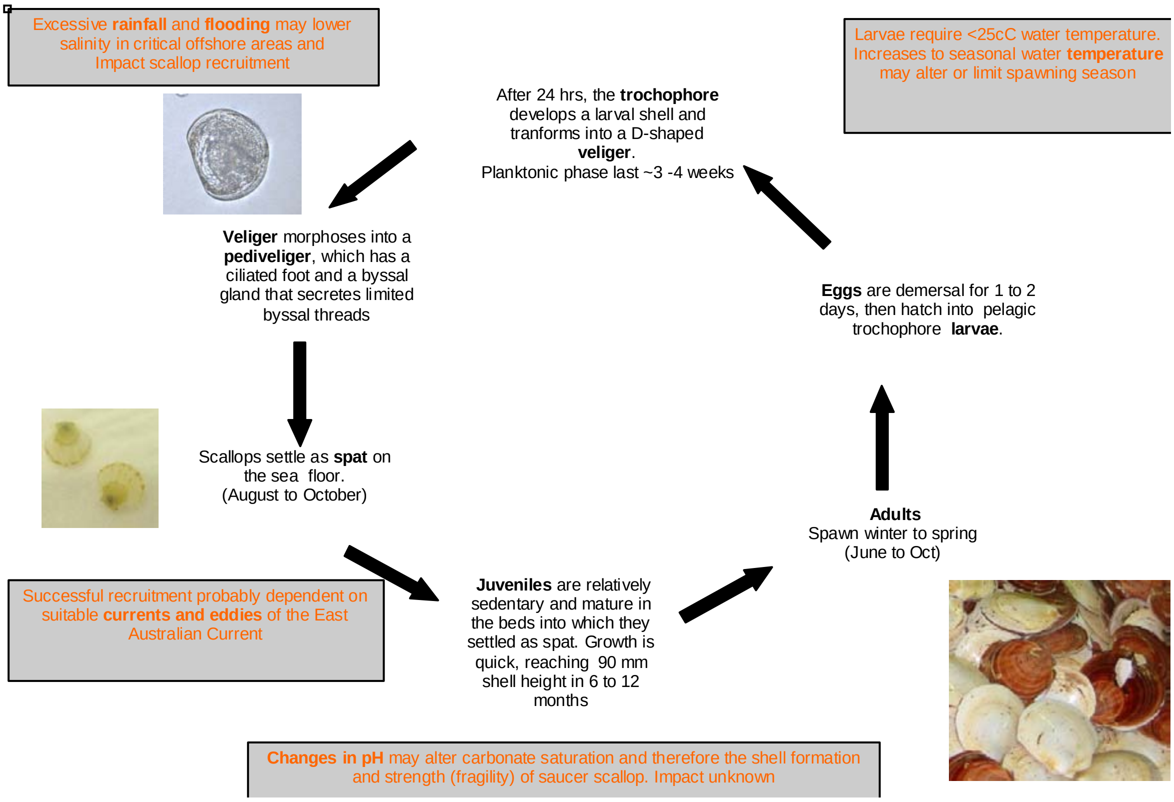

Figure 6.2. Generalised life cycle of saucer scallop (Images sourced from QDAFF and Sizhong Wang, QDAFF)

Saucer scallops have fast growth rates that vary with region and year. Water temperature is thought to be one of the significant drivers of variable growth in bivalves (Campbell et al. 2010). As water temperature can be a function of depth (i.e., warmer in shallower waters), saucer scallops in shallow waters (30 to 40 m) have faster reported growth rates than those from deeper waters (40 to 42 m) (Campbell et al. 2010). Water flow velocities that occur as a consequence of currents can affect food availability and feeding and thus growth. Campbell *et al*. (2010) reported slower growth rates than that reported by Williams and Dredge (1981) and suggested that the difference might be due to changed climatic conditions, competition for food or other density related processes or the season(s) during which the most recent work was conducted.

Reduced growth rate of saucer scallops was observed in Shark Bay scallops in November 2010 and February 2011 during the annual WA Fisheries fishery independent scallop survey (Pearce et al. 2011). Reduced growth was speculated to be linked to the higher water temperatures in Shark Bay (i.e., the WA marine heat wave) and possible variation in food availability. An additional (later than normal) settlement of scallops was also observed. The marine heat wave in WA, occurring between November 2010 and March 2011, from monthly satellite-derived sea surface temperatures (SST's) showed ocean warming of >2°C above average, with small areas (including Shark Bay) where temperatures were >3°C above average. Higher temperatures coincided with flood events in Shark Bay in December 2010 and February 2011, resulting in lowered salinity and higher turbidity in the waters of Shark Bay.

Distribution, habitat and environmental preferences

Saucer scallops are predominately a sub-tropical species that occurs in waters between 15°S and 25°S on the east coast of Australia and between 18°S and 35°S on the west coast of Australia (Dredge 2006). They are found in oceanic waters between 15 and 50 m deep, and in Queensland are most abundant in water depths >40 m and south of 20°S. Saucer scallops bury into sediment and as such occur in bare, sandy, rubbly or sponge garden habitats that have a soft but not muddy, sediment.

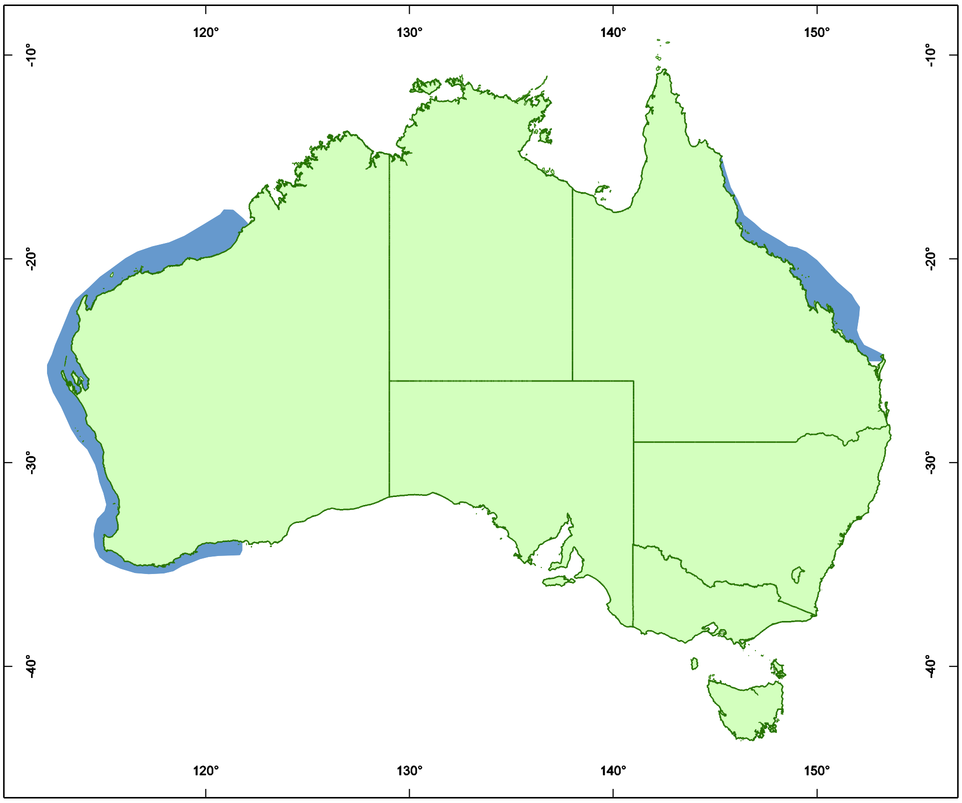

Figure 6.3. Australian distribution of saucer scallop.

Predators and prey

Saucer scallops are filter feeders and consume a variety of microscopic organisms in the wild, probably including phytoplankton and benthic diatoms. In aquaculture studies, saucer scallops have been fed algal cultures including *Tetraselmis suecia*, *Chaetoceros gracilis*, *C. clacitrans*, *Pavlova lutheri* and Tahitian *Isochrysis* (aff.) *galbana* (Cropp 1993).

Predators of saucer scallops include the slipper lobster (*Thenus orientalis*), the blue swimmer crab (*Portunus pelagicus*), the coral crab (*Charybdis cruciata*), loggerhead turtles (*Caretta caretta*), octopus and snapper (*Pagrus auratus*) (Dredge 2006).

Recruitment

Recruitment of saucer scallops is highly variable between years and at small spatial scales (Joll 1994; Joll and Caputi 1995). High recruitment into the Shark Bay scallop fishery is usually associated with low mean sea levels (= weak Leeuwin Current) over the winter (spawning) months (Joll 1994). Joll and Caputi (1995) speculated that short-term variations in the structure and strength of the Leeuwin Current along the Western Australian coast provides periods of favourable and unfavourable environments within Shark Bay that subsequently determine recruitment success i.e. hydrological flushing of larvae (Caputi et al. 1996). Caputi *et al*. (1996) alternatively suggested that scallop recruitment may be linked to the effect of warmer water on spawning or fertilisation events. Similar impacts of the East Australian Current on recruitment success of saucer scallops in central Queensland have been speculated but not investigated.

Annual landings from the fishery in Western Australia are highly correlated with recruitment levels (Mueller et al. 2012). In Shark Bay, Mueller *et al.* (2012) suggested that environmental factors, such as tides, currents, and winds during scallop spawning and recruitment would be important factors in scallop recruitment because of the low correspondence between residual stock distribution (after fishing) and recruit distribution. Scallops in Shark Bay were affected by a "marine heat wave", where it is speculated that lowered salinity and higher temperatures may have exceeded the tolerances of adult scallops (Mueller et al. 2012).

Current impacts of climate change

Key points:

- Changes in major Australian currents (such as the Leeuwin and East Australian Current) are likely to impact recruitment of saucer scallops.

Recruitment variability of saucer scallops has been linked to weak Leeuwin Current in Western Australia in El Nino years (Caputi et al. 2010). An increased frequency of El Nino events may contribute to more years of good saucer scallop recruitment and therefore, be of benefit to WA fisheries (Caputi et al. 2010).

For other species of scallop (*Pectin maximus*) in the northern hemisphere, warmer spring temperatures (and not oxygen or chlorophyll a) have had a positive effect on gonad development and it has been suggested that this leads to increased gamete production and subsequent recruitment and catch (Shepard et al. 2010). It has also been suggested that warmer water, in the absence of excess food would have a negative effect on growth and reproductive development (Pilditch and Grant 1999). Whether this applies to saucer scallops in sub-tropical waters in unknown.

Sensitivity to change

Key points:

- Scallops have an unknown sensitivity to environmental variability.

Saucer scallops have restricted latitudinal ranges on the east and west coast of Australia, which probably reflects specific habitat requirements (bottom type, water depth, temperature and food availability) as well as dispersal mechanisms for larvae and spat (i.e., eddies).

Resilience to change

Key points:

- The resilience to change of saucer scallops is unknown, and as such has been classified as having a high level of ecological vulnerability to climate change.

Morison and Pears (2012) completed an expert based vulnerability assessment of the Queensland East Coast Otter Trawl Fishery and concluded that saucer scallops had a high level of ecological vulnerability from changed rainfall patterns and increased tropical storm intensity that could result in flooding, increased nutrients, pollutants and sediments. These events could reduce salinity and reduce available habitat and result in recruitment failure.

Morison and Pears (2012) also found that saucer scallops had high ecological vulnerability to higher sea surface temperature and ocean acidification, possibly effecting spawning triggers, larval development and inducing fragile shells. They also concluded that saucer scallops had a high level of ecological vulnerability to altered ocean circulation as larval dispersal and spat recruitment is (probably) dependent on eddies of the East Australian (and Capricorn) Current.

Other

Key points:

- Research into the links between environmental drivers and saucer scallop productivity in Queensland is needed.

Ecosystem level interactions

The abundance of some scallop populations have been significantly affected by predator levels (Hart 2006). This may or may not be the case for saucer scallops.

Additional (multiple) stressors

There are no known additional stressors on saucer scallops.

Critical data gaps and level of uncertainty

Little or no work has occurred linking indices of scallop abundance in Queensland (either catch, CPUE or fishery-independent recruitment surveys) with environmental influences, despite the strong anecdotal and scientific speculation of environmental drivers on saucer scallops. Further research into the links between scallop productivity and environmental drivers should investigate sea surface temperature, sea surface salinity, sea level anomalies (which captures warm and cold core eddies), and currents (see http://www.bom.gov.au/oceanography/forecasts/forecast-help.shtml).

Also, research is needed into the response of saucer scallops to changed ocean acidity to determine if saucer scallops are at risk of developing fragile shells as the pH of ocean water changes.

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7. Sea cucumbers (beche de mer, trepang)

Author: David J. Welch

The fishery

Key points:

- Recently active fisheries have been in WA, the NT and Qld while the Torres Strait fishery is generally inactive.
- Species targeted vary among jurisdictions. Key species are: sandfish (*Holothuria scabra*), redfish (*Actinopyga echinites*), burrowing blackfish (*Actinopyga spinea*) and white teatfish (*Holothuria fuscogilva*).
- Sea cucumber species are generally susceptible to overfishing and currently fishing for some species is banned due to overfishing.

Fisheries catch and status

The beche de mer or trepang fisheries across tropical and sub-tropical northern Australia are all hand collection fisheries by divers on snorkel, SCUBA or hookah, or by wading in shallow waters. These fisheries are almost exclusively commercial and are multi-species with species composition differing among jurisdictions. They are harvested primarily for the dried body wall and most are exported to Asia. In Western Australia (WA) only two species are taken (redfish – *Actinopyga echinites* and sandfish – *Holothuria scabra*) and in the Northern Territory (NT) the predominant species is *H. scabra* (Department of Fisheries, 2011; Northern Territory Government, 2011). On the Queensland (Qld) east coast there are at least 10 species taken and, although the species composition is variable through time, is dominated by two major species (burrowing blackfish – *A. spinea* and white teatfish – *H. fuscogilva*) (Anon, 2011a). In the Torres Strait historically there have been at least 16 different species targeted however in recent years there has been very little activity in the fishery due to the ban on taking some of the highest value species due to declining abundance. The prohibited species are *H. scabra* (since 1998), *H. whitmaei* and *A. mauritiana* (since 2003) (Anon, 2011b). Since 2008 there have been only 3 active fishers in the Torres Strait (all Traditional Inhabitant licensees) and very little commercial catch has been reported since 2005. Because there are only 3 active fishers catch figures in recent years have not been publicly available due to confidentiality reasons (Anon, 2011b). Prior to 2007 the WA fishery was essentially a single species fishery with ~99 % of the catch being *H. scabra*. In the past two years in Qld the fishery is targeting curryfish (*Stichopus hermanni*), mainly due to its higher value and improvements in processing.

Total commercial catch was 121 t in WA in 2009-10 (redfish – 71 %, sandfish – 29%), 22 t in the NT in 2010[1], and 352 t in Qld in 2009-10 (burrowing blackfish – 70 %, white teatfish – 20 %, curryfish – 9 %). In WA sandfish has been the major species historically and targeting of redfish has only picked up

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[1] The average annual catch over the period 1998 to 2007 was 235 t and low catches in the past three years can be attributed to the sole NT licensee shifting most of his effort to WA during those years.

since 2007 (Figure 7.1). In the NT catch of sandfish has been highly variable with effort (and catch) noticeably decreasing since 2002 (Figure 7.2). Currently sea cucumber fisheries are considered to be fished at sustainable levels in WA and Queensland (Anon, 2011a; Department of Fisheries, 2011) while in the NT they have not been assessed (Northern Territory Government, 2011). On the Great Barrier Reef black teatfish (*H. whitmaei*) is over-fished and the fishery for them has been closed since 1999 (Uthicke et al, 2004). Between 2001-02 and 2009-10 sea cucumber catch on the GBR has been fairly stable (Figure 7.3). The catch value of the WA fishery was estimated to be $330,000 for the year 2010 (Department of Fisheries, 2011), and the catch from the Qld fishery was estimated to value $4.9 M in 2009-10 (Anon, 2011a).

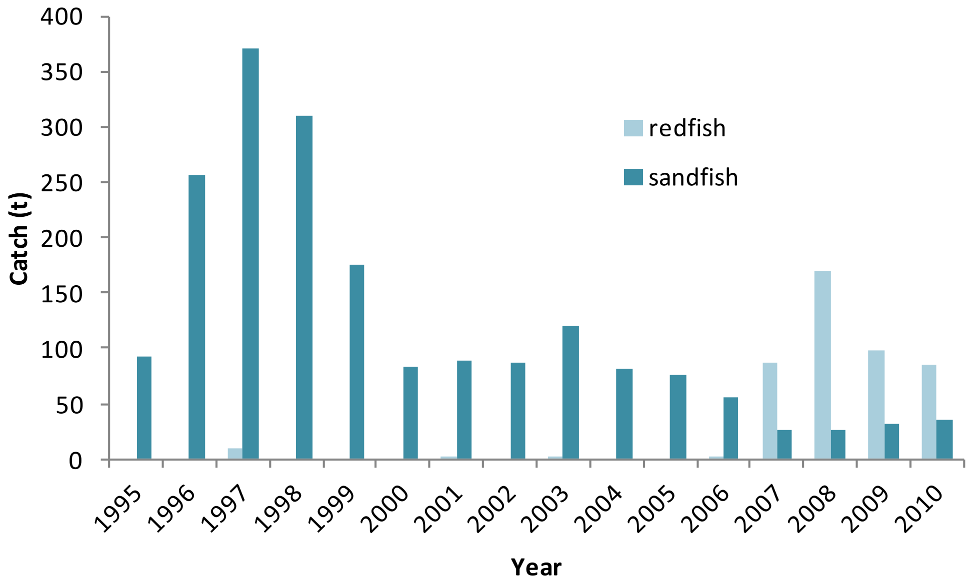

Figure 7.1. Catch of the two major sea cucumber species in commercial fisheries in WA from 1995-2010 (Source: Department of Fisheries, 2011).

Fisheries Management

Although fisheries for holothurians (sea cucumbers) globally have a history dating back hundreds of years, growing demand and resulting high value in SE Asia meant fisheries targeting increased during the 1980s. Throughout their history sea cucumber fisheries have been characterised by boom-and-bust cycles due to life history and ecological characteristics of holothurians. Management of wild sea cucumber fisheries therefore require careful and conservative strategies to ensure sustainability (Anderson et al, 2011; Purcell et al. 2011).

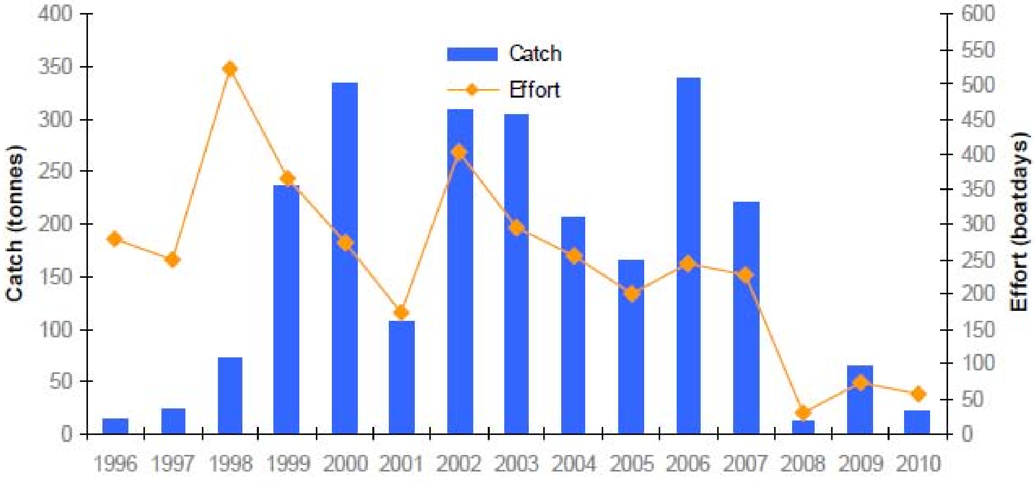

Figure 7.2. Catch of sandfish by NT commercial fishers during 1996-2010. (Source: Northern Territory Fisheries, 2011).

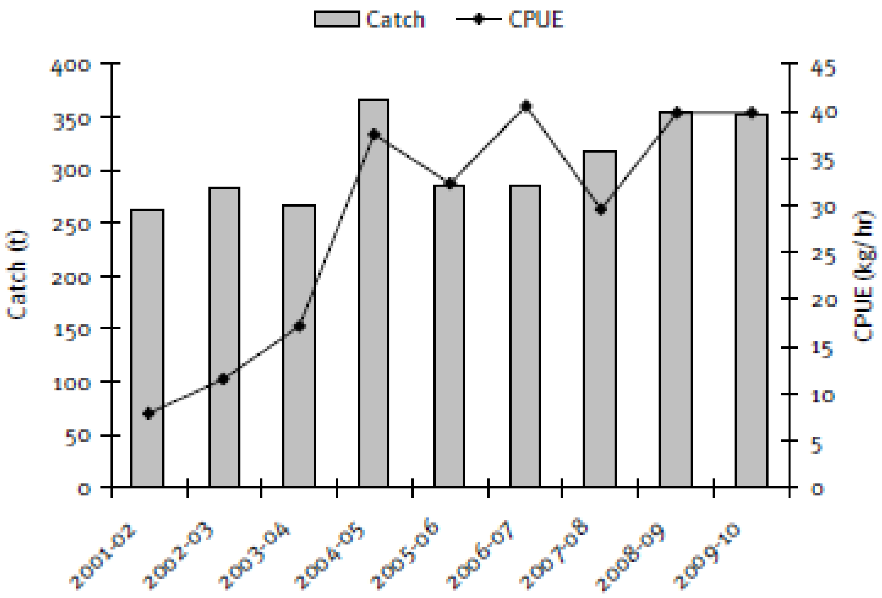

Figure 7.3. Total catch of sea cucumber on the GBR from 2001-02 to 2009-10. (Source: DEEDI, 2011).

Western Australia

The WA fishery operates from Exmouth Gulf to the NT border and is managed through a number of input controls. These include limited entry, a maximum number of divers, hand collection only, size limits depending on the species and gear restrictions. There are 6 vessels licensed to fish however in the past three seasons only two of these have been operating in the fishery. Catch is reported separately for the two species, as is effort, which is spatially separate due to the different habitats the two species occupy. This also means that management performance measures are species-specific (Department of Fisheries, 2011).

Northern Territory

The NT fishery covers the entire coastline to 3 nautical miles but the major areas where catch and effort is focused are the Cobourg Peninsula and Groote Eylandt along the Arnhem Land coast. Key management strategies used include limited entry (6 licenses of which all are held by the one licensee), separate management zones with limited entry by licence, a limited number of collectors, and hand collection only (Handley, 2010).

Queensland

The fishery in Queensland can operate from Tin Can Bay to Cape York however most of the historical effort has been in north Qld reef areas north of Townsville. Working depths are greater than in other jurisdictions (30 m) due to the targeting primarily of white teatfish. Management controls include a total allowable catch of 361 t of which there are individual species quotas for black teatfish (currently not fished and has 0 t quota), white teatfish, and other species, limited entry (currently 18 transferable licences of which only 7 reported catch in 2009-10), minimum size limits for key species, gear limitations, area closures through the Great Barrier Reef zoning, and a rotational zoning scheme (RZS). The RZS is an industry led scheme that divides the total fishing area into 154 fishing zones which can be fished only one in every three years and even then for a maximum of 15 days annually. Catch (but not effort) is reported by species and there are performance measures for the key species (Anon, 2011a).

Life history

Key points:

- Sea cucumbers generally have very low replenishment rates making them susceptible to overfishing and slow at recovering from perturbations.
- Successful recruitment is likely to be influenced (in part) by adequate densities of spawning adults.
- Sea grass appears to be an important habitat for *H. scabra* recruits.

Life history information documented here is generalised for all sea cucumbers unless individual species are indicated. There is a general focus on *H. scabra* due to its relative fishery importance and high level of knowledge relative to other species. It is acknowledged however that the species-specific biology and ecology of sea cucumbers can be highly variable (Conand, 2006).

Life cycle, age and growth

Tropical and sub-tropical sea cucumbers are primarily broadcast spawners with fertilisation taking place in the water column however some species exhibit asexual reproduction by transverse fission (Uthicke, 2001a). Broadcast spawning is generally annual or bi-annual, though some species (eg. *H. scabra*) are capable of spawning year round in warmer equatorial waters (Morgan, 2000a), while asexual reproduction occurs in early winter (Uthicke, 2001a). Temperature appears to be the main cue to spawning though there may be other exogenous cues and is often linked to lunar cycles. Spawning seasons are generally Spring-Summer and can vary by species and spatially (Morgan, 2000a) with a few species preferring to spawn during winter (eg. black teatfish, *H. whitmaei*; Shiell and Uthicke, 2006). *H. scabra* is currently the only tropical sea cucumber that can be mass reared in hatcheries, although recent developments suggest that broad-scale culture of curryfish (*Stichopus* spp.) may also be possible (Hamel et al, 2001; Hu et al, 2010). Holothurian broodstock are induced to spawn generally by raising the tank water by 3-5 °C (Morgan, 2000b; D. Welch, pers. obs.), however the introduction of micro-algae into tank water has also been shown to trigger spawning in a number of holothurians species (Battaglene, 1999).

Egg development in holothurians is generally short (24 hrs) and the planktonic larval duration varies among species and for some of the key harvested species ranges from 12 - 22 days (Ramofafia et al, 2003). In cultured situations for *H. scabra* temperatures are kept between 26 °C and 29 °C during larval development. Larvae feed on different species of micro-algae and successful metamorphosis has been shown to be dependent on the algal species consumed. One of the better algal species, *Chaetoceros muelleri*, is very tolerant of high temperatures (Battaglene, 1999). Larvae develop through the feeding stage auricularia, the non-feeding doliolaria, and the pentactula stage that develops tentacles and settles (Fig 1.; Ramofafia et al, 2003). Preferred habitat types for settlement appear to be on sea grass leaves for *H. scabra* (Mercier et al, 2000a) with cues including the presence of particular food types such as diatoms and certain bacteria (Battaglene, 1999). Generally, however, very little is known of the larval movement and settlement processes in the wild (Conand, 2006).

Growth rates of sea cucumbers are also poorly understood but are generally believed to be slow with low overall productivity (Uthicke et al, 2004). Hu et al (2010) were able to grow curryfish (*Stichopus* sp.) juveniles to approximately 20 cm within 7 months in a hatchery. Aging of holothurians in the wild has not been possible however modelling by Uthicke et al (2004) suggested that *H. whitmaei* are long-lived (potentially several decades).

Distribution, habitat and environmental preferences

Sea cucumbers are benthic animals found mostly on soft substrates such as sand and mud however they are usually associated with sea grass, algae and corals.

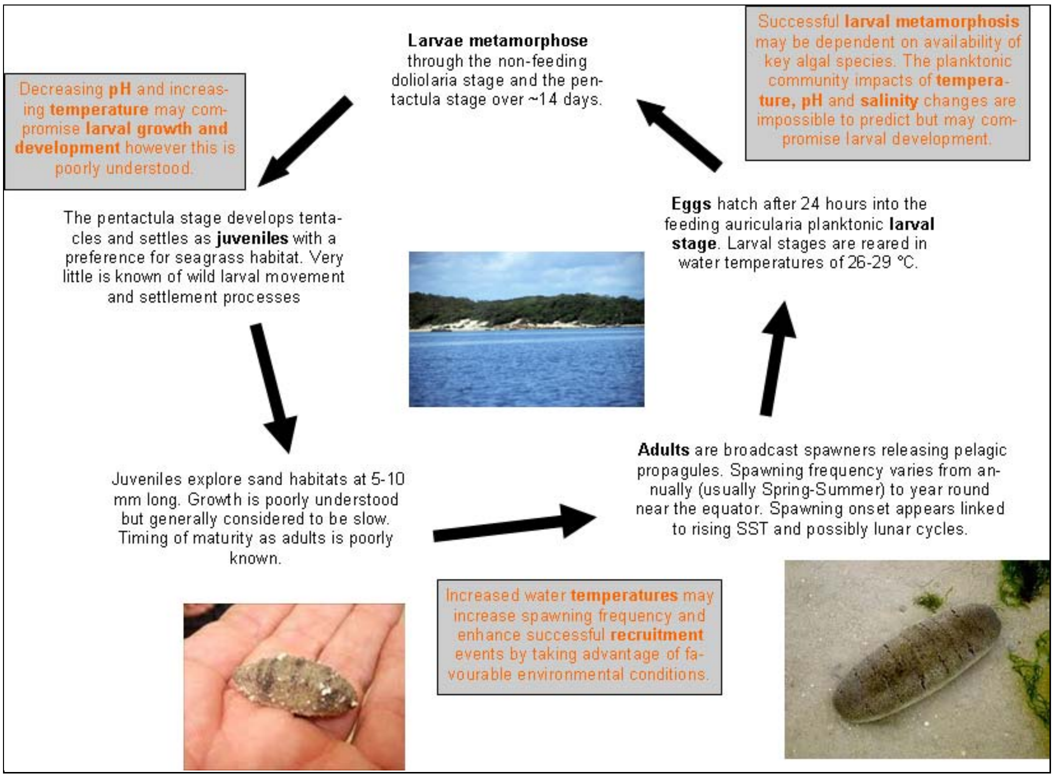

Figure 7.4. Life cycle of the sandfish, *Holothuria scabra*, in cultured systems where larvae are induced to settle on plates. This cycle is typical of many tropical sea cucumbers (Source: Battaglene, 1999). Images: GBRMPA.

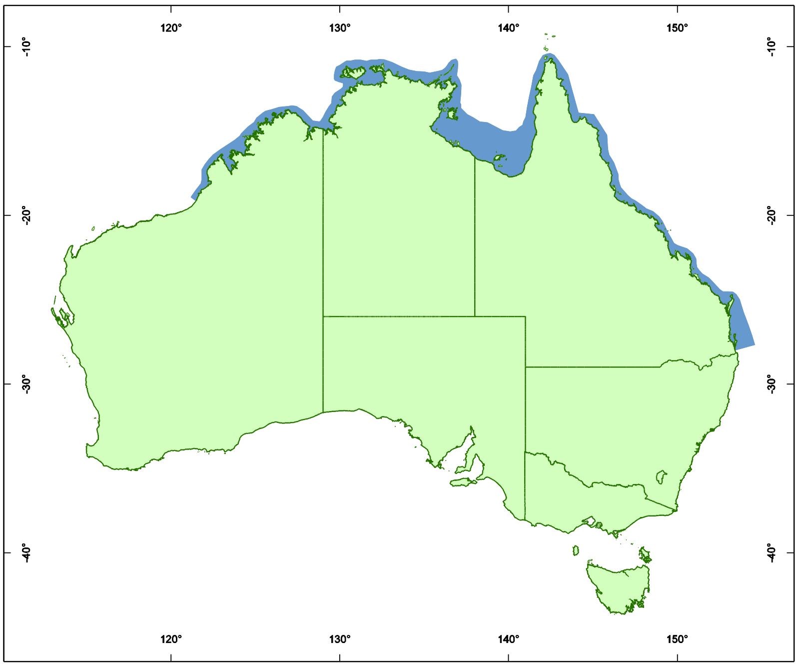

Figure 7.5. Australian distribution of *H. scabra*.

Predators and prey

Sea cucumbers are benthic deposit feeders feeding on micro-algae, bacteria, diatoms and detritus. Ecologically they play a very important role in bioturbation of the upper sediment layers and provide an important nutrient recycling function thereby increasing the benthic productivity of oligotrophic systems such as coral reefs (Uthicke et al, 2004). Predation is possibly greatest during the larval stage when other larvae can eat them.

Recruitment

Modelling by Uthicke et al (2004) suggested that *H. whitmaei* recruitment is low and sporadic due to the apparent slow rate of population recovery after overfishing. A study of *H. scabra* in the Solomon Islands found monthly recruitment of newly-settled juveniles (Mercier et al, 2000b). Typically, successful recruitment of low mobility marine organisms such as sea cucumbers require adequate adult densities to ensure successful fertilisation of released eggs.

Current impacts of climate change

There are no known documented current impacts of climate change.

Sensitivity to change

Key points:

- Studies of environmental sensitivity for key Australian fishery holothurian species are generally absent from the literature.
- From existing studies, changes in temperature, salinity and pH may affect holothurian distribution and abundance with early life history stages being most vulnerable.

Rearing of sea cucumbers for restocking and/or to supplement over-fished wild stocks has elucidated optimal conditions for rearing larvae of some tropical sea cucumber species and gives some insight into preferences and tolerance limits. These include *H. scabra*, *Actinopyga echinites* and *H. atra* and optimum temperature ranges for these species was between 27 and 30 °C (Battaglene, 1999; Chen and Chian, 1990; Ramofafia et al, 1995). In a study of a tropical sea cucumber commercially harvested in India until the fishery collapsed in 2001, the effects of temperature, pH and salinity on growth and survival of *H. spinifera* larvae were experimentally determined (Asha and Muthiah, 2005). When comparing the temperatures 20, 25, 28 and 32 °C they found that growth and survival was far greatest at 32 °C, however this also reduced the time to settlement and therefore is likely to reduce dispersal capabilities. Growth was significantly affected by salinity with 35ppt the best salinity when compared with 15, 20, 25, 30 and 40ppt. Comparing pH of 6.5, 7.0, 7.5, 7.8, 8.0, 8.5 and 9.0 they found that survival was significantly enhanced at 7.8 (83 % survival), at 9.0 there was 0% survival, and at all other pH regimes survival ranged between 47 and 60 %. Comparisons of growth however, could not be carried out since deformities occurred in larvae in all pH regimes except for 7.8 (Asha and Muthiah, 2005).

The major holothurians targeted by tropical fisheries possess microscopic components in their body wall called spicules which for the internal skeleton. These spicules are calcareous as is the peripharyngeal ring (Conand, 2006). The effects that ocean acidification may have on these species is unknown. Experimental studies on different species of the Phylum Echinodermata, of which sea cucumbers are part of, to changes in seawater pH had varying results and included reduced fertilisation rates and reduced larval sizes (sea urchin, *Echinometra mathaei*, Kurihara and Shirayama, 2004) and reduced survival and larval size (sea urchin, *Tripneustes gratilla*, Clark et al, 2009). Given species-specific responses to changes in pH, potential impacts on sea cucumbers will remain highly uncertain without studies on the species of interest.

Resilience to change

Key points:

- Due to low mobility the capacity for sea cucumber species to move away from unsuitable environmental conditions is poor.
- The timing of spawning of most tropical species means they are likely to be resilient to increases in temperature. The notable exception is the black teatfish that is a winter spawner in the tropics.

Population genetic techniques showed that populations of *H. whitmaei (*previously *H. nobilis)* on individual reefs in the GBR are highly connected and that even populations from West Australia and on reefs in the Coral Sea are potential sources of recruits (Uthicke & Benzie, 2000*b*, 2003). This is not likely to reflect contemporary scales given the low mobility of adults and the relatively short larval duration. Conversely, studies have found that gene flow in *H. scabra* in New Caledonia, north-eastern Australia and the Solomon Islands was restricted even on small spatial scales (Uthicke and Benzie, 2001; Uthicke and Purcell, 2004). Stock structure is not well understood for other northern Australian species and based on the above studies is likely to vary depending on the species.

Holothurians feed on micro-organisms in benthic substrates. Micro-organisms form the basis of food webs and, although holothurians are dependent on this food source, their availability is not likely to be limiting. Spawning seasons of many sea cucumbers are during Spring-Summer and with forecast temperature increases this may begin earlier or spawning may even become year round as seen in *H. scabra* close to the equator (Morgan, 2000a). Reproductive success in species that spawn during winter (eg. *H. whitmaei*) may be compromised and any such impacts will be evident in more northern tropical regions first. Upper thermal limits for spawning and larval growth and development are not known however cultured holothurian larval stages are currently raised in 26 – 29 °C water (Battaglene, 1999), and some species larval survival and growth is better at higher temperatures (32 °C) (*H. spinifera*, Asha and Muthiah, 2005).

Other

Key points:

- Sea cucumbers play an important ecological role in maintaining benthic productivity by remineralising organic nutrients. They also play an important role in buffering ocean acidification at local scales.
- Specific studies on key commercial sea cucumber species are needed to assess the effects of altered environmental conditions, particularly during the early life history stages.

Ecosystem level interactions

Holothurians are known to play an important ecological function. For example, on coral reefs holothurians are able to bioturbate the upper 5 mm of sediment (equivalent to 4.6 t/ha) annually (Uthicke, 1999). Holothurians feed on bacteria, diatoms, and detritus (Yingst, 1976; Moriarty, 1982) and by digesting these organisms they remineralize large quantities of organic nutrients (Uthicke, 2001b). This important nutrient recycling loop increases the benthic productivity of oligotrophic systems such as coral reefs (Uthicke & Klumpp 1998; Uthicke 2001c). Therefore, it is possible that impacts that decrease holothurian populations will result in reduced overall productivity of coral reefs.

Perhaps more importantly in the context of climate change, and in particular to the forecast acidification of sea water with increased atmospheric CO_2, is the role that holothurians play in the dissolution of $CaCO_3$ on coral reefs. Schneider et al (2011) examined two commercially exploited sea cucumber species (*S. herrmanni* and *H. leucospilota*) at One Tree Island on the southern Great Barrier Reef and determined that, as well as being important in the natural turnover of $CaCO_3$, their role in the dissolution of CaCO3 sediment was also an important source of alkalinity. Sea cucumber therefore may play a role in buffering ocean acidification at least at local scales on coral reefs, thereby reducing associated impacts such as reduced coral growth and larval survival.

Additional (multiple) stressors

Holothurian fisheries have a history of being 'fished down' and have followed a cycle of periods of fishing and recovery. Most species therefore appear to be prone to overfishing. The effect of poor water quality on nearshore species is poorly understood.

Critical data gaps and level of uncertainty

Estimates of age and growth rates of holothurians are rare and subject to considerable error. The small larvae produced from external fertilization of gametes cannot be physically tagged, and newly settled animals are usually rarely detected, leading to a major gap in knowledge concerning the sources and numbers of recruits. The sensitivity of important fishery holothurian species to changes in the environment are unknown.

Acknowledgements

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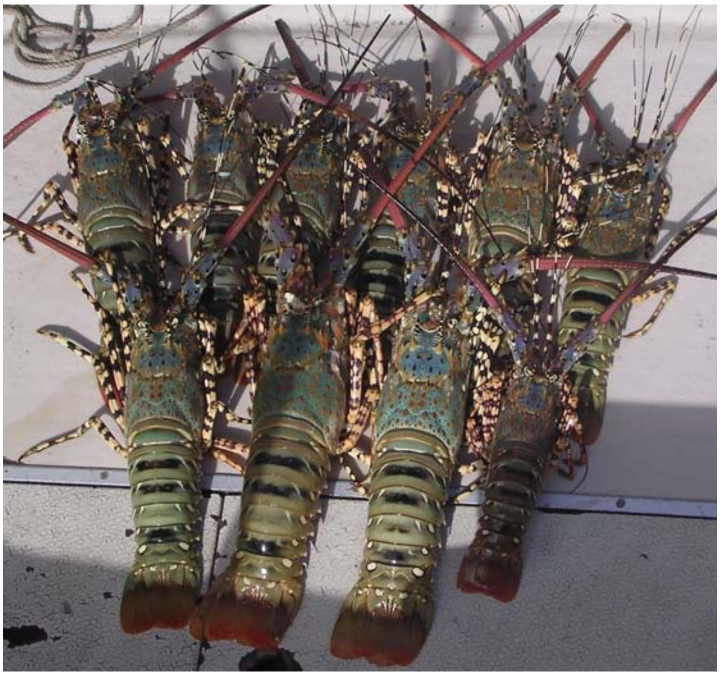
8. Tropical rock lobster, *Panulirus ornatus* (ornate rock lobster)

Authors: David J. Welch and Julie Robins



Recreationally caught tropical rock lobster. Photo: D. Welch.

The fishery

Key points:

- Only Queensland and Torres Strait support significant fisheries in Australia.
- Both of these fisheries are relatively low yield but highly valuable.
- Catch levels are thought to be determined by variable annual recruitment.

Operational characteristics

Fisheries for tropical rock lobster in northern Australia only occur in NE Queensland and Torres Strait waters as separate fisheries based on jurisdiction (State and Commonwealth). The key specie targeted is the ornate rock lobster, *Panulirus ornatus*, and although other species are taken they make up insignificant portions of the catch (eg. < 2% of the Qld fishery). The fisheries are dive-based with commercial collection methods by divers using hookah or freediving and collecting by hand, nooses (snares), or in some cases using hand spears. Divers work around coral reefs in depths up to 20 m and operate almost exclusively during daylight hours (AFMA, 2010; DEEDI, 2010). There is a small domestic market for product however most are exported overseas to mainland China via Hong Kong (Pitcher et al., 2005). The major product form is as frozen tails however there is a live component also (AFMA, 2010; DEEDI, 2010).

Torres Strait fishery

Characteristics

The area of the fishery is in Torres Strait from the tip of Cape York to the northern border of the Torres Strait Protected Zone. The commercial fishery within this zone is shared between Australia and Papua New Guinea under a formal arrangement (AFMA, 2010). There is a small recreational fishery within the Torres Strait. The Torres Strait commercial fishery is comprised of two sectors – the non-Indigenous (TVH) sector and the Traditional Inhabitant (TIB) sector (AFMA, 2010). Dive operations consist either of a mother vessel from which a number of smaller (4-6 m) tender vessels operate with divers working from each tender (TVH operators), or of a small 4-6 m vessel with divers using solely freediving (TIB). There are 13 TVH primary licences with 34 tenders attached to these, while in the TIB sector there are currently 470 licenses of which only 293 are active (as of September, 2010).

Fisheries catch and status

The fishery catch is managed through a quota system with an annual Total Allowable Catch (TAC) that is shared between Australia and Papua New Guinea. The historical catch from the fishery is variable from year-to-year and is thought to be driven by variable recruitment. In 2009 the total catch from the fishery was valued at $AU7.5 M, and was comprised of 228 t (live weight) for the Australian portion (Figure 8.1) and 114 t for the PNG portion. For the 1989 to 2009 time period Papua New Guinea fishers took approximately 31% (range: 19 – 57%) of the total Torres Strait catch. Within the Australian catch, historically the TVH sector has taken the most however in recent years, due to effort controls (regulated and voluntary), most of the catch is taken by the TIB sector and in 2009 they took 59% of the catch (Table 8.1) (AFMA, 2010). The most recent assessment of the fishery is that it is not overfished nor is it subject to overfishing.

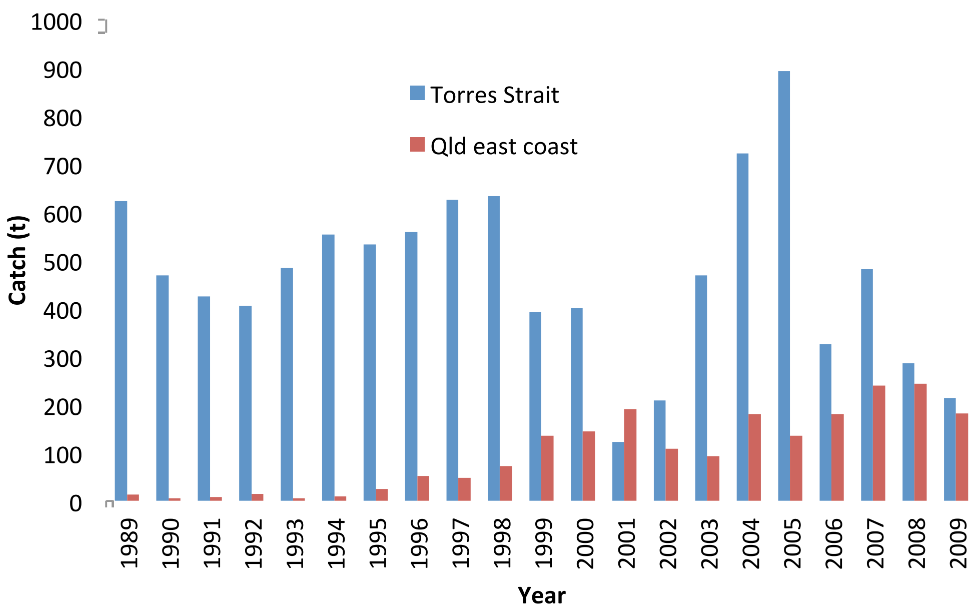


Figure 8.1. Historical Australian commercial catch for the Torres Strait and commercial catch for the east coast of Australia for the years 1989 to 2009. Catch has been converted to tonnes live weight (Source: AFMA, 2010).

Fisheries Management

Management is under the Torres Strait Fisheries Act 1984 and through policies agreed to under the protected Zone Joint Management Authority. Regulations include restrictions on the number of TVH licenses and how many tenders per primary vessel, however there is no limit on the number of TIB licenses that can be issued. Other regulations include taking of lobster only by hand or hand-held implements, a ban on the use of hookah during December and January each year, a minimum tail size of 115 mm or a minimum carapace length of 90 mm, and bag limits of 3 per person, or 6 per dinghy for recreational fishers and traditional fishing.

Table 8.1. Catch (whole weight in tonnes) of the non-Indigenous (TVH) sector and the Traditional Inhabitant (TIB) sectors of the Torres Strait Rock Lobster fishery from 2001 to 2009 (Source: AFMA, 2010).

Year	TVH	TIB	Total	TIB (%)
2001	70	53	123	43
2002	144	65	209	31
2003	350	118	468	25
2004	465	257	722	36
2005	523	370	893	41
2006	130	196	326	60
2007	257	238	495	48
2008	98	177	274	65
2009	88	126	214	59

Queensland fishery

Characteristics

The fishery comprises commercial, recreational and Indigenous sectors. The commercial sector is restricted to the far northern region of the Great Barrier Reef (~ north of Princess Charlotte Bay) and the Gulf of Carpentaria. Dive operations consist of a mother vessel from which a number of smaller (4-6 m) tender vessels operate with divers working from each tender. There are 28 primary licences with 93 tender licences attached to these, however only 11 primary licences accessed the fishery in 2009. There is also 5 t catch limit allowed annually for Indigenous Fishing Permit holders. Catch from the Gulf of Carpentaria is negligible. Recreational catch is taken south of the commercial fishery area on the east coast and extends south to at least the Qld border.

Fisheries catch and status

The commercial catch has been slowly but steadily increasing since 1995 from 25 t to 192 t in 2009 (Figure 8.1). From surveys conducted in 2001 and 2005 it was estimated that the Indigenous sector took 13,000 lobsters, while recreational fishers were estimated to take 17,000 lobsters (Henry and Lyle, 2003; DEEDI, 2010). Although the fishery is considered fully exploited, a recent stock assessment concluded that current catch levels (now regulated by a TAC) is within MSY estimates, and the fishery is considered as “being managed in a precautionary and sustainable manner” (DEEDI, 2010).

Fisheries Management

The Queensland east coast fishery and the Torres Strait fishery have been shown to comprise the same lobster stock (Pitcher et al, 2005). As such, management of each fishery has been moving more towards being complementary. Management of the Qld fishery is the responsibility of Fisheries Queensland, part of DAFF. Management of the fishery is by limited commercial entry, a Total Allowable Commercial Catch system, mated and egg-bearing females cannot be taken by commercial fishers, a seasonal closure between October 1 and January 31 within the commercial fishing area, minimum size limits consistent with the TS fishery, and recreational bag limits (DEEDI, 2010).

Life history

Key points:

- In NE Australian waters many *P. ornatus* adults undergo an annual migration of between 70 and 500 km into deep continental shelf waters of the Coral Sea for spawning.
- Larvae drift in oceanic waters of the NW Coral Sea for approxmately 6 months prior to settlement.
- NW Coral Sea currents are highly important for recruitment dynamics in NE Australia and Torres Strait.

Life cycle, age and growth

The breeding season for adults is between November and April. Adult breeding *P. ornatus* migrate to breed at 2.5 to 3 years old and females outnumber males in the breeding migrations 2:1. Large males and one-year-old lobsters do not migrate. Shorter migrations are undertaken by lobster on the north-east coast of Queensland (average 70km), whilst larger migrations are undertaken by lobsters in Torres Strait (up to 511km). Breeding sites include deep water (40 to 120m) areas on the continental shelf outside the Great Barrier Reef and Yule Island in the Gulf of Papua. Breeding sites on the Great Barrier Reef are predominantly in the far north however breeding sites are known to occur south to at least Townsville (19° S) (Bell et al, 1987). Some adults migrate from reefs in Torres Strait from August to November. Lobsters that migrate to Yule Island generally do not survive after breeding (Pitcher et al, 2005). *P. ornatus* are highly fecund and multiple broods may be carried and reared during one spawning season, although the first brood is thought to represent the major spawning within a season. In captivity females produce an average of 3 batches each breeding season at 28 °C (M. Kenway, pers. comm.). Queensland and Torres Strait *P. ornatus* are considered to be a single genetic stock with Torres Strait and far NE areas being source populations to areas of the GBR further south (Pitcher et al, 2005).

Eggs are fertilised as they exit the female’s body and attach to the pleopods, where they are carried for approximately 35 days at 29 °C (Pitcher et al, 2005). Under captive conditions in tanks at 28 °C females carry eggs for 26 days (M. Kenway, unpublished data). Larvae hatch as phyllosoma that are carried by wind and tides in the plankton of oceanic waters of the NW Coral Sea and go through as many as 24 morphological stages over approximately 6 months (Pitcher et al, 2005; Smith et al, 2009). The larvae develop into the peurulus stage that is an active non-feeding swimming stage that seeks out suitable benthic habitat. The peurulus swims across the continental shelf to settle in coastal areas as benthic juveniles. Sub-adult lobsters (~95 mm CL) move offshore during March/April to mid-shelf reefs. In the Torres Strait sub-adults move widely throughout the region seeking suitable reef habitat and/or large beds of bastard shell, *Pinctada albina* (M. Kenway, pers. comm.).

Growth of *P. ornatus* has been generalised using the von Bertalanffy growth function and was derived from tag-recapture and aquarium data. Longevity is estimated to be approximately 8 years at which *P. ornatus* have a carapace length of approximately 150 mm (Phillips et al, 1992; Skewes et al, 1997). In wild populations larger individuals tend to be males, possible due to higher natural mortality rates on females from the annual breeding migration and egg brooding.

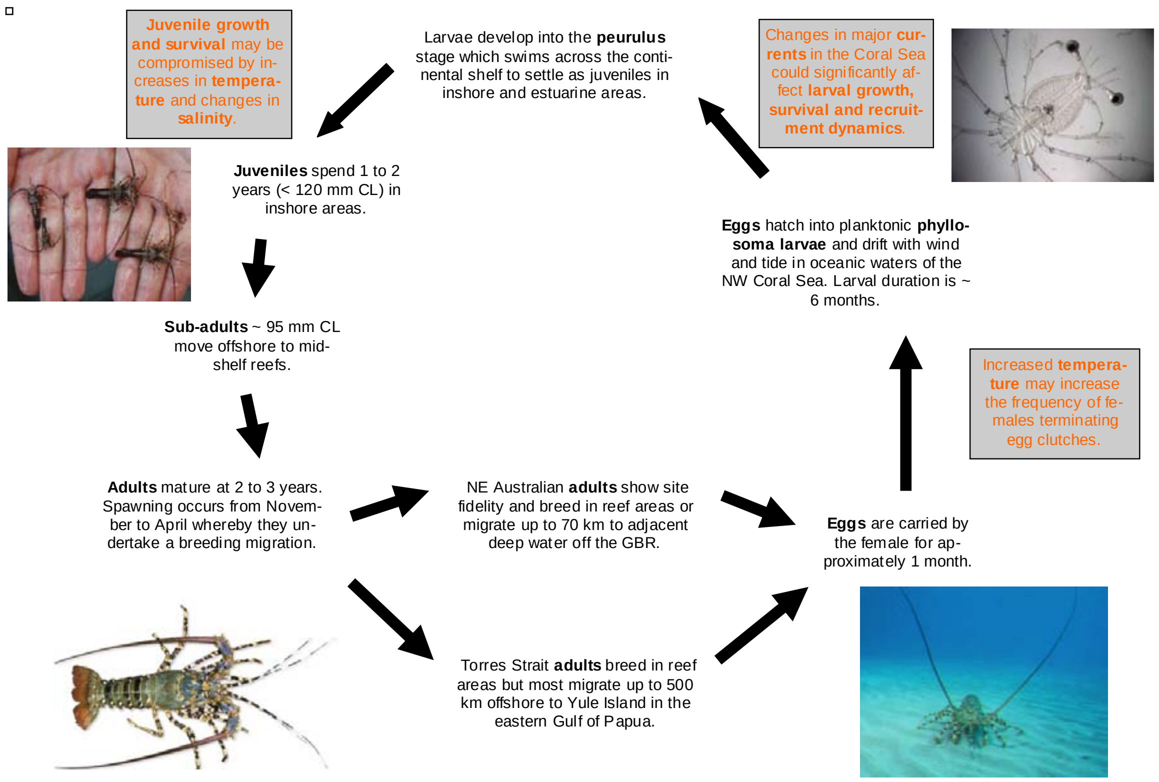


Figure 8.2. Generalised life cycle of the ornate rock lobster, *Panulirus ornatus*, from the NE region of Australia and the stages of potential environmental driver impacts. Images: Queensland DEEDI; Pitcher et al, 2005.

Distribution, habitat and environmental preferences

Tropical rock lobsters occur in northern Australia and inhabit reef tops, reef slopes and rocky inter-reef areas, up to 200m deep on the continental shelf (Kailola et al, 1993). *P. ornatus* are known to have a broad habitat use including deep (> 200 m) oceanic waters to muddy reefal areas adjacent to estuaries and river mouths, which reflects a very wide distribution (Pitcher et al, 2005). They prefer reef habitat and within NE Australia and Torres Strait can be found across the entire continental shelf.

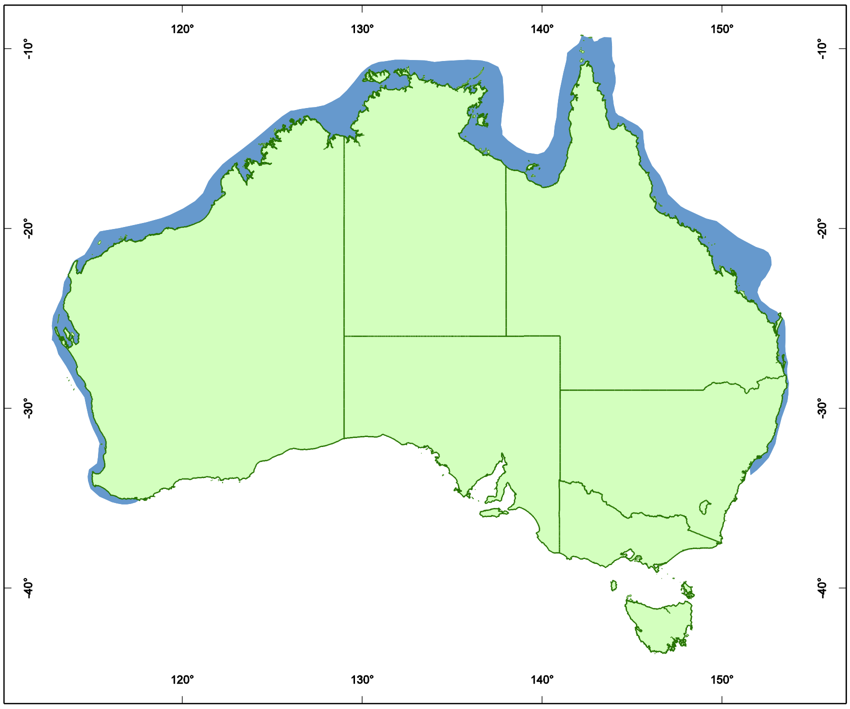


Figure 8.3. Distribution map for *P. ornatus* within the Australian region.

Predators and prey

P. ornatus have been described as opportunistic carnivores that feed mainly on benthic invertebrates. Several studies that have analysed gut contents of juveniles and adults have found a variety of different molluscs including bivalves, chitons and gastropods, other crustaceans such as barnacles, crabs and other decapods, polychaete worms and echinoderms (see Williams, 2007). Commercial divers in the Torres Straits and on the east coast maintain that they target *P. albino* beds when collecting rock lobsters suggesting this mollusc species is important habitat and/or as a prey item (M. Kenway, pers. comm.).

Several early studies have documented the capability of planktonic phyllosoma stage larvae of various other lobster species to feed on a variety of different planktonic prey items. These include eel and fish larvae, trochophore veliger larvae, calanoid copepods, hydromedusa, polychaetes, ascidian larvae, crab zoeas, chaetognaths and salps (eg. see Batham, 1967). Given the similarity in development among species it is assumed that *P. ornatus* larvae possess similar feeding capabilities. Some very early studies documented the attachment of phyllosoma larvae to medusa (Thomas, 1963; Hernnkind et al, 1976) however to this day it is still unclear whether this is a feeding mechanism or something else (eg. predator avoidance). There are no published studies on the natural predators of *P. ornatus*.

Recruitment

In the NE Australian region the distribution of *P. ornatus* phyllosomas and pueruli in relation to ocean currents support the hypothesis that phyllosomas are transported from the Gulf of Papua breeding grounds by the Hiri boundary current into the Coral Sea Gyre and then by surface onshore currents onto the Queensland coast, Torres Strait and SE Papua New Guinea. There appears to be distinct regions that act as recruitment 'sources' and 'sinks' which is determined by the bifurcation of the South Equatorial Current off the GBR approximately adjacent to Cooktown on the NE Queensland coast. Areas to the north of this bifurcation can be termed both source and sink regions and to the south as a sink region (Figure 8.4) (Dennis et al., 2001; Pitcher et al, 2005). The peak timing of settlement in NE Queensland occurs during winter (June-August) in most years however the seasonality of settlement is highly variable.

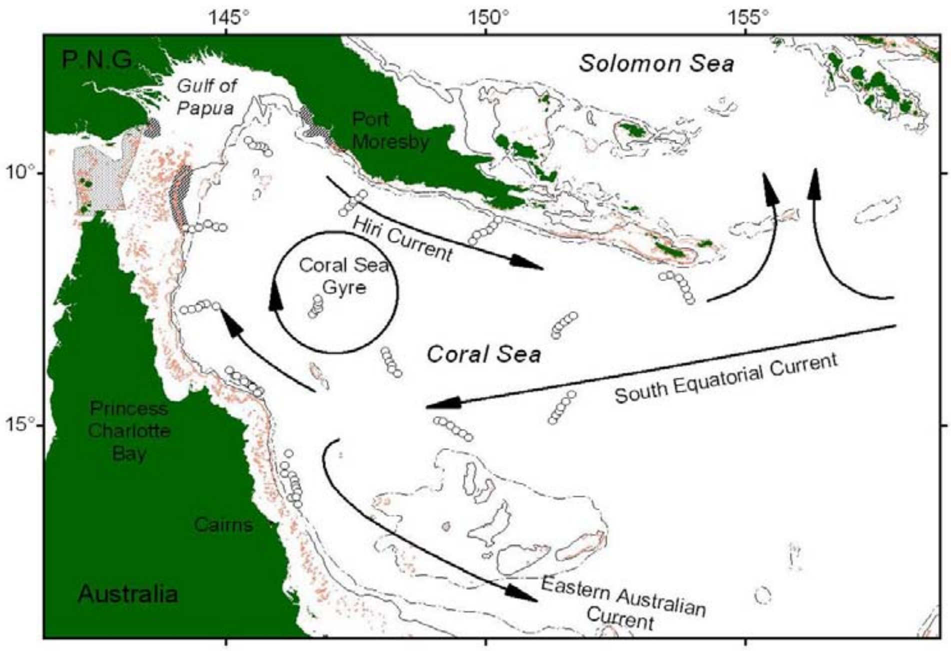


Figure 8.4. Map of the NW Coral Sea region showing the major currents that influence the eventual recruitment of *P. ornatus* larvae. Circles indicate areas of plankton sampling conducted during May 1997 and hatched areas indicate the known breeding grounds (from Dennis et al, 2001).

Current impacts of climate change

Key points:

- Catchability has been affected during recent warmer than average years when lobsters move to deeper waters less accessible to divers.

Commercial divers in Torres Strait reported that during recent "hot" years *P. ornatus* moved to deeper cooler water making them less accessible for capture (Welch and Johnson 2013).

Sensitivity to change

Key points:

- *P. ornatus* appear to have distinct temperature preferences at all life history stages and females even terminate egg clutches at ≥ 32 °C.
- *P. ornatus* juvenile growth and survival appear to be moderately influenced by temperature and salinity.

Temperature and salinity tolerances of *P. ornatus* were investigated by Jones (2009). He found that juvenile growth was significantly affected by temperature with maximum growth in 25 – 31 °C water and the optimal temperature being 27 °C. Salinity was also found to have a significant effect on juvenile growth and survival with lowest survival but fastest growth at 35 ppt. Sachlikidis et al (2010) found that *P. ornatus* terminated their egg clutches in temperatures ≥ 32 °C. Currents in the NW Coral Sea are extremely important for carrying *P. ornatus* larvae and the determination of areas of settlement (Pitcher et al, 2005).

Western rock lobster (*Panulirus cygnus*) are thought to have a decrease in their size at maturity due to rising sea temperatures. The Leeuwin Current (influenced by the Southern Oscillation Cycle) is also thought to influence puerulus settlement (Caputi et al, 2010).

Resilience to change

Key points:

- *P. ornatus* have broad habitat preferences and extensive available habitat on the east and west coasts.
- The future of the Torres Strait/Queensland fisheries may be dependent on large-scale changes to ocean currents in the NW Coral Sea.

P. ornatus have a broad geographical range and a broad habitat preference. Within the key fishery regions of northern Australia a single genetic stock is present with distinct 'source' and 'sink' regions (Pitcher et al, 2005). Although larval development is approximately 6 months, under culture situations there is evidence that this period can be as short as 4 months indicating some plasticity in their early development (Smith et al, 2009). Experimental studies have shown juvenile growth to be maximised between 25 – 31° C water temperatures (Jones (2009), while Sachlikidis et al (2010) found that *P. ornatus* terminated their egg clutches in temperatures ≥ 32° C, making them susceptible to projected SST increases. The long larval phase may be a significant limiting factor to successful recruitment depending on the nature of future change, particularly with respect to ocean currents in the NW Coral Sea.

Other

Key points:

- Better understanding of how ocean currents in the NW Coral Sea may change under climate change will allow more certain predictions of the recruitment dynamics of *P. ornatus* in the future.

Ecosystem level interactions

The role of *P. ornatus* larval stages play in the plankton in terms of predator-prey interactions with other plankton species is poorly understood and may be significant especially given their larval duration.

Additional (multiple) stressors

P. ornatus are commercially and recreationally fished in the Torres Strait and the NE GBR, however elsewhere they are only lightly harvested by recreational and Indigenous fishers. Juveniles use inshore and estuarine habitats during the first 18 months after settlement and so pollution and runoff may be additional stressors at various times and places, although currently most recruitment is in the far northern region of the GBR and Torres Strait where pollution and runoff impacts are relatively low compared with areas further south.

Critical data gaps and level of uncertainty

Variation in annual environmental conditions determines the successful recruitment of *P. ornatus* which drives the Torres Strait and Queensland fisheries. A critical knowledge gap therefore is the likely change in ocean currents in the NW Coral Sea and how these may influence the recruitment dynamics of *P. ornatus*.

Acknowledgements

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FINFISH AND SHARKS

9. Barramundi, *Lates calcarifer*

Authors: Emily Lawson, Thor Saunders and Julie Robins

A Northern Territory barramundi. (Image sourced from NT Fisheries).

Barramundi is an important and iconic species throughout northern Australia and are important for all fishing sectors economically, socially and culturally.

The fishery

Key points:

- Barramundi represent a very important fishery species across northern Australia for recreational, commercial and Indigenous sectors.
- The annual harvest is regionally variable and is often positively linked to rainfall/riverflow.

Western Australia

In Western Australia barramundi are captured in the commercial Kimberley Gillnet and Barramundi Managed Fishery (KGBF) which operates in the nearshore and estuarine zones of the North Coast Bioregion from the border between Western Australia and the Northern Territory (~129° E) to the top of Eighty Mile Beach, south of Broome (19° S). The KGBF is managed by limiting entry, gear restrictions, and seasonal and spatial area closures. Currently only seven licences access the KGBF. The total landings of barramundi from all four prescribed fishing areas within the KGBF were 59.6 t and 57.1 t for 2009 and 2010 respectively and are the highest recorded catches since 1987 which is primarily due to a large increase in effort during these years (Department of Fisheries 2011). Recreational catch of barramundi in the KGBF was last assessed in 2000 and represents 1-2% of the commercial catch (Department of Fisheries 2011).

Northern Territory

The commercial sector of the barramundi fishery in the Northern Territory operates from the high water mark to three nautical miles seaward from the low water mark and is restricted to waters seaward from the coast and river mouths. This fishery uses gillnets and has tight management controls that restrict the number of licences, areas and seasons fished as well as gear type and amount. Catches have varied in the commercial barramundi fishery over the last 37 years but effort has declined substantially which has resulted in some of the highest CPUE recorded in recent years (Figure 9.1). The major commercial fishing areas are the Van Diemen Gulf, East Arnhem Land, Anson Bay, Central Arnhem Land and Limmen Bight (Northern Territory Government 2011).

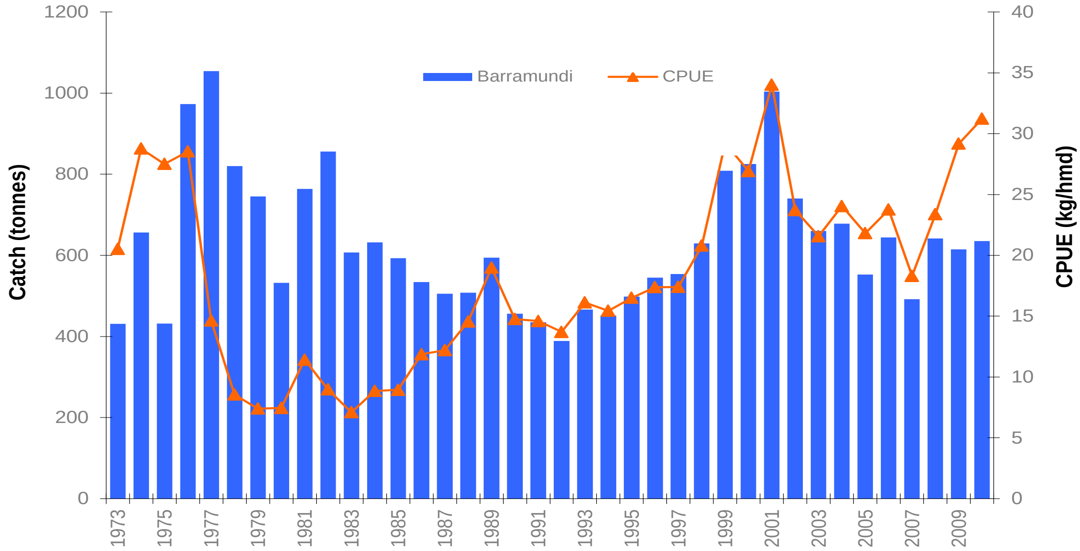

Figure 9.1. Catch and catch-per-unit-effort (CPUE) for the Northern Territory commercial barramundi fishery from 1973 to 2010.

Recreational anglers and Fishing Tour Operators (FTOs) also target barramundi using rod and reel in the same areas as the commercial sector and have gear restrictions, possession limits and seasonal area closures. All sectors in the Northern Territory have a minimum legal size of 55 cm total length (Table 9.1). An estimated annual harvest of 105,131 barramundi (~368,000kg) was recorded for the NT recreational fishery and 70% of the Indigenous barramundi catch in Australia is from the Northern Territory (Henry and Lyle 2003). Barramundi is the most targeted fish by recreational anglers in the Northern Territory (Coleman 1998). FTOs catch approximately 40,000 barramundi annually; FTOs and the recreational sector release between 70 and 90% of the barramundi they catch, with a high (~91%) post-release survival rate (de Lestang *et al.* 2004).

Table 9.1. Fisheries regulations for barramundi in respective jurisdictions of northern Australia.

Jurisdiction	Minimum legal size (total length in cm)	Maximum legal size (total length in cm)	Closure rules
Western Australia	55	Nil	na
Northern Territory	55	Nil	na
Queensland - Gulf of Carpentaria	60	120	October to January, variable on spawning moon
Queensland - East Coast	58	120	1st November to 1st February

While there were some concerns about overfishing in some of the more popular river systems in the 1970's and 1980's, current assessments of the barramundi stocks across the NT indicate that they are being harvested well within sustainability limits (Northern Territory Government 2011).

Queensland

In Queensland barramundi are taken as part of two commercial finfish fisheries: Gulf of Carpentaria Inshore and East Coast Inshore. In each fishery, specific fishing endorsements (i.e., licences) are required to harvest barramundi. These two fisheries are managed separately by limited entry, minimum and maximum size limits (Table 9.1), spatial closures (some of which allow recreational only fishing), temporal closures to protect spawning stock, and a recreational bag limit. Commercial catches of barramundi vary spatially and temporally (Figure 9.2) and can be significantly related to river flow or rainfall (Robins *et al.* 2005; Balston 2009a) and evaporation (Balston 2009a). Variability in catch probably represents changes in underlying stock abundance linked to environmental drivers, although in many studies there is still a significant amount of variation in catch that is unexplained (DEEDI 2010a&b).

Barramundi is a key species for recreational fishers. The recreational harvest of barramundi was estimated to be ~230 tonnes in 2000 (Henry and Lyle 2003). In addition, in 2005 the estimated harvest by recreational fishers in Queensland was 51 t (McInnes 2008). Barramundi, are a less significant part of the indigenous finfish harvest, compared to NT and was estimated to be ~5,745 barramundi in 2000 (Henry and Lyle 2003).

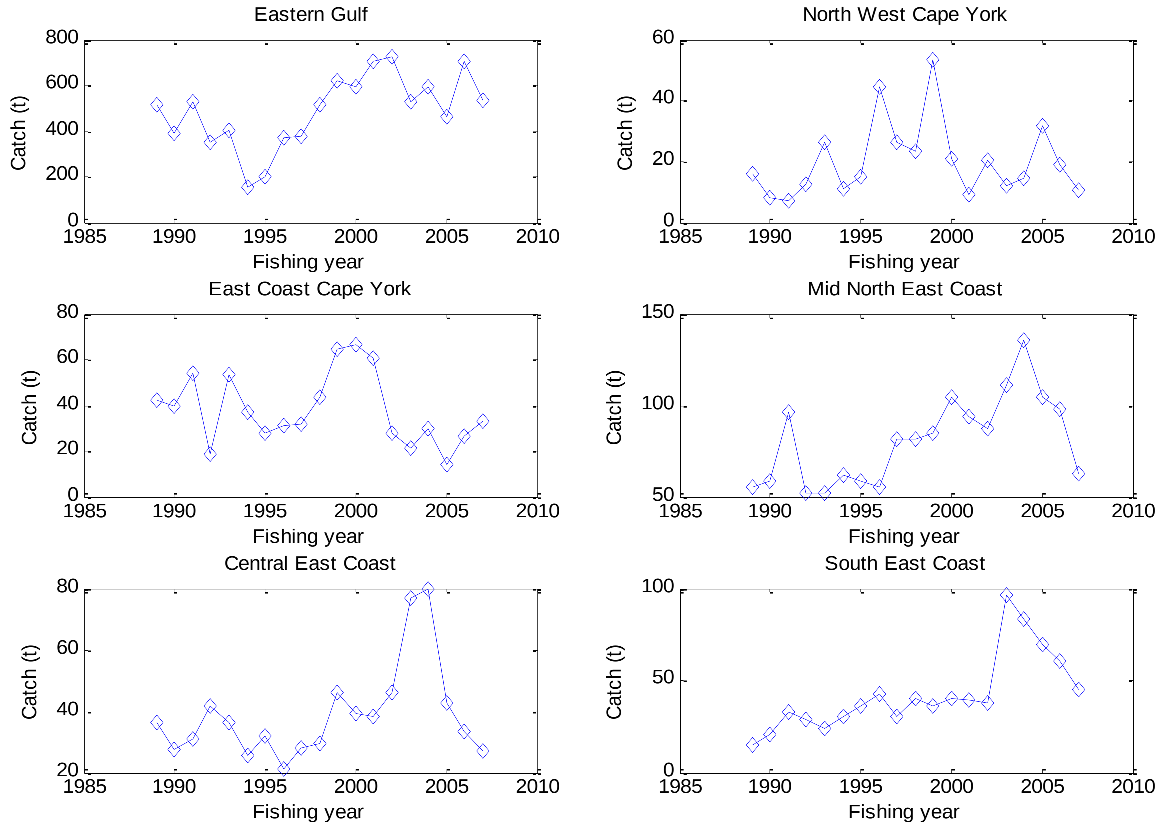

Figure 9.2. Regional commercial catch (tonnes) of barramundi in Queensland 1989 to 2007 (taken from Campbell *et al.* 2007). Eastern Gulf stock and North-west Cape York stock located in the Gulf of Carpentaria. All other stocks are located on the Queensland east coast.

Life History

Key points:

- Sub-stocks exist across northern Australia, usually associated with river systems, with limited exchange between sub-stocks.
- Recruitment is highly variable and is correlated with seasonal rainfall or riverflow.

Life cycle, age, and growth

Barramundi have a complex and spatially variable life history, displaying non-obligatory catadromy i.e., migrating from freshwater to saltwater to spawn. The proportion of the population that migrates to freshwater habitats varies between catchments and within years within catchments (Pender and Griffin 1996; Milton *et al.* 2008; Halliday *et al.* 2012). The proportion of the barramundi population that accesses freshwater habitats probably depends on the variable accessibility of these habitats associated with seasonal rainfall. For example, in the perennially flowing Daly River, ~86% of estuarine adult barramundi had accessed freshwater habitats for a period of greater than three months (Halliday *et al.* 2012) compared to the Fitzroy River (Queensland east coast) where ~50% of estuarine adult barramundi had accessed freshwater habitats (Milton *et al.* 2008).

Barramundi are also protandrous hermaphrodites, initially maturing as males at two to five years then changing sex to females at between five and seven years, although a small proportion of the population are primary females and are mature at much smaller sizes and age (Moore, 1979; Davis 1984). Mature female barramundi are thought to reside in the lower reaches of estuaries and along the coastal foreshore (i.e., in saltwater habitats, Dunstan 1959). The life cycle of barramundi generally results in the spatial separation of male and female fish, with smaller and younger male fish residing in the upper estuary or in freshwater reaches of the river. Mature males must move downstream to the estuary in order to participate in spawning. Mature barramundi are thought to be stimulated to move downstream to areas of higher salinity by the first freshwater flow in spring that lowers the salinity of estuarine waters (Rod Garrett, pers. comm. 2000). This could be achieved by small freshwater flows that do not necessarily release landlocked individuals. Most barramundi participate in one or more spawning seasons as males before undergoing sexual inversion, becoming functional females by the next breeding season (Schipp *et al.* 2007).

In Australia, barramundi spawn during spring and summer. The timing and duration varies between regions, rivers and years, depending on water temperatures and lunar and tidal cycles (Table 9.2). Breeding takes place in high-salinity reaches of estuaries and nearby coastal foreshores. In general, spawning activity peaks during new and full moon periods (Grey 1987), as large incoming tides may help eggs to move into estuaries. Movement of adults to spawning areas is triggered by the seasonal increases in water temperature (Grey 1987). High salinity appears to be the main requirement of spawning grounds i.e., 32 to 38 ppt (Davis 1987; Rod Garrett, pers. comm. 2000). Gametogenesis in barramundi is initiated by seasonal increases in water temperate and photoperiod (Russell 1990). Each female commonly releases three to six million eggs which are pelagic, average 0.7 mm in diameter (Russell and Garrett 1985), and once fertilised will hatch in less than 24 hours at water temperatures of ~28°C (Schipp 1996; Griffin; Rod Garrett, pers. comm. 2000). Optimal hatching occurs at salinities between 20 and 30 ppt with lowered hatching success at salinities higher or lower i.e., 35 or 5-15 ppt (Maneewong 1987). Of the limited work that has been published on the optimal pH for hatching success, De (1971, cited by Pusey *et al*. 2004) reported that larval barramundi had a narrow pH range of 7.4 to 7.6 units. Barramundi larvae spend about three weeks in inshore waters and require high salinity water (Schipp 1996). The completion of the major part of the breeding cycle before the onset of the wet season is probably a strategy for eggs and larvae to avoid low-salinity water (Russell and Garrett 1985) and so that juveniles can take advantage of the aquatic habitat that results from rains in the monsoon season (Davis 1985).

Table 9.2. Spawning seasons of barramundi across northern Australia.

Location	Spawning season	Source
Northern Territory	September to February	Davis (1985)
Southern Gulf of Carpentaria	November to March, peak in December	Davis (1985)
Northern Gulf of Carpentaria Far northern east coast of Queensland	From October	Williams (2002)
Queensland east coast	November to February (peak)	Stuart (1997)
Southern Queensland east coast (e.g. Rockhampton)	October to January	Dunstan (1959)

Post-larval barramundi move to available estuarine wetlands and flood plains as nursery habitats (Russell and Garrett 1985). Moore (1980) suggested that barramundi larvae are cued or attracted upstream by chemicals released from swamps. Peak spring tides and seasonal flooding assist barramundi post-larvae to enter supra-littoral habitats (Russell and Garrett 1985), coastal lagoons (Grey 1987) and other seasonal habitats that form during the monsoon season (Williams 2002). Coastal swamps (i.e., adjacent to the coast and estuary) form the predominant nursery habitat for post-larval barramundi in areas of northeastern Queensland where large river systems are absent (Russell and Garrett 1985). Monsoon rains also create a variety of temporary nursery habitats for juvenile barramundi that are highly productive in food resources and are thought to offer protection from larger predatory fish. These swamps rely on "flood rains" to connect with more permanent waters (Russell and Garrett 1985). Juvenile barramundi were reported moving into supra-littoral pools in the Fitzroy River estuary during March (Hyland 2002). Griffin (1985) suggests that rainfall replenishes the water levels in supra-littoral habitats between high tides (thereby maintaining these nursery habitats for longer periods) and that "the amount of time that the young of the year fish are able to utilise this safe and rich environment is limited by the amount and extent of rainfall during the wet season". Griffin (1985) only considers rainfall, although it is possible that floods that inundate flood plains may have a similar effect in extending the spatial and temporal extent of these high quality nursery habitats. This relationship was further confirmed with an additional two years of data, when Griffin (1987) reported a significant correlation (r^2=0.81) between juvenile abundance (i.e., young of the year) and early wet season rainfall. So not only is rainfall important for juvenile survival but also the timing of the rainfall.

Juvenile barramundi depart these habitats at the end of the wet season. Lowering of water levels and depletion of food in seasonal habitats is likely to stimulate juvenile barramundi to move to other habitats (Russell and Garrett 1985). For example, juvenile barramundi began moving from swamps in Trinity Inlet (Cairns) in April and remained in tidal creeks until December and January (Russell and Garrett 1985). In the Gulf of Carpentaria, floodwaters recede around March. Some juvenile barramundi move to permanent freshwater habitats when the seasonal coastal habitats dry-out (Russell and Garrett 1985); these individuals are moving upstream to freshwater habitats at about three to five months of age. In comparison, juvenile barramundi in Papua New Guinea waters take more than one year to reach inland freshwater habitats because of the need to migrate along the coast from spawning areas.

Where access to permanent freshwater permits, a varying proportion of the juvenile barramundi population migrates upstream, predominantly in spring and summer towards the end of their first year of life i.e., >9 months (Stuart 1997; Stuart and Mallen Cooper 1999). Otherwise juveniles remain in estuarine habitats and either access upstream habitats in their second year or remain in the estuary for their entire life (Russell and Garrett 1988; Pender and Griffin 1996). Barramundi mature at three to four years of age and then return to the estuary when conditions permit, to spawn alongside estuarine residents (Grey 1987).

Barramundi are capable of rapid growth, typically reaching 35 cm total length in their first year of life, 50 cm in their second year and 60 cm by the end of their third year (Griffin and Kelly 2001). Their asymptotic length is >150 cm, with a weight of up to 40 kg. Growth is seasonally variable (Xaio

2000) and probably reflects seasonal water temperature and food availability, as feeding activity is greatly reduced at water temperatures less than 24°C (Pusey *et al*. 2004). Growth is also spatially and temporally variable (Davis 1987), and is probably a reflection of environmental conditions. Growth variability is significantly related to the freshwater flows experienced by individuals (Robins *et al.* 2006), although other factors (e.g. genetic variation) are also likely to be important.

Variable growth may also account for the observed variable size-at-maturity. Davis (1982) reported that size-at-maturity for males was 60 and 55 cm for fish in the Northern Territory and South-eastern Gulf of Carpentaria respectively, and for females was 90 and 85 cm respectively. Davis (1982) went on to speculate that these "size differences were due to a slower growth rate of barramundi in the Gulf of Carpentaria, both processes being related to age rather than size. Griffin (1988) also speculated that growth rates differ between the Daly and Liverpool River (Northern Territory) based on differences in the size-at-age structure in the two rivers. Barramundi are a relatively long-lived species i.e., >20 years, with specimens of 32 years recorded from central Queensland (Staunton-Smith et al. 2005; Halliday et al. 2011). Longevity is likely to vary between regions, depending on environmental conditions and fishing pressure.

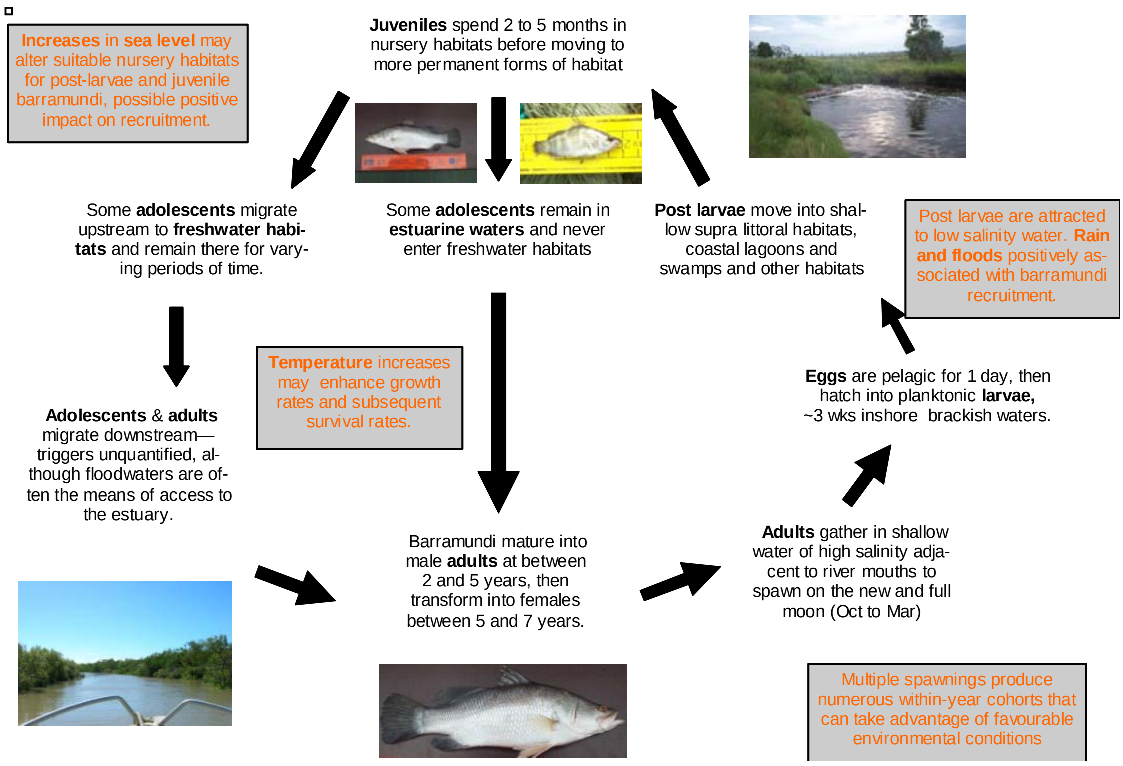

Figure 9.3. Summary of the life cycle of barramundi (*L. calcarifer)* and the points of exposure to relevant climate change drivers or known impacts. (Images sourced from QDAFF).

Distribution, habitat and environmental preferences

Barramundi are widely distributed throughout the tropical and sub-tropical waters of the Indo-Pacific region from the Arabian Gulf eastwards to China and Japan and southwards to Papua New Guinea and Australia (Pusey *et al.* 2004*).* In Australia, barramundi occur from the Ashburton River

(22°30' S) in the Kimberley and Pilbara regions of Western Australia northwards throughout the Northern Territory and Gulf of Carpentaria and down the Queensland east coast as far south as the Noosa River (26°30' S) (Figure 9.4; Schipp 1996).

Barramundi occur in a wide range of habitats including coastal foreshores, estuaries, tidal creeks, swamps, flood plains, coastal lagoons and upstream rivers where accessible from the sea. Juvenile and adult barramundi appear to be highly tolerant to a wide range of water acidity having been collected over a wide range of pH: 4.0 to 7.2 in the Alligator River region (NT); 6.1 to 9.12 in floodplain lagoons of the Normanby River (Qld); 5.2 to 5.6 in dune lakes of Cape Flattery region (Qld); and <4 in tidal creeks near Trinity Inlet, Cairns (Qld) (Pusey *et al.* 2004). Barramundi are more abundant in areas where there are large, slow flowing rivers and absent from areas without large river flows (Dunstan 1959). Barramundi occur in both clear and turbid waters. Temperatures appear to limit their distribution, with 15°C a critical lower thermal limit and 44°C a critical upper limit (Rajaguru 2002), although their optimum for growth and protein metabolism is 27 to 33°C (Katersky and Carter 2007).

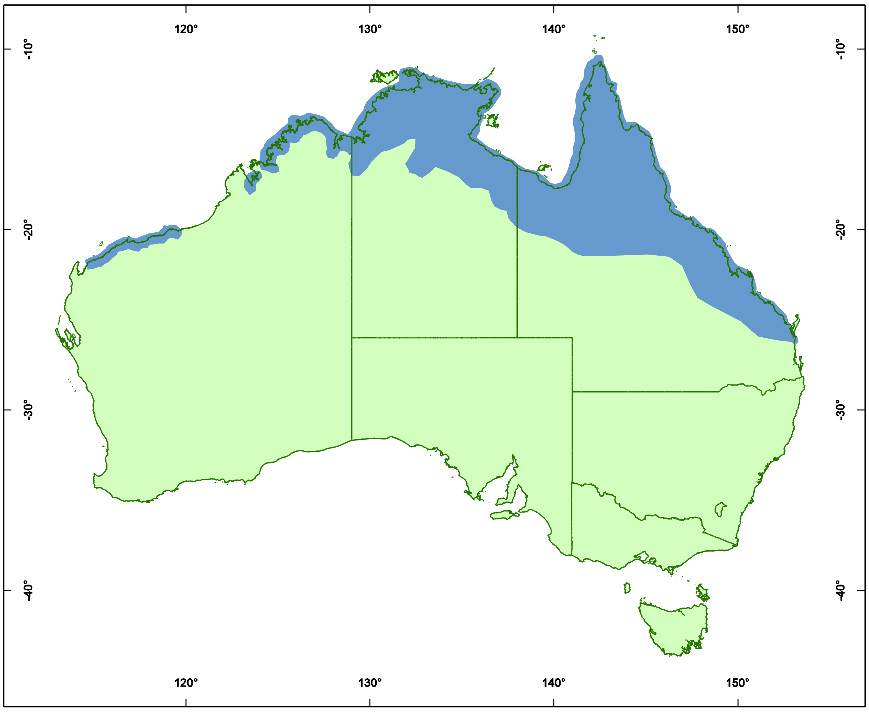

Figure 9.4. Distribution of barramundi in Australia.

Predators and prey

Barramundi have an important ecological role in tropical Australian estuaries (Dunstan 1959) as a large opportunistic ambush predator. Barramundi have an ontogenetic change in diet from insect larvae and micro-crustaceans to macro-crustaceans to fish (Davis 1987), which roughly corresponds to the size of organism that will fit into their mouth. In some circumstances, barramundi are also cannibalistic with young-of the year eaten by larger individuals of older cohorts (Russel and Garret 1985, Schipp 1996).

Recruitment

Barramundi recruitment is variable temporally and spatially (Griffin and Kelly 2001; Staunton-Smith *et al.* 2004; Halliday *et al.* 2011; Halliday *et al*. 2012). Successful recruitment of barramundi to the commercial fishery depends on the ability of post-larvae, juveniles and adults to migrate between the wetland, freshwater and marine environments suitable for each stage in the life cycle (Moore and Reynolds 1982). It also depends on the survival rate of each of these stages, which may be related to growth rates and freshwater flow (Robins *et al.* 2006). Griffin and Kelly (2001, p7) suggested "rainfall is an important influence (on recruitment), presumably through its effect on the availability and habitability of swamp habitat, particularly in the early part of the spawning season". Staunton-Smith *et al.* (2004) and Halliday *et al.* (2012) reported significant positive relationships between seasonal freshwater flows and the year-class strength of barramundi in five catchments in northern Australia (i.e., the Fitzroy, Mitchell, Flinders, Daly and Roper Rivers). Sawynok and Platten (2011) reported positive relationships between catch rates of recreationally caught 0+ barramundi in the Fitzroy River region (central Queensland) and rainfall and riverflow variables, with January rain having the highest r value (i.e., 0.56 $p<0.01$). They also reported a significant (step-wise backward) generalized linear model, that explained 50.6% of variation in 0+ catch rates that included wet season (Nov to Mar) flow ($p=0.092$), January flow ($p=0.097$), January rain ($p=0.006$) and February rain ($p=0.103$).

Barramundi stocks in northern Australia are genetically different between the Gulf of Carpentaria and the Queensland east coast (Shaklee and Salini 1985; Salini and Shaklee 1988; Williams 2002). Davis (1985, p189) suggests that because of localised spawning and genetic evidence of stock heterogeneity that "recruitment into major river systems would depend largely on the successful spawning of local populations" and that "the populations in different river systems may be quite independent of each other, and it may be appropriate to manage them as separate stocks". Tagging studies have demonstrated that while barramundi can move large distances between estuaries, most individuals remain within a specified region.

Current impacts of climate change

Key points:

- Barramundi populations are known to be reliant in many ways on rainfall and riverlow however there are no current impacts that can be attributed to climate change.

There are no documented current impacts of climate change on barramundi, although there are documented links between river flow/rainfall.

Sensitivity to change

Key points:

- Barramundi are sensitive to changes in rainfall and riverflow, which can influence catch, annual recruitment and growth rates.
- Predicting local impacts on populations is complex due to wide use of habitats during different life history phases, however; generally lower rainfall is likely to have negative consequences for populations.

There are several well documented strong relationships for barramundi between rainfall/riverflow and (i) catch (Robins *et al.* 2005; Meynecke *et al.* 2006; Balston 2009a, b; and Meynecke *et al.* 2011); (ii) recruitment (Staunton-Smith *et al.* 2004; Halliday *et al.* 2011, 2012; Sawynok and Platten 2011); and (iii) growth (Robins *et al.* 2006). Recent modelling of the possible effects of climate change on barramundi populations suggests that, on average, stock sizes and harvests would be reduced as a consequence of reduced river flows (Tanimoto *et al.* 2012).

A vulnerability assessment of Kakadu to climate change impacts found that barramundi were a key species that had "medium-high" risk of "decrease in abundance" by 2030 and 2070 (BMT WBM 2010). This was based on losses in nursery habitats as a consequence of sea level rise, although the report recognised possible increases in adult habitat, but reduced floodplain connectivity from reduced rainfall.

Sawynok and Platten (2011) suggested that the increase in the duration between large flood events may impact on strong recruitment years for barramundi. Currently, strong recruitment years are a feature of several regional stocks of barramundi (Halliday *et al*. 2012) and appear to drive the productivity of associated fisheries for several years. Sawynok and Platten (2011) then suggest that if the length of time between large recruitment events exceeds eight years, then there may be issues with the sex ratio of the spawning population with "uncertain consequences".

Resilience to change

Key points:

- Barramundi are likely to be resilient to increases in temperature projected for northern Australia over at least the medium-term (~50 years) as they have a wide thermal tolerance and are capable of large spatial movements.
- Populations of barramundi are likely to be impacted by reduced riverflows, particularly by periods of extended drought.

Barramundi are likely to be resilient to climate change as they are adapted to a wide variety of habitats and temperature and salinity levels (Grey 1987) and are capable of large within catchment movements. However, populations associated with specific river catchments may suffer reductions in abundance as a consequence of potential reductions in important freshwater habitat (squeezed by sea level rise).

Other

Key points:

- Water resource extraction/management (particularly on the Queensland east coast) is a potential additional stressor of the estuarine ecosystem, particularly through reducing the connectivity of floodplains to downstream ecosystems.

Ecosystem level interactions

Barramundi are a key predator in tropical river systems. They take advantage of seasonally available food resources in both estuarine and floodplain habitats (Salini *et al*. 1990; Jardine *et al*. 2011). Predation by barramundi is an important factor that determines the structure of the fish assemblage in many upstream habitats (B. Pusey unpublished data). Factors that influence the productivity of the lower food web will impact on barramundi populations.

Additional (multiple stressors)

Barramundi production is linked to river flows and the connectivity of floodplains to estuaries (Jardine *et al. 2011*). Management of water resources for human use has the potential to exacerbate climate stressors, particularly under scenarios with reduced rainfall as human demand for water resources often takes precedent over ecosystem needs.

Critical data gaps and level of uncertainty

It is relatively well documented that variability in abundance in barramundi populations in northern Australia is linked to variation in rainfall and river flow (Halliday *et al.* 2011, Halliday *et al*. 2012) and is dependent on floodplain connectivity and productivity (Jardine *et al.* 2011). What is not well understood is how these systems will respond to the changing climate.

Acknowledgements

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10. Barred Javelin, *Pomadasys kaakan*

Authors: Richard J. Saunders, Natasha Szczecinski and David J. Welch

A juvenile barred javelin, *Pomadasys kaakan.* (Image sourced from JCU).

The Barred Javelin, *Pomadasys kaakan*, is a member of the family Haemulidae (the grunters). The species occurs throughout the Indo-Pacific from the Red Sea and the east coast of Africa to south-east Asia and northern Australia (Froesy & Pauly 2012).

The fisheries

- Commercial catches of barred javelin are generally reported as "grunter". This is a complex containing at least three species.
- The barred javelin is an important by-product species in commercial fisheries targeting barramundi
- The species is an important recreational fishery species, particularly in north Queensland

Western Australia

25 t of grunter (*Pomadasys* spp.) were landed across all of WA's commercial fisheries in 2009/10 financial year (Department of Fisheries 2011). Although this complex includes *P. kaakan*, *P. argenteus* and *P. maculatus* the latter is likely to be a minor component given their small size. *P. kaakan* has been identified as one of the top 20 species landed by recreational fishers in the Pilbara and West Kimberley but the size of the catch in the region has not been estimated. Some fine scale regional data is available on catch in north-west WA (Newman et al. 2009).

Northern Territory

Grunters are taken as by-product in commercial barramundi fisheries in the NT. However, less than 2 t of grunter have been reported each year for 2008, 2009 and 2010 (NT Government 2011). No data on the importance of *P. kaakan* in recreational fisheries in the NT is available however most of the NT recreational catch comes from the Gulf of Carpentaria (Thor Saunders, pers. comm.).

Queensland

In Qld, commercial fishers land grunter in the Gulf of Carpentaria Inshore Fin Fish Fishery (GOCIFFF) and the East Coast Inshore Fin Fish Fishery (ECIFFF). Average catch in the GOCIFFF over the past seven years was 27 t (to 2009) (DEEDI 2011a). In the ECIFFF average catch was 28 t over the past four financial years (to 2009/10) (DEEDI 2011b). The annual catch by charter operators in the ECIFFF has ranged from 401 kg to 2,288 kg since 2004. The status of the species in Queensland is listed as uncertain due to poor knowledge of the recreational harvest.

The species has been noted as one that is a common target species by recreational fishers (Greiner & Patterson 2007; Hart & Perna, 2008). The tourist recreational catch of *P. kaakan* in the Gulf of Carpentaria was estimated to be between 100 and 118 tonnes over the period March – September 2006. Further, at a local scale, the Karumba recreational tourist fishery (from May to August inclusive) catch of *P. kaakan* was 13.5 t, representing 30% of the total catch in that fishery (Hart & Perna, 2008).

Recent research work in the Lucinda region of the north Queensland east coast indicates that recreational fishers catch fish predominantly between 280 and 360 mm TL whereas commercial fishermen catch a more even spread of sizes with significantly more fish over 600 mm than recreational fishers (Szczecinski, unpublished data). Furthermore, the recreational catch of grunter was highly skewed toward females with a ratio of 15:1. In the commercial sector however, this ratio was only 2:1 (Szczecinski, unpublished data).

Life history

- Barred javelin occupy estuarine and nearshore habitats across tropical and sub-tropical Australia.
- They mature at a small size by 3 years of age and in many parts appear to have a protracted spawning season lasting much of the year.

Life cycle, age and growth

The life history of *P. kaakan* is poorly understood as very limited research has been done. However, on the Queensland east coast the reproductive period off Townsville is reported to occur between September and November (Bade 1989). Further south on the Qld east coast, a more extensive reproductive period, from September to March, has been reported (Russell 1988). Recent research in the Lucinda region in far north Queensland also indicates an extremely protracted spawning season with actively spawning fish collected from August to June, although fish were not collected during January, April, May and December (Szczecinski, unpublished data). The species is thought to mature by its third year (Garrett, 1996). In the Lucinda region, over 50% of fish (males and females) are mature by 200-239 mm TL (Szczecinski, unpublished data). Histological sections of mature ovaries indicate the species is most likely a multiple batch spawner (Bade, 1989). Frosey & Pauly (2012) note that spawners form shoals near river mouths during the winter, but the statement is unreferenced.

Age and growth of *P. kaakan* were described for the Queensland east coast by Garrett (1996). Von Bertalanffy growth parameters reported were L_∞ = 579 mm FL, K= 0.35 and t_0= -0.66. More recent information on growth has been determined for the species in the Lucinda area (near Hinchinbrook Island, Far North Queensland) and this data differed from that of Garrett (1996) with Von Bertalanffy parameters L_∞ = 746 mm FL, K= 0.18 and t_0= -0.79 (Szczecinski, unpublished data). The oldest fish reported was 14 years (Garrett 1996), estimated from increments in whole otoliths. *P. kaakan* is reported to reach 800 mm (Froesy & Pauly 2012) but in Bade (1989) the largest fish reported was 530mm TL, and 610mm FL in Garrett (1996).

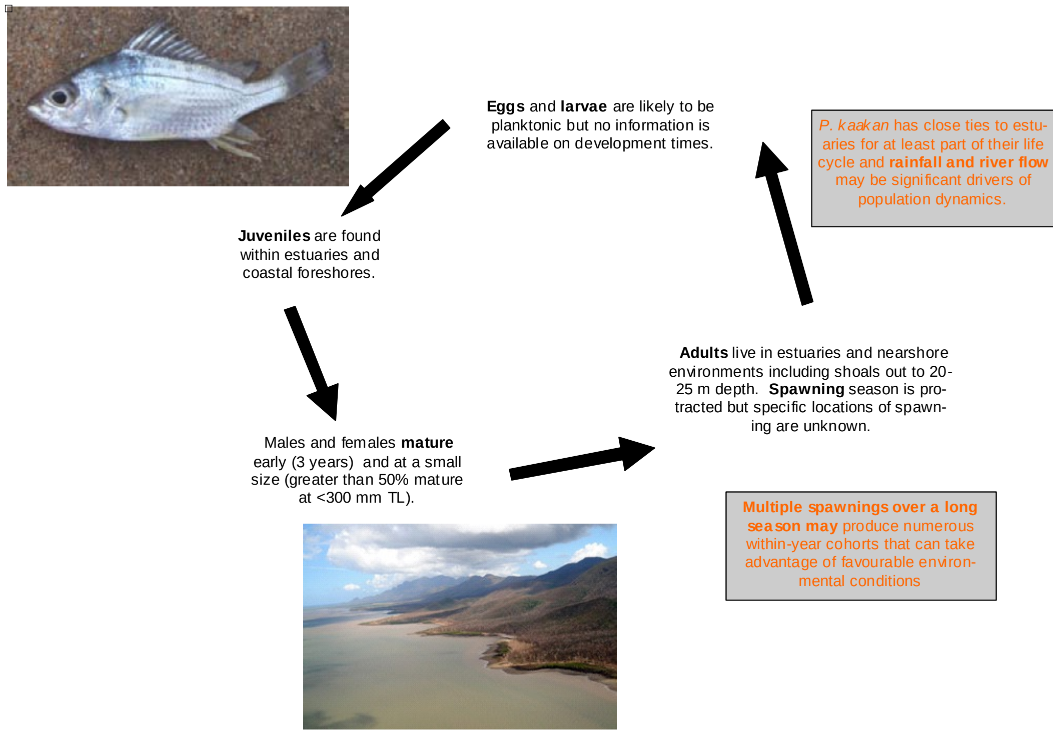

Figure 10.1. Generalised life cycle of the barred javelin, *P. kaakan*, and the stages of potential environmental driver impacts.

Distribution, habitat and environmental preferences

P. kaakan occurs throughout the Indo-Pacific from the Red Sea, east coast of Africa, south-east Asia and northern Australia (see Figure 2) (Froesy & Pauly 2012). It lives inshore primarily in estuarine and shallow coastal waters (Bade 1989; Smith & Heemstra 1986).

Predators and prey

The diet of *P. kaakan* around Townsville on Australia's east coast was described in Bade (1989). Principal prey items identified from stomach contents were polychaetes, crustaceans and fishes (Bade 1989). In that study, the most common prey item for larger fish (over 150mm) were decapods, while polychaetes were the most common prey item for specimens under 150mm.

Recruitment

There are no known measures of recruitment of grunter species in Australia and no population age structure information is available.

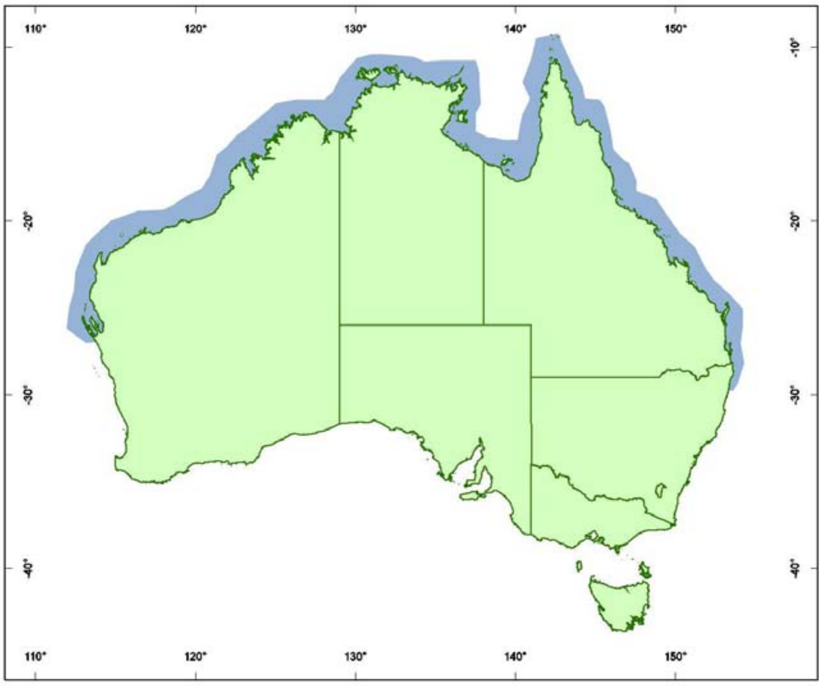

Figure 10.2. The Australian distribution of barred javelin.

Current impacts of climate change

There are no known current impacts of climate change on grunter species in Australia.

Sensitivity to change

- Sensitivity of barred javelin to environmental change is unknown.

The sensitivity of barred javelin to changes in environmental conditions is not known. However, they occupy nearshore and estuarine habitats and environments that are subject to large fluctuations in variables such as salinity, temperature and nutrient levels. As such, they are likely to be resilient to changes. It is also possible that rainfall and river flows are significant drivers of population recruitment and growth rates given this has been found to occur in several other nearshore/estuarine species (Halliday et al., 2008; Meynecke et al., 2006; Robins et al., 2006; Staunton-Smith et al., 2004).

Resilience to change

- Likely to be resilient due to their widespread distribution covering varying nearshore dynamic habitats.

Barred javelin are distributed widely across northern Australia occupying many different tropical regions in environments known to vary widely (see above). They are therefore likely to be resilient to changes in the environment. They also have habitat to the south of their current range that they could occupy with increasing marine temperatures.

Other

- Due to little research historically there is a need to understand better the sensitivity of barred grunter to changes in climate-related variables.
- There is also a significant recreational fishery across parts of northern Australia however catcah estimates are lacking making it not possible to make statements about fishery sustainability.

Ecosystem level interactions

As with many other similar species the ecosystem level interactions of barred javelin under climate change are very difficult to predict given uncertainty in exposure and sensitivity as well as predation and competition.

Additional (multiple) stressors

Fishing impacts are probably low at current levels in most regions of tropical Australia, however there remains a high level of uncertainty in the level of recreational harvest and the sustainability of this catch, particularly in the GoC and where recreational catches may be excessive (Hart and Perna, 2008). The stock structure of *P. kaakan* is unknown and will determine their sensitivity to localised depletions under fishing pressure or other impacts. Finally, barred grunter occupy estuaries and nearshore environments throughout their life cycle and are therefore exposed to land-based impacts such as water quality, agricultural and mining run-off, etc.

Critical data gaps and level of uncertainty

Recreational harvest levels is a key concern (Greiner & Patterson, 2007; Hart & Perna, 2008) and uncertainty for barred grunter in northern Australia and better estimates are needed for future more robust assessments of populations. Better understanding of the sensitivity of the barred grunter (and the spotted grunter, *P. argenteus*) to environmental variables such as temperature, salinity, pH and rainfall/river flow is needed to make more robust predictions about the potential impacts of climate change on these species.

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11. Black Jewfish, *Protonibea diacanthus*

Authors: Thor Saunders and Emily Lawson

A recreationally caught black jewfish. (Image sourced from Jenny Ovenden).

The Fishery

Key points:

- The Northern Territory Line fishery is the only northern Australian fishery that takes significant quantities of black jewfish.
- They are likely to be overfished on the Queensland east coast.

Western Australia

The Kimberley Gillnet and Barramundi Managed Fishery (KGBF) currently take a small catch of black jewfish as a byproduct species. The total catch of black jewfish from the KGBF in 2010 was 4.3t (Department of Fisheries 2011). The recreational catch of black jewfish was estimated at 2-10% of the commercial catch in 2000. The Indigenous catch of black jewfish is unknown but is unlikely to be high.

Northern Territory

The Coastal Line Fishery of the NT is the only fishery in northern Australia that takes significant numbers of this species. This fishery operates in the near-shore waters and harvests a wide range of species, predominantly using hook and line gear. The fishery comprises commercial, recreational, Fishing Tour Operator (FTO) and Indigenous sectors and mainly targets black jewfish (*Protonibea diacanthus*) and golden snapper (*Lutjanus johnii*) (Phelan *et al.* 2008a, Northern Territory Government 2011). Black jewfish annual catch in this fishery has almost always been over 100 t (Figure 11.1). At the point of first sale in 2010, the catch value of the commercial sector of the fishery was $0.43 million of which black jewfish comprised $0.37 million (Northern Territory Government 2011).

Recreational and FTOs also target black jewfish although these sectors tend to catch substantially more of this species in the NT compared to Qld and WA. Recreational fishing surveys indicate that black jewfish catches by this sector are at least equivalent to the commercial harvest and substantially more when FTO catches are included. There is no size limit for black jewfish in the NT however various personal possession limits are in place to help regulate the impact of the recreational fishing sector. Presently, the recreational possession limit for black jewfish is two.

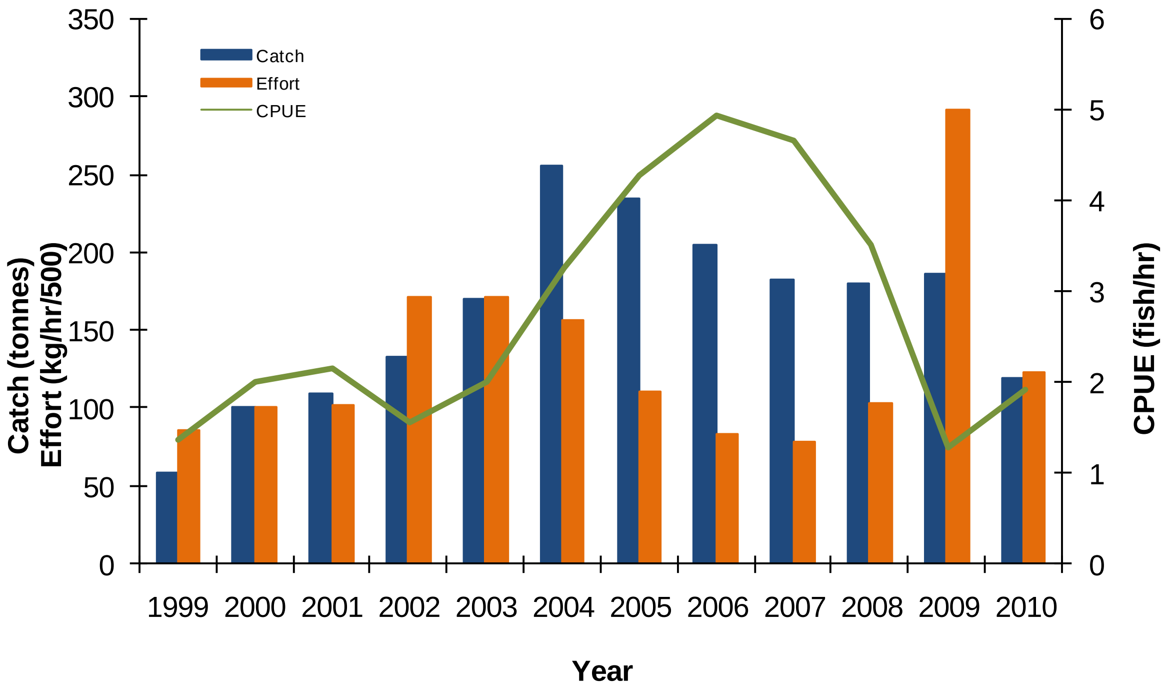

Figure 11.1. Catch and effort data of black jewfish from the commercial Coastal Line Fishery of the NT 1999-2010.

Queensland

The N3 inshore net fishery of the Gulf of Carpentaria Inshore Fin Fish Fishery (GOCIFFF) takes a small amount of black jewfish as a byproduct species with 9t caught in 2009. In addition, charter operators take a small quantity of black jewfish in the GOCIFFF with 157 kg caught in 2008 of which 67 kg was released (DEEDI 2010). On the east coast the commercial catch is insignificant and the recreational harvest is unknown, however anecdotal reports suggest that this species has been overfished. Indigenous harvest has also shown to be significant in waters off Cape York (Phelan 2002).

Life History

Key points:

- Black jewfish grow and mature quickly.
- Black jewfish are highly aggregative and suffer significant mortality from barotrauma-related injuries when caught in deeper waters.
- Juveniles inhabit coastal bays and estuaries suggesting that recruitment may be influenced by coastal climatic factors.

Life cycle, age and growth

The black jewfish is a member of the Sciaenid family, which are also known worldwide as croakers or drums due to the distinct drumming noise they make using their swim bladder. Black jewfish grow fast, reaching almost 60 cm in their first year and 90 cm in their second, and live up to 13 years (Phelan and Green 2008). Phelan and Errity (2008) found that black jewfish in NT waters grow faster and spawn at different times than conspecifics in northern Queensland, despite similarities in both latitude and environmental conditions at the aggregation sites. Fifty per cent of black jewfish are sexually mature at 89 cm or around two years of age (Northern Territory Government 2011). In the coastal waters of the NT reproductive activity occurs during an extended season from August to January with peak spawning activity occurring in December (Phelan and Errity 2008). Black jewfish are known to form large aggregations during spawning making them vulnerable to capture during this time.

Black jewfish suffer significant barotrauma related injuries when captured at depth. From research surveys fish retrieved from less than 10 m were likely to survive if handled and released appropriately. However, 48% of fish caught at 10–15 m were likely to die when released and all fish landed from deeper than 15 m were likely to die when released (Phelan *et al.* 2008c).

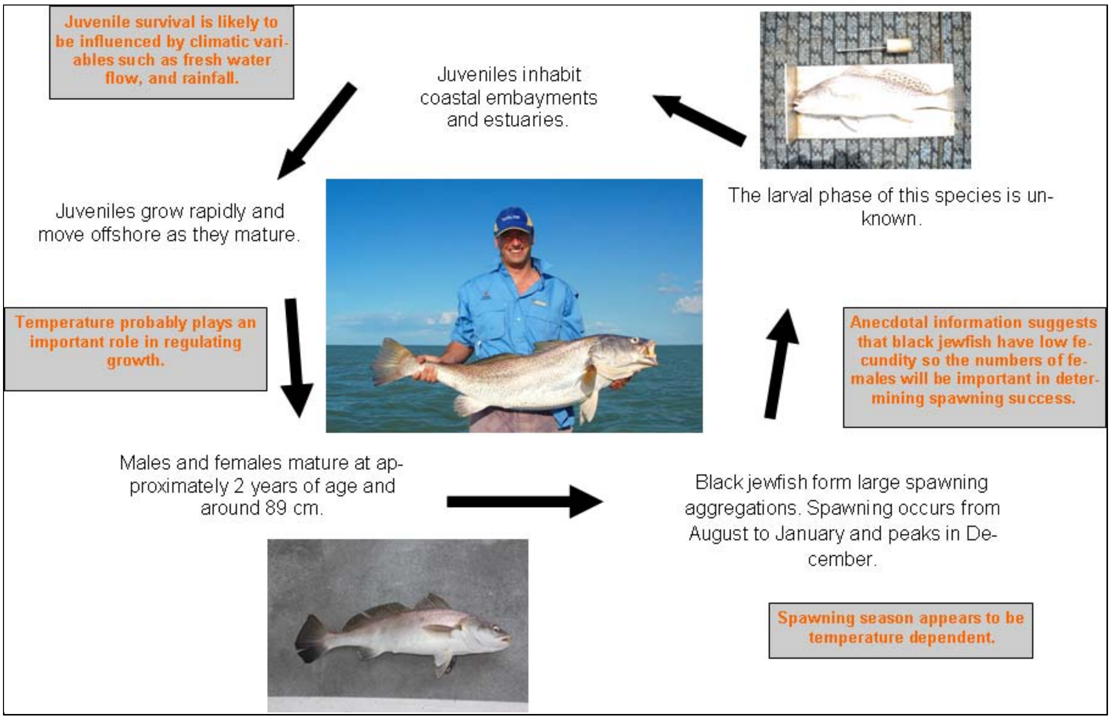

Figure 11.2. Summary of the life cycle of black jewfish and the points of exposure to relevant climate change drivers or known impacts.

Distribution, habitat and environmental preferences

Black jewfish is a migratory species found in turbid coastal waters throughout the Indo-West Pacific (India, Sri Lanka, Mayanmar, the Malay Peninsula, Thailand, Indonesia, Northern Australia, the Philippines, China and Japan). Adults tend to occupy near shore reefs (although they do occur in deeper waters offshore) while juveniles tend to inhabit coastal embayments and estuaries (Hay *et al*. 2005). In northern Australia waters black jewfish occur from central eastern Queensland to northern Western Australia (Figure 11.3; Newman 1995, Phelan 2008).

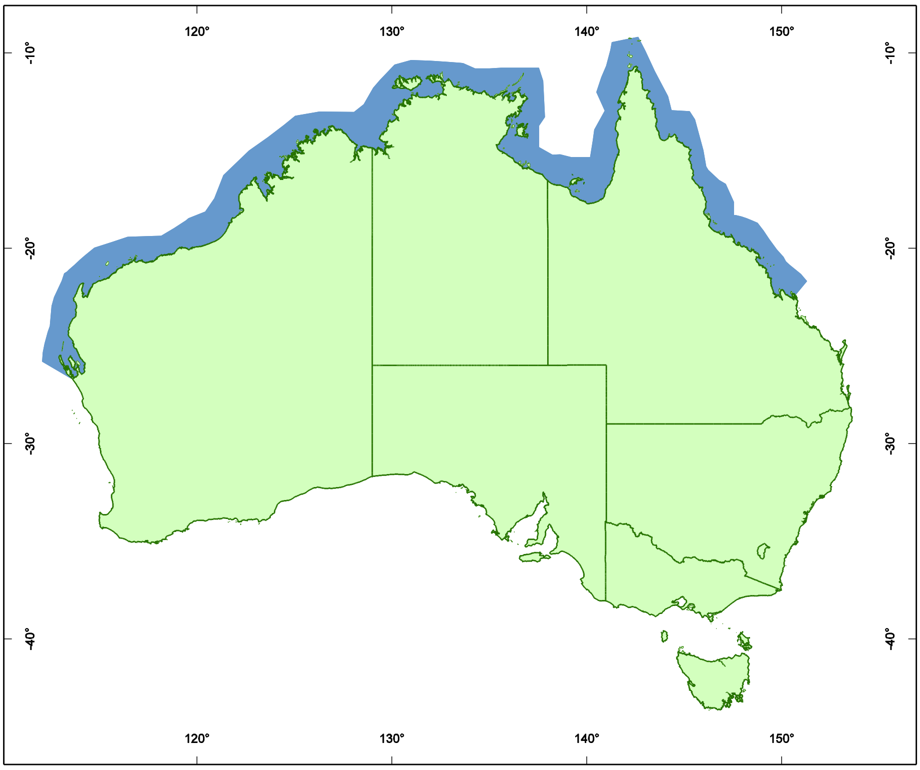

Figure 11.3. Australian distribution of black jewfish.

Predators and prey

Adult black jewfish are an opportunistic carnivore that preys on crustaceans, octopus, squid and fish (Hay *et al.* 2005) whereas juveniles are likely to feed on smaller crustaceans and fish due to their smaller size and different habitat. Juvenile black jewfish are likely to be preyed upon by large coastal fish such as barramundi or larger conspecifics and sharks.

Recruitment

Spawning takes place between August and January and peaks in December and January in the NT (Phelan and Errity 2008) and between April and September in Cape York (Phelan 2002). The factors that influence recruitment success are poorly understood although it is likely that abundance of spawning females, and coastal environmental drivers such as rainfall and river flow are important.

Current impacts of climate change

There are no known current impacts of climate change on black jewfish.

Sensitivity to change

Key points:

- The sensitivity of black jewfish to changes in environmental variables is poorly understood however it is highly likely that rainfall and riverflow are important given their life cycle.

The impact of climatic variables on this species is poorly understood. Given that juveniles mainly inhabit coastal estuaries and embayments, rainfall is likely to influence food availability and as a result growth and survival.

Resilience to change

Key points:

- High mobility and an extended spawning season provides some resilience to this species however they appear to be prone to overfishing as this appears to have occurred on the Queensland east coast.

Adults of this species are likely to be resilient to changes in climatic variables since they predominantly inhabit the marine environment and are capable of moving significant distances and occupying a range of depths/habitats. The protracted spawning period of this species also provides some resilience to environmental changes that produce unfavourable spawning conditions.

Other

Key points:

- Barotrauma related mortality is likely to cause additional pressures on populations, particularly those close to population centres where high levels of recreational fishing occur.
- The linkage between black jewfish abundance and environmental factors, particulary rainfall/riverflow, is poorly understood.

Ecosystem level interactions

While this species is a large higher order predator in the tropics it is unlikely changes in abundance will significantly impact ecosystem function. Seasonal changes in productivity, and the factors that influence this, may be significant drivers of annual recruitment success.

Additional (multiple) stressors

The predictable aggregating behaviour of this species makes them vulnerable to targeted fishing (Semmens *et al.* 2010). Even sectors practicing catch and release whilst targeting these aggregations, are probably killing most fish they catch because of their sensitivity to barotrauma related injuries. A high level of fishing is therefore capable of rapidly removing a significant proportion of spawning adults and reducing egg production (Sadovy and Domeier 2005). Selective fishing of these aggregations may also truncate the size and age structure through targeting of larger fish (Sala *et al.* 2001), leaving the population less fecund (Eklund *et al.* 2000, Sala *et al.* 2001), and may alter genetic composition (Smith et al. 1991) and skew the sex ratio (Phelan *et al.* 2008c, Semmens *et al.* 2010).

Critical data gaps and level of uncertainty

There is very little known about the linkages between variation in environmental factors and black jewfish abundance. While the aggregative nature of this species is well documented their stock structure across northern Australia is unknown. In addition, the general biology and ecology of this species is poorly understood.

Acknowledgements

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12. Black tip sharks, *Carcharhinus tilstoni* & *C. limbatus*

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A blacktip shark off the NSW coast. Photo: Pascal Geraghty.

Black tip sharks in Australian waters are comprised of two co-occurring species that are morphologically indistinct, making identification virtually impossible in the field. The two species are the common blacktip shark, *Carcharhinus limbatus*, and the Australian blacktip shark, *C. tilstoni*. Recent research has developed a genetic assay test to distinguish between the two species, however this is complicated by recent evidence of widespread hybridisation occurring between the two species in northern Australian waters (Morgan *et al.*, 2011; 2012). Vertebral counts and reproductive ecology has also been shown to be able to potentially distinguish the two species (Harry *et al.*, 2012), and more recently some key morphometric measurements have been demonstrated to distinguish between the two species with a 96% accuracy (Grant Johnson, unpublished data). Blacktip sharks have dominated commercial shark fisheries catches in northern Australia for the past 40 years (Stevens and Wiley, 1986; Harry *et al.*, 2011).

The fishery

- Blacktip sharks are commercially important across most of northern Australia but tend not to be targeted by other sectors.
- Highest catches are taken in the Northern Territory, the Gulf of Carpentaria and the east coast of Queensland.
- Catches are quite variable and appear to be driven by market demand rather than environmental drivers.

Western Australia

The northern shark fisheries are the main fisheries targeting blacktip sharks in Western Australia (WA). These fisheries comprise the state-managed WA North Coast Shark Fishery (WANCSF) in the Pilbara and western Kimberley, and the Joint Authority Northern Shark Fishery (JANSF) in the eastern Kimberley. These fisheries historically used demersal longline with a small amount of pelagic gillnetting in the JANSF. Because of their similarities the northern shark fisheries are considered as a single fishery. Due to recent declines in sandbar shark (*C. plumbeus*) catch this fishery is tightly managed by; limited entry, substantial gear limitations and restricted access to a few areas within the fishery. Annual blacktip shark catch averaged 67 t in this fishery from 2006 to 2008 and, despite declines in other shark species, blacktip catches have remained stable over time, although their status is uncertain (Department of Fisheries, 2011). The recreational, charter and indigenous take of blacktip sharks in the northern shark fishery is unknown but is likely to be negligible because of the isolated nature of this coastline.

Northern Territory

The commercial Offshore Net and Line Fishery (ONLF) targets blacktip sharks along with grey mackerel. The fishery operates from the high water mark to the boundary of the Australian Fishing Zone (AFZ), although most of the effort occurs within 12 nautical miles (nm) of the coast. The fishery is managed by limited entry (17 licences permitted to operate), individual transferable effort allocations and strict gear specifications that facilitate the selective targeting of smaller, more productive sharks species, with a lesser impact on larger, less productive shark species. The fishery is managed by the Northern Territory (NT) Fisheries Joint Authority (NTFJA), in accordance with the *NT Fisheries Act 1988*.

Blacktip sharks were reported as a single group (*C. limbatus, C. sorrah* and *C. tilstoni*) until 1998. During this time blacktip shark catches increased from almost nothing to 670 tonnes in 1996 before declining to 266 tonnes in 1998. Thereafter, *C. limbatus* and *C. tilstoni* catches were reported separately and have increased from 104 tonnes in 1999 to 337 tonnes in 2010 and have remained stable above 300 tonnes for the last three years (Figure 12.1). In 2010 at the point of first sale the black-tip shark component of the fishery was valued at $0.83 million.

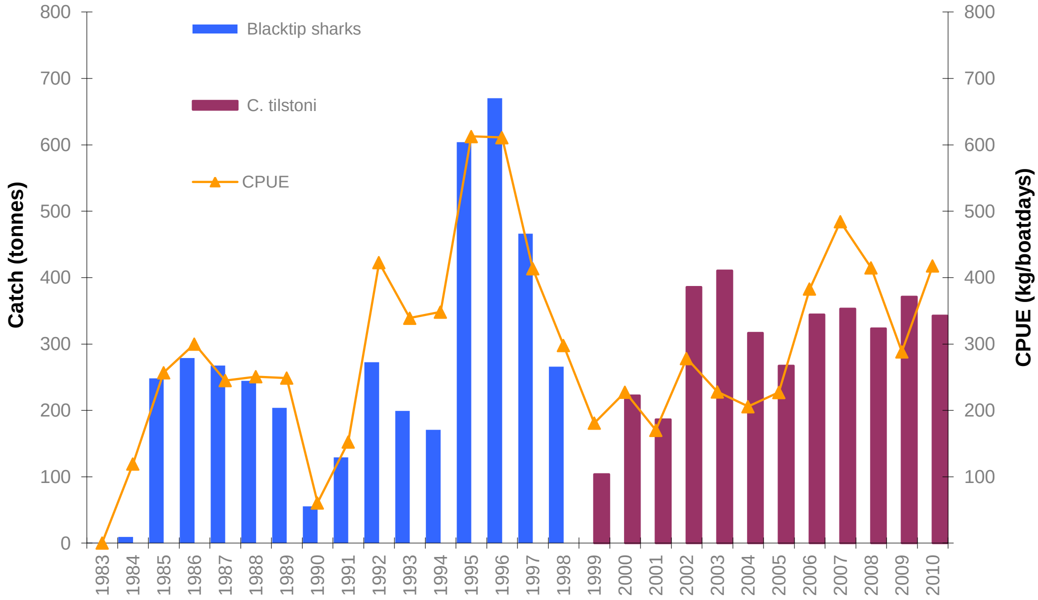

Figure 12.1. Northern Territory Offshore Net and Line Fishery catch and catch-per-unit-effort (CPUE) of blacktip shark for the years 1983-2010.

Sharks are generally not targeted by recreational fishers or Fishing Tour Operators (FTOs) in the NT, but are caught during other targeted fishing activities. In 2000-01, a survey of recreational fishers found that over 76,000 sharks were caught, with 8,000 harvested and the remainder released (Coleman, 2004). FTOs do not report sharks accurately by species. However, in 2010, FTOs caught 5,274 sharks and released 5,166 (98%). Currently individual recreational anglers are only permitted to retain two sharks (Northern Territory Government, 2010).

Queensland

Gulf of Carpentaria

The Gulf of Carpentaria Inshore Fin Fish Fishery (GOCIFFF) comprises inshore (N3) and offshore (N9) commercial net components, commercial bait netting (N11) and recreational, Indigenous and charter boat fishing within the Queensland jurisdiction of the Gulf of Carpentaria (DEEDI, 2012). The N9 net fishery harvests the most blacktip sharks (*C. limbatus, C. sorrah* and *C. tilstoni*) in the GOCIFFF and operates between 7 and 25 nm offshore. Smaller numbers of blacktip sharks are harvested in the N3 fishery, which mainly targets barramundi. Both net fisheries are authorised to use set mesh nets but are restricted by limited entry, allowable net length and drop and mesh size (DEEDI, 2012).

The recent historical annual commercial catch of all sharks in the Gulf of Carpentaria has been between approximately 300 and 650 t (Figure 12.2). However reporting by species in logbooks was only introduced in 2007 and so blacktip shark composition could not be determined until 2008 (DEEDI, 2012). For the years 2008 – 2010 blacktip sharks comprised an average of 68 % of the total catch.

Recreational fishers primarily use hook and line to catch target fish species and sometimes catch sharks as bycatch. In the most recent recreational survey (2005) only the total catch of shark was estimated so the catch of blacktip shark is unknown. Similarly, although charter operators have begun to report blacktip sharks separately, they generally only report total harvest of sharks and so blacktip composition is uncertain. Between 2004 and 2010 the charter sector reported catching on average 1,126 sharks with only one shark retained on average each year (DEEDI, 2012). There are no estimates of the Indigenous catch of shark in the Gulf of Carpentaria. The status of sharks in the Gulf of Carpentaria is ‘undefined’ due to lack of data.

East coast

The East Coast Inshore Fin Fish Fishery (ECIFFF) comprises multi gear commercial fisheries and recreational, charter and Indigenous fishing within all Queensland waters outside of the Gulf of Carpentaria (DEEDI, 2011). In the ECIFFF sharks are targeted by the commercial sector away from the coastline but generally within a few nautical miles. Nets account for 95% of the shark catch with line fishing taking the other 5%. In 2009, a Total Allowable Commercial Catch (TACC) of 600 tonnes, including rays, was introduced. In addition, tighter management arrangements were enforced, included limited entry into the fishery with licensees granted a fisheries ‘S’ symbol, and greater species resolution for shark species in logbook catch reporting (DEEDI, 2011). Although species reporting was done prior to 2009 the accuracy of identification is likely to improve after several years of reporting using the more detailed logbooks.

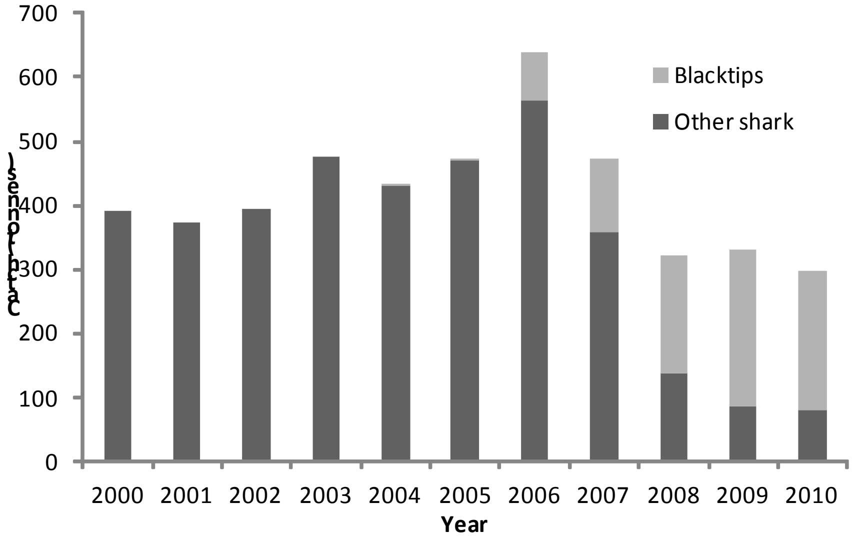

Figure 12.2. Reported commercial catch of sharks in the Gulf of Carpentaria inshore fishery (includes N3 and N9 sectors and net and line combined) for the years 2000 – 2010. The composition of blacktips in the catch is indicated and is not considered representative until at least 2008 due to compulsory reporting by species introduced in 2007. (Source: DEEDI, 2012).

The reported commercial catch of shark for the three years prior to the introduction of the TACC was 996 t, 1086 t, and 996 t respectively. During these years the blacktip shark (*C. limbatus, C. sorrah* and *C. tilstoni*) catch averaged 226 tonnes. The effect of management changes was a reduction in total shark catch to 475 t in 2009-10 of which 36 % was reported to be blacktip shark (171 tonnes) (DEEDI, 2011). Blacktip sharks comprise a greater proportion of the total shark and ray catch in the northern region (41%) compared to the southern region (26%) of the fishery (DEEDI, 2011).

Sharks are not identified to species by recreational and charter operators so blacktip shark catch is unknown. The most recent estimates of recreational shark catch estimate that in 2002 there were 212 individual sharks harvested and 1,750 released, while in 2005 there were 104 harvested and 1,345 released (DEEDI, 2011). The reported catch (and release) of shark by the charter fishing sector in 2009-10 was less than 1 t. There are currently no estimates of Indigenous catch of shark in this fishery. The status of sharks in the ECIFFF is unknown and no assessment has been done due to lack of data (DEEDI, 2011).

Life history

- The common blacktip is found in tropical/sub-tropical waters globally while the Australian blacktip is endemic to tropical/sub-tropical Australia.
- The common and Australian blacktip species have different life history characteristics meaning effects of harvest are likely to be different for each species.
- The Australian blacktip is more productive and likely to be more resilient than the common blacktip shark.

Life cycle, age and growth

The common blacktip shark (*C. limbatus*) and the Australian blacktip shark (*C. tilstoni*) are are virtually indistinct species morphologically. Distinguishing between the two species is nearly impossible in the field and currently relies on using genetics, vertebral counts or reproductive ecology (Morgan *et al.*, 2011, 2012; Harry *et al.*, 2012). However, ecologically they are quite different species.

Australian blacktip shark

C. tilstoni give birth around January in northern Australia while on the east coast it appears to be slightly earlier in December, although this may vary from year to year (Stevens and McLoughlin, 1991, Stevens *et al.,* 2000; Harry *et al.*, 2012). In northern Australia, the usual size at maturity for *C. tilstoni* is 105 to 115 cm for males and 120cm for females, although females are not in maternal condition until 130 cm (Stevens and Wiley 1986). On the east coast of Australia maturity occurs at a slightly larger size; 120cm for males and 125cm for females although females are not in maternal condition until 138cm (Harry *et al.* 2013). Mating occurs in February-March with ovulation in March-April. The gestation period is 10 months and individuals breed each year. The average litter size is three to four and the size at birth is approximately 60-62 cm (Figure 12.3; Table 12.1) (Stevens and Wiley, 1986; Harry *et al.*, 2012; Harry *et al.* 2013).

Growth is relatively rapid in the first year of life: vertebral ageing indicated 17 cm growth in total length (TL) for *C. tilstoni* during the first year after birth. By the time the sharks are 5 years old, growth has declined to 8-10 cm per year and they attain a maximum size of approximately 180 cm (Harry *et al.* 2012). Females begin reproducing at 5 to 6 years off northern Australia and 7 to 8 years off the east coast of Queensland (Stevens and Wiley 1986, Harry *et al.* 2013). The maximum recorded ages based on vertebrae are 8 to 13 years for males and 12 to 15 years for females (Davenport and Stevens, 1988; Harry *et al.* 2013). Vertebrae probably underestimate the maximum age of this species and tag returns indicate *C. tilstoni* is capable of living to at least 20 years (Stevens *et al.* 2000; Harry *et al.* 2013). Based on inshore fisheries catches all life history stages appear to occupy nearshore coastal habitats (Table 12.1) (Harry *et al.*, 2011). The life cycle of *C. tilstoni* is summarised in Figure 12.4.

Common blacktip shark

In Australia *C. limbatus* is born at approximately 72 cm and can attain a maximum size of 265 cm (Figure 12.3; Table 12.1) (Stevens, 1984; Macbeth *et al.*, 2009; Harry *et al.*, 2012). Off eastern Australia, males mature between 185 and 205 cm while females mature between 200 and 215 cm (Macbeth *et al.* 2009). Elsewhere, size at maturity varies between geographic regions with males maturing between 135-180 cm and females from 120-190 cm (Last and Stevens, 2009). Usual litter size is 4-7 (maximum 10) produced after a 10-12 month gestation. Individual females breed every other year, although a triennial reproductive cycle has been suggested in South Africa (Dudley and Cliff, 1993). Age at maturity in other parts of the world is 5-6 years for males and 6-7 years for females (Table 11.1) (Last and Stevens, 2009). Adult females are assumed to move in to coastal waters to give birth. Only neonates and juveniles of *C limbatus* are caught in east coast inshore fisheries in these habitats suggesting that adults generally prefer deeper water (Harry *et al.*, 2011). The life cycle of *C. limbatus* is summarised in Figure 12.5.

Distribution, habitat and environmental preferences

C. tilstoni is endemic to northern Australia and *C. limbatus* is found in subtropical and tropical waters worldwide. In Australia *C. limbatus* and *C. tilstoni* co-occur in subtropical and tropical waters however *C. tilstoni* are more common in tropical warmer waters and *C. limbatus* are more common in sub-tropical waters (Last and Stevens 2009; Ovenden *et al.* 2010) (Figure 12.5). *C. tilstoni* is found in continental shelf waters of tropical Australia and adults, juveniles and neonates appear to co-occur in coastal fishery areas (Harry *et al.*, 2011). The southern limits of its distribution are uncertain, as it has been confused with *C. limbatus*. On the east coast reported *C. tilstoni* has been reported as far south as Moreton Bay (27°S) based on vertebral counts (Harry *et al.* 2012), and as far south as Sydney (34°S) based on genetic samples (Boomer *et al.*, 2010). On the west coast, *C. tilstoni* is known to occur as far south as Dampier (21°S). *C. limbatus* adults appear to prefer deeper shelf waters since they are not generally encountered in the ECIFFF, while neonates and juveniles are found in shallow nearshore habitats (Harry *et al.*, 2011).

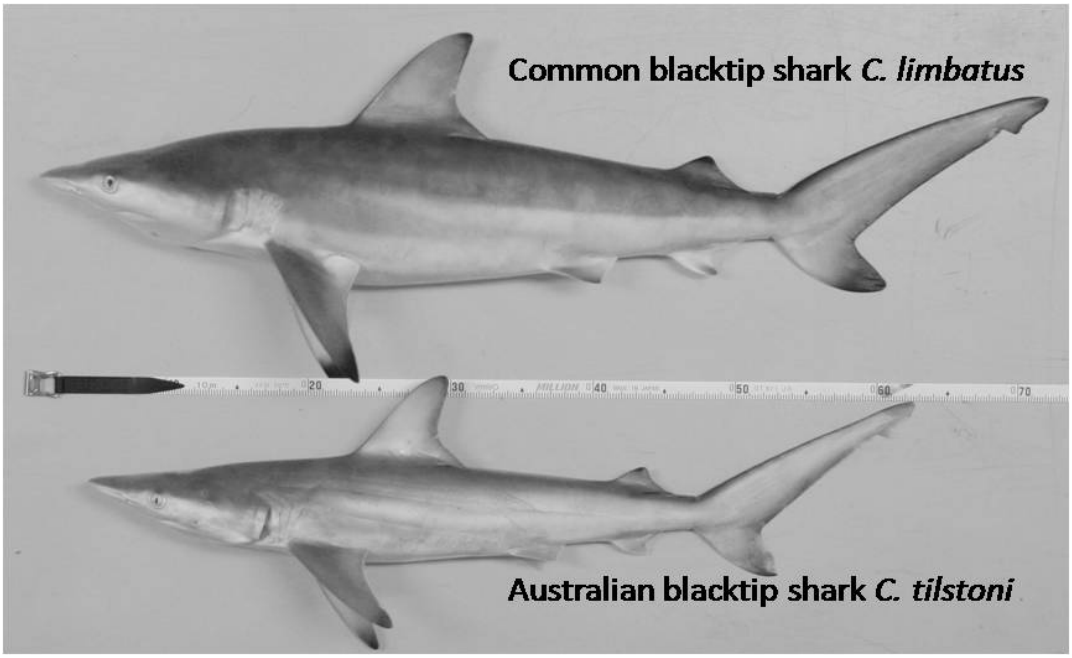

Figure 12.3. Comparative sizes of neonate blacktip sharks showing *C. limbatus* tending to be larger than *C. tilstoni* at birth (Source: Alastair Harry).

Table 12.1. Key aspects of the life history/ecology of *C. limbatus* and *C. tilstoni* that can assist in distinguishing between the two species. Sizes refer to SL = stretched total length. (Sources: Stevens, 1984; Davenport and Stevens, 1988; Last and Stevens, 2009; Macbeth et al., 2009; Ovenden et al., 2010; Harry et al., 2012; Harry et al., 2013).

Species	Australian distribution	Timing of birth	Mean size @ birth	Size @ maturity	Maximum size
C. limbatus	Most common in the sub-tropics	Oct-Jan Peak Nov	72 cm ±29sd	185-205 cm ♂ 200-215 cm ♀	265 cm
C. tilstoni	Most common in the tropics	Dec-Jan Region-specific	60-62 cm	105-120cm ♂ 120-125 cm ♀	180 cm

Predators and prey

The diets of blacktip sharks are known to contribute significantly to the natural mortality of valuable commercial prawns (Salini *et al.,* 1990; Brewer *et al*., 1991; Salini *et al*., 1992). Stomach contents indicate that teleost fish are an important component of the diet of both species and there is some indication of a change in feeding depth with shark size (Stevens *et al.*, 1986).

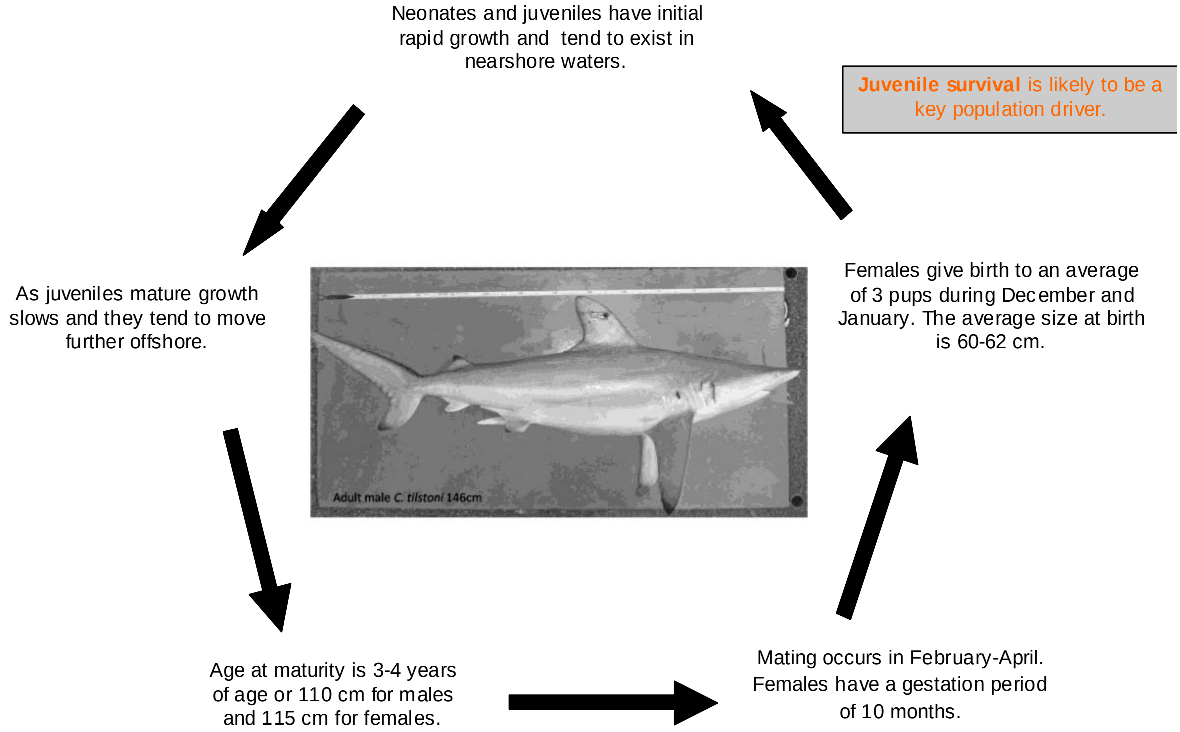

Figure 12.4. Summary of the life cycle of the Australian blacktip shark (*Carcharhinus tilstoni*).

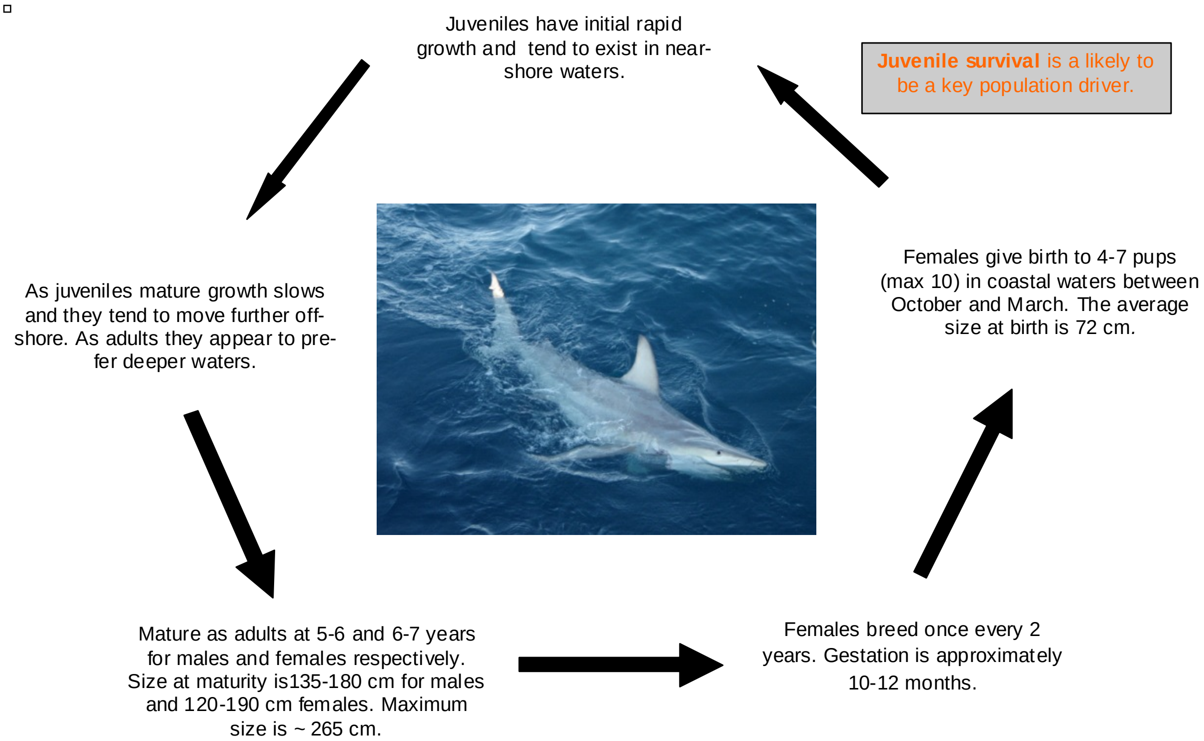

Figure 12.5. Summary of the life cycle of the common blacktip shark (*Carcharhinus limbatus*).

Recruitment

Given the low fecundity of blacktip sharks recruitment is likely to be heavily influenced by the abundance of mature females.

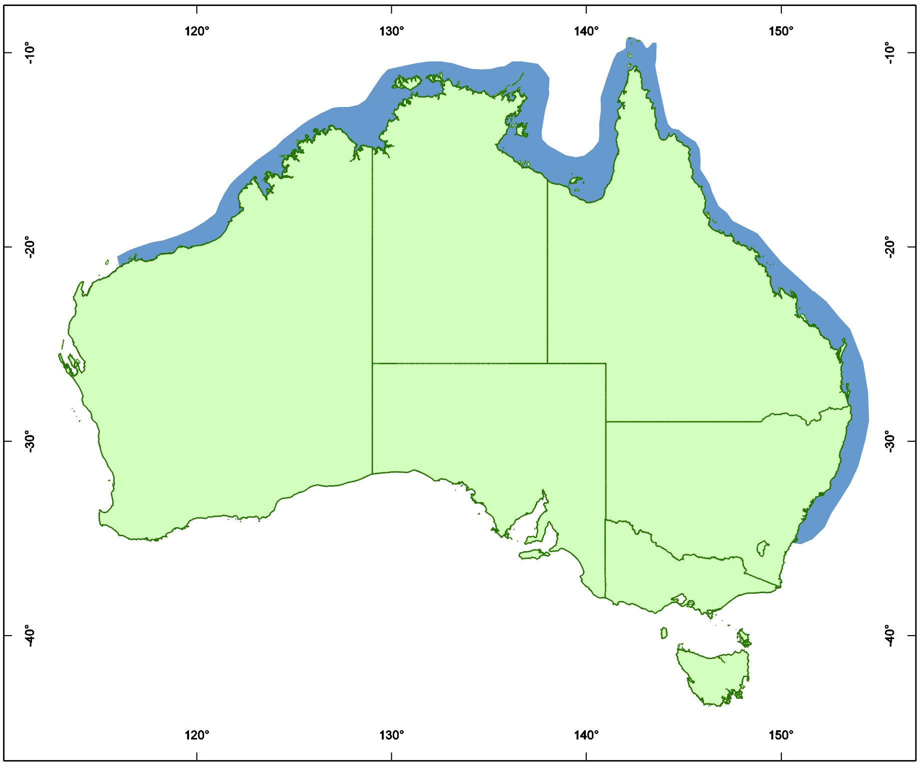

Figure 12.6. Distribution of *C. tilstoni* and *C. limbatus* within Australian waters.

Current impacts of climate change

Current impacts of climate change are unknown for the two blacktip species. A recent vulnerability assessment of sharks and rays on the Great Barrier Reef concluded that both the Australian blacktip and the common blacktip shark had a low vulnerability to climate change (Chin et al 2009).

Sensitivity to change

Key points:

- Sensitivity of blacktip sharks to environmental change is unknown although temperature may influence embryonic growth rate.

The sensitivity of each blacktip shark species to environmental changes is unknown. Although some coastal sharks in general show particular environmental preferences (eg. salinity: Heupel and Simpfendorfer, 2008; freshwater flow rates: Knip et al., 2011), they appear to be adapted to a range of environmental conditions including temperature, salinity and pH. Because sharks tend to give birth to relatively small numbers of young (or lay a small number of eggs) recruitment in shark populations is thought to be closely dependent on stock size and less affected by environmental conditions (Walker, 1998). However, Harry *et al.* (2013) noted a close correlation between ambient environmental temperature and embryonic growth rate in *C. tilstoni* and spot-tail shark, *C. sorrah*. This observation suggests that species such as *C. tilstoni*, which spend their entire lives in the relatively dynamic coastal environments, may still be sensitive to environmental conditions.

Resilience to change

Key points:

- It is likely that both species are resilient to climate change given their high mobility and wide habitat/environmental preferences.

Globally, populations of *C. limbatus* are widespread covering a vast range in environmental conditions suggesting their high resilience to changes in the environment. Within Australia both black tip shark species occur over a relatively wide latitudinal range and environmental conditions and are therefore likely to be resilient to changes in their environment. They are also highly mobile animals enabling them to readily move between preferred environments. Blacktip sharks are therefore likely to be resilient to climate change.

Other

Key points:

- Future population levels of blacktip sharks will be influenced by prey availability and therefore impacts on fish species will affect sharks, depending on the species.
- The general low productivity of blacktip sharks, particularly *C. limbatus*, means they have a low capacity to recover from any future impacts of climate change.

Ecosystem level interactions

Sharks constitute a major fraction of the predator biomass in tropical waters (Blaber *et al.* 1989, 1990a; Salini *et al.* 1992) and as a consequence exert an important top down influence impact on tropical coastal ecosystems.

Additional (multiple) stressors

Sharks in general are vulnerable to overexploitation due to their slow growth, late maturity and low fecundity (Ovenden *et al.,* 2010). Currently shark fisheries in Australian waters are generally managed tightly and so increased pressure from any fishing sector in the future is unlikely. Despite this, fishing pressure may exacerbate any impacts on blacktip populations from climate-induced changes. Illegal, unregulated and unreported fishing has increased off northern Australia in recent years and could potentially affect these species (Field *et al.,* 2009).

Critical data gaps and level of uncertainty

Although there have been recent major advances in methods for distinguishing among the two blacktip species (Morgan et al., 2011; Harry et al., 2012), further information on the catch composition of each species is required to assess the impact of the ongoing targeting by commercial fisheries. Also, the recent evidence of widespread hybridisation between the two species suggests further research should investigate the fitness of hybrids (Morgan et al., 2012).

Acknowledgements

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13. Coral trout, *Plectropomus spp.*

Author: David J. Welch

Common coral trout, *Plectropomus leopardus*. Photo: Anthony Roelofs.

Across northern Australia there are several species of the Family Serranidae that are known as coral trout. These belong to the genera *Plectropomus* and *Variola* and their relative abundance varies regionally and across the continental shelf. By number, the most common species in most regions of northern Australia is the common coral trout or leopard coral grouper (*Plectropomus leopardus*). Other species include bar-cheek coral trout (*P. maculatus*), bluespot coral trout (*P. laevis*), passionfruit coral trout (*P. areolatus*), highfin coral trout (*P. oligacanthus*), coronation coral trout (*Variola louti*) and lyretail coral trout (*V. albimarginata*) (Heupel et al, 2010). In fisheries across northern Australia *P. leopardus* comprises the vast majority of the total catch and so this review will primarily focus on this species.

The fisheries

- Most of the catch comes from the Great Barrier Reef on the Queensland east coast. Catches in Western Australia, Northern Territory and the Gulf of Carpentaria are negligible.
- Coral trout represent a valuable and important target species for all sectors in the Great Barrier Reef line fishery.
- Commercial catch is regulated by quota, while recreational catch is not well estimated.
- Coral trout are considered sustainably fished on the GBR.

Commercial catches of coral trout species are negligible in Western Australia and Northern Territory with most of the catch likely to be taken by the recreational fishing sector. In the Queensland Gulf of

Carpentaria line fishery the reported commercial catch is also very low with only 1.92 t taken annually in the period 2000 - 2009 (DEEDI, 2010). The charter fishing sector takes similarly low quantities, and assuming historically similar catch composition with the charter sector, the 2005 recreational coral trout catch in the Gulf of Carpentaria is likely to be approximately 14 t (DEEDI, 2010).

Queensland Reef Line fishery

Coral trout are the predominant target species for the Queensland Great Barrier Reef line fishery (RLF) historically comprising approximately 50% of the total catch (Welch et al, 2008). The fishery is multi-species, comprising in excess of 125 species, and multi-sectoral comprising commercial, recreational and charter fisheries. Fishing methods used are handlines (all sectors) and rod and reel (recreational and charter), with fishers operating from small vessels on individual coral reefs usually in depths less than 20 m (Welch et al, 2008). Since the mid-1990s, there has been a rapid growth of an export market for live fish, particularly coral trout (*Plectropomus spp*.), to south-east Asia (Mapstone et al., 2001; Sadovy et al., 2003), although a small number of vessels still supply dead product (Figure 13.1) (Welch et al 2008). The live fish market has increased the profitability of the RLF and the 2009-10 estimate of the commercial gross value of production of $45 million (DEEDI, 2011a) is based primarily on the coral trout catch component. Currently there are 369 commercial fishing endorsements for the RLF (RQ symbol) of which approximately 205 are active (DEEDI, 2011a).

Prior to 2004 the commercial sector was regulated mainly by effort controls, and the recreational and charter sectors had trip and/or bag (in possession) limits. For all sectors a minimum size limit (MSL) of 38 cm (TL; total length) was applied to coral trout for all sectors. In 2003–2004 management of the fishery changed substantially with the introduction of an annual total allowable commercial catch (TACC) allocated as individual transferable quotas (ITQs) for the key fishery species groups (coral trout, red throat emperor and ‘Other’ species). The coral trout TACC introduced was 1,350 t. Since quota was introduced the TACC has not been realised in any year and in 2009 the reported commercial harvest of coral trout was 1,028 t (80% of the TACC) (Figure 12.2) (DEEDI, 2011b). The MSL for *P. leopardus* and *P. maculatus* remained at 38 cm TL, and revised size limits for *P. laevis* were introduced with a minimum size of 50 cm TL and a maximum size of 80 cm TL for all sectors (Coral Reef Fin Fish Fishery Management Plan, 2003). There is also a seasonal spawning closure in place that prevents any fishing for coral reef finfish for five days around the new moon in October and November each year (DEEDI, 2011b). Other management arrangements include gear restrictions (eg. number of lines and hooks), boat size restrictions (max. 20 m for primary vessels), and restrictions on the number of fishing tenders for each licence. Extractive uses of the Great Barrier Reef Marine Park are also regulated through a zoning plan that includes extensive areas of no-take reefs.

Coral trout are also popular target species for recreational and charter fishing sectors. The harvest estimate for the charter sector in 2009/10 was 80 t while in the recreational sector for the years 1997, 1999, 2002 and 2005 harvest ranged from 196,000 – 332,000 fish. No estimate of recreational catch is available in terms of weight. The current stock status of coral trout in the GBR RLF is assessed as ‘sustainably fished’ (DEEDI, 2011b).

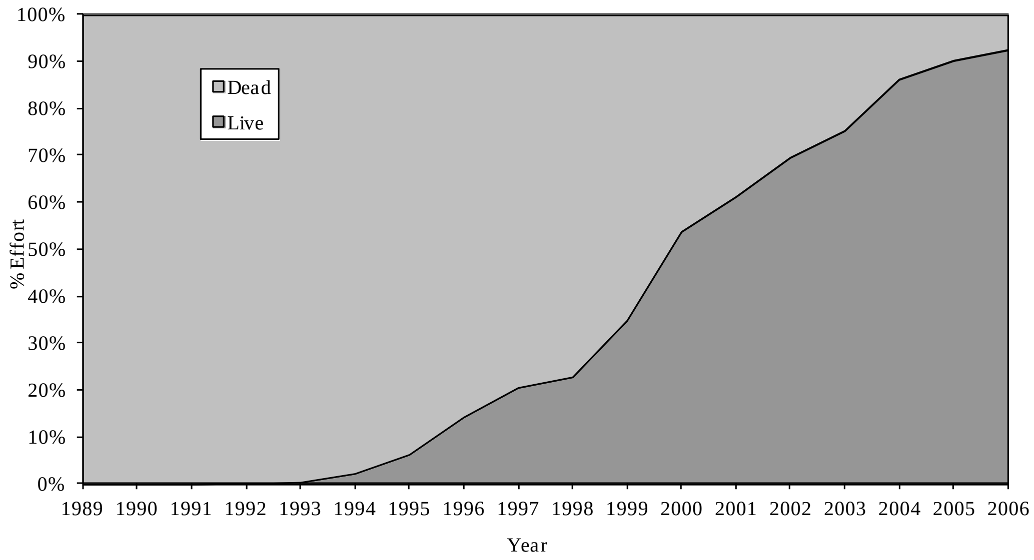

Figure 13.1. Changes in the commercial effort in the GBR line fishery showing the dramatic change in targeting dead to live product from 1989 to 2006. (Source: Welch et al, 2008).

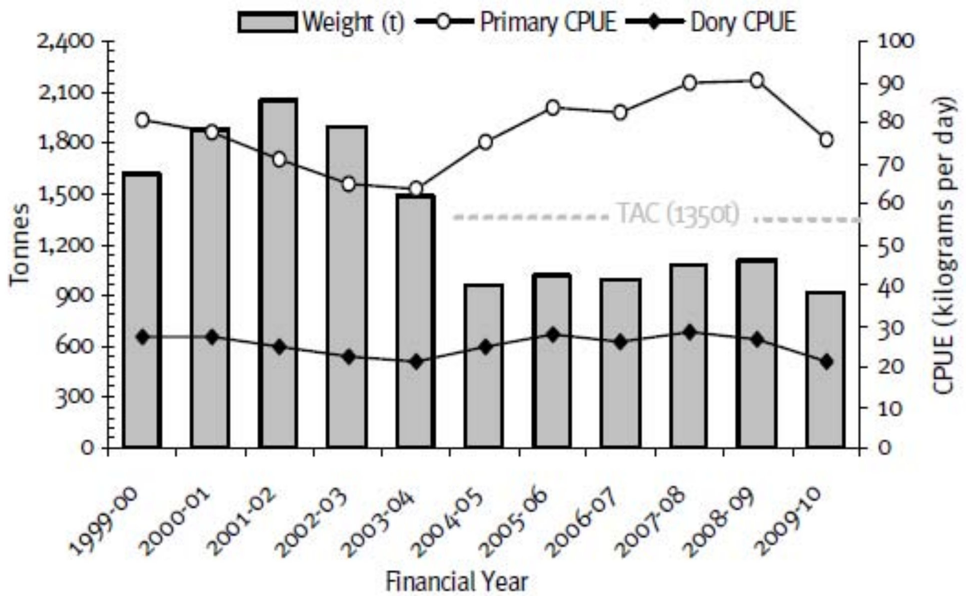

Figure 13.2. Commercial catch of coral trout from the Great Barrier Reef line fishery for the financial years (quota years) from 1999-00 to 2009-10. Catch-per-unit-effort (CPUE) for primary vessels and dories are also indicated. (Source: DEEDI, 2011b).

Life history

Key points:

- Coral trout are protogynous hermaphrodites; they mature first as females and change sex to become males as they get older and larger.
- *P. leopardus* are fast growing and early maturing and live for at least 17 years.
- Coral trout occupy a range of habitats but overall have a dependency on coral reefs and from a young age show strong site fidelity.

Life cycle, age and growth

Coral trout are protogynous hermaphrodites meaning that they develop primarily as females and change sex during their life to become males (Goeden, 1978; Ferreira, 1995). Coral trout spawn either in pairs, small groups or large (>100 individuals) aggregations with peak spawning activity during new moons from September – December (Ferreira, 1995; Samoilys, 1997; Samoilys and Squire, 1994). The numbers of individual fish involved and the timing is variable among and within years but the onset of spawning appears to be correlated with rising sea water temperatures (> 24° on the GBR) (Samoilys, 1997). They are broadcast spawners that rush to the surface in pairs to release gametes into the water column (Samoilys and Squire, 1994).

Longevity in *P. leopardus* is at least 17 years (Lou et al, 2005) and growth was first estimated by Ferreira and Russ (1994) for the northern GBR. Growth is fast in the first 2-3 years and slows to an asymptote as they get older. Growth was described using the von Bertalanffy growth function with parameter estimates of L_∞ = 522 mm FL, K = 0.35, and t_o = -0.77. More recent VBGF parameter estimates covering a greater area of the GBR show regional variation for the respective parameters being[2]: L_∞ = 424 - 488 mm FL, K = 0.48 – 0.59 (Welch, 2001). *P. leopardus* can reach sizes in excess of 70 cm FL and 7 kg in weight.

Size and age at first reproduction in *P. leopardus* was first estimated to be 24 – 36 cm FL, and 2-4 years from samples collected in the northern GBR, while sex change can occur across a wide range of sizes and ages (Ferreira, 1995). Adams et al (2000) found that *P. leopardus* may exhibit regional variation in their reproductive strategies, particularly the size and age at which sex change occurs.

The inshore or bar-cheeked coral trout, *P. maculatus*, has similar growth characteristics to *P. leopardus* (Williams et al, 2008) and can reach at least 75 cm FL and 8 kg in weight. The oldest specimen examined by Ferreira and Russ (1992) was 12 years old however they are likely to have similar longevity as *P. leopardus*. *P. maculatus* also show similar reproductive strategies as *P. leopardus* with first maturity at ~ 30 cm and 2 years of age and sex change can occur across a wide range of sizes and ages (Ferreira, 1993). More recent work from the Torres Strait indicate *P. maculatus* are capable of reaching maturity (~ 25 cm FL) and changing sex at smaller sizes than *P. leopardus* (Williams et al, 2008).

The blue spot coral trout, *P. laevis*, grows substantially larger than other coral trout species and reaches sizes in excess of 120 cm FL and 25 kg. Despite this, longevity of *P. laevis* is probably similar

[2] Estimates of t_o are not given because the fitting of growth models constrained t_o to a size at hatching of 1.62 mm (following Masuma et al, 1993; $t_o \approx 0$) to minimise biases from gear selectivity during sampling.

to that of *P. leopardus*, since Heupel et al (2010) sampled fish up to 14 years old but less than 100 cm FL. Spawning of *P. laevis* is also similar to *P. leopardus* but may extend farther into the Austral summer period (Heupel et al 2010). The length at 50 % maturity for females was estimated to be 45 cm FL however maturity can occur at 30 cm FL and 1 year old, while the length at 50 % sex change is 87 cm but can occur as small as 46 cm (Heupel et al, 2010).

Distribution, habitat and environmental preferences

Coral trout (*Plectropomus* spp.) are medium-large sized, relatively sedentary predatory species that prefer coral and/or rocky habitats and are distributed in tropical and sub-tropical regions including the eastern Indian Ocean and the western Pacific Ocean extending from Australia and Fiji to southern Japan (Randall and Hoese, 1986). Throughout northern Australia they can be found in a range of habitat types generally associated with reef habitat and from depths of 2 m to at least 40 m. Within Australia *P. leopardus* range from the Abrolhos Islands in Western Australia to SE Queensland in eastern Australia, with rare encounters south of these limits (Figure 13.4). *P. leopardus* are particularly common on the GBR and the Abrolhos Islands.

On the GBR *P. leopardus* are found across the continental shelf from inshore reefs and headlands to offshore barrier reefs, however they are most common on mid-shelf reefs (Newman et al, 1997). Other species of coral trout also show differential habitat/shelf preferences. The inshore (or bar-cheek) coral trout, *P. maculatus*, is so named for its preference of inshore reef areas while *P. laevis* is most often encountered on offshore reefs. *P. areolatus* are more commonly found in northern parts of the GBR and particularly the Torres Strait (Williams et al, 2008). The two *Variola* spp are far less common and tend to be sighted more often on offshore reefs, particularly on steep reef slopes.

In assessing microhabitat preferences for juvenile *P. maculatus*, although a range of different microhabitats were used, Wen et al (2012) found that approximately 60% of all fishes (127/212) preferred *Acropora* corals situated on loose substrates (e.g., sand), despite this specific microhabitat accounting for only 12.8% of benthic cover in the study areas. It is likely that other species of coral trout will have preferred micro-habitats during early and adult life history stages.

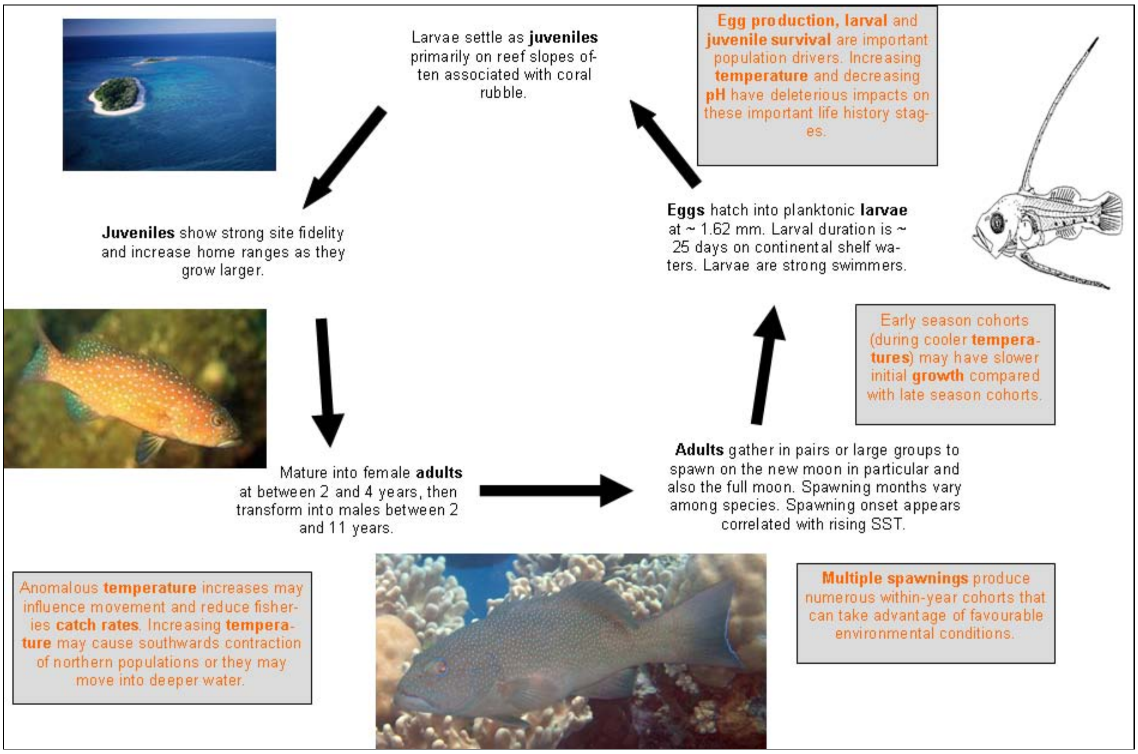

Figure 13.3. Generalised life cycle of the common coral trout, *P. leopardus*, and the stages of potential environmental impacts. Images: Masuma et al, 1993, GBRMPA, Anthony Roelofs.

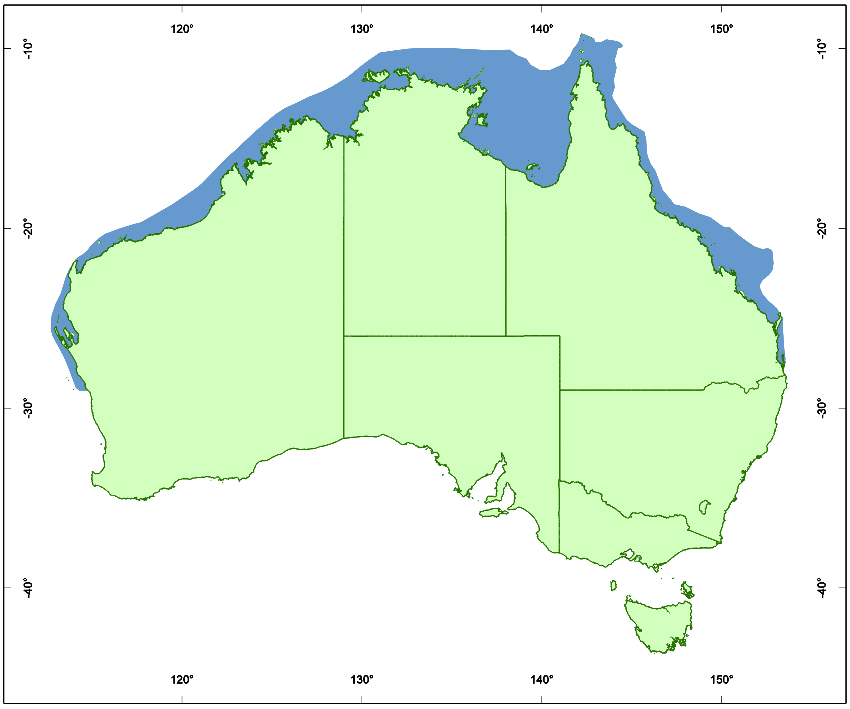

Figure 13.4. Distribution map showing the 'usual' range of the common coral trout, *Plectropomus leopardus,* within Australia.

Predators and prey

As juveniles coral trout consume a high proportion of benthic crustaceans, mostly penaeid shrimps, as well as small fish, whereas adults are almost entirely piscivorous (St John, 1999). Given the broad diet of *P. leopardus*, and because the two major prey families (Pomacentridae and Labridae) are diverse and abundant on coral reefs, St John et al (2001) concluded that coral trout are resilient to changes in abundances of particular prey species.

Recruitment

Coral trout eggs develop over a period of approximately 26 hours and have a size at hatching of 1.62 mm. The planktonic larval duration is approximately 25 days (Doherty, 1996; Masuma et al, 1993). Masuma et al (1993) give a very detailed account of the developmental larval stages. Once hatched, larvae show competent swimming capabilities with directional movement (Leis and Carson-Ewart, 1999). Variation in annual egg production, and in the survival of larval and juvenile stages, is significant and an important driver of population dynamics of coral trout with strong recruitment cohorts persisting over many years (Doherty and Williams, 1988; Doherty, 1996; Russ et al, 1996). Juvenile settlement occurs on reefs, primarily on reef slopes deeper than 4 m and they show a strong preference for habitat with a high proportion of coral rubble, algae, sand and rock. Recruits also show strong site fidelity and increase their home range size as they grow in size (Light, 1995). Light (1995) also presented evidence that earlier cohorts in a season, when temperatures are lower, exhibit slower initial growth compared with later cohorts when temperature is higher.

Current impacts of climate change

Key points:

- Cyclones have been shown to affect fishery catch rates of coral trout long after (many months) the passing of the cyclone with social and economic impacts on fishers.

Research by Tobin et al. (2010) demonstrated depressed catch rates of coral trout in the RLF following the crossing of Cyclone Hamish in 2009, a very large (Category 5) tropical cyclone, over parts of the Great Barrier Reef. The impact on the fishery was environmental, social and economical as some boats had to move substantial distances to other ports to remain profitable, or remain in their home port resulting in loss of fishing crew. The shift to other regions also caused localised stock depletions in some areas and increased conflict regarding resource use. The research also examined Cyclone Justin (1997) which, although a less intense system was a long-lived cyclone, and resulted in significant decreases in coral trout catch rates accompanied by significant increases in catch rates of red throat emperor (*Lethrinus miniatus*), the secondary target species of the RLF. Underwater visual surveys conducted following Cyclone Hamish documented structural reef damage as high as 66 % on some reefs, however the same surveys also observed nominal increases in coral trout abundances. There was no apparent correlation between sea surface temperature and catch rate. For Cyclone Justin however, a distinct cool water anomaly was found to be the most likely driver of decreased coral trout catch rates (reduced by up to ~50 %) and increased red throat emperor catch rates (increased by up to ~200%) (Tobin et al 2010). The impacts were spatially and temporally variable for each cyclone making general statements about likely impacts of cyclones highly uncertain.

There are also several recent anecdotal reports that describe an increase in the sightings and captures of coral trout in the SE Queensland region, relative to historical levels.

Sensitivity to change

- Increases in temperature above ~28°C will have deleterious effects on coral trout early life history stages.
- Water chemistry changes may impact juvenile survival by altering predator-prey interactions.
- Cool water anomalies and/or cyclones may depress coral trout fishery catch rates.

Recent experimental studies on the effects of temperature and water chemistry on *P. leopardus* have greatly advanced our knowledge of the sensitivity of coral trout, and potentially other coral reef fish. Under different temperature regimes ranging from 24°C to 33°C, Pratchett et al. (2013) found that survival of larval coral trout is significantly reduced at increased temperatures above 28°C over the endogenous nutrition phase. The endogenous nutrition phase is the period between developing embryo and first feeding on live prey items (exogenous feeding). The study also found that at higher temperatures larvae had smaller initial yolk reserves, increased metabolic rate, were significantly smaller at the end of the endogenous phase, and had a more restrictive diet due to a smaller mouth gape, explaining the higher mortality observed. Further, at higher temperatures the duration of coral trout sperm motility was decreased, egg hatching rate was lower, and egg development showed increased irregularities. pH did not appear to have any impact on egg development and survival (Pratchett et al, 2013).

Pratchett et al (2013) found no difference in thermal sensitivity between northern and southern coral trout populations (separated by > 1200 km). The implications of this are that northern populations are likely to express responses to warming waters before southern populations. This could be a contraction of the species range southwards or redistribution of animals to deeper waters. At temperatures greater than 30°C the energy demands on coral trout became so great that normal function is likely to be compromised (Pratchett et al., 2013).

A related experimental study found that juvenile *P. leopardus* are sensitive to changes in water chemistry. At elevated pH levels juvenile coral trout became more attracted to the odour of predators and were more significantly more active and more inclined to move away from shelter, making them more vulnerable to predation. Munday et al. (2012) reared juvenile coral trout in laboratory conditions under different levels of pCO_2 (~495, 570, 700 and 960 µatm). The results showed that above 600 µatm CO_2 fish were more active and ventured further from shelter, and actually were attracted to the odour of predators. Similar research on a larval coral reef fish (*Amphiprion percula*) also showed a breakdown in the olfactory abilities in detecting predators with changes in water pH (Dixson et al., 2010).

The only other documented evidence of environmental effects on coral trout appear to be the influence of cyclones and temperature on catch rates, whereby cooler water can reduce catch rates (Tobin et al, 2010). Such water incursions can also be induced through upwelling and changes in water current patterns and pathways on the GBR are poorly understood. Other sources of evidence are either anecdotal or on similar species. For example, based on fishers' reports, coral trout may be moving farther south on the east coast of Queensland.

Research on other species show differential effects of changes in temperature and water chemistry on aspects of the species life history. In one example on a species related to coral trout, *Epinephelus malabaricus*, Yoseda et al (2006) found that the mean volume of yolk sac at larval onset of mouth opening and at onset of feeding was significantly larger at lower temperatures (25 °C) compared with higher temperatures (28 °C and 31 °C). They also found that larvae tended to absorb the yolk sac and consume the oil globule more rapidly with increasing temperature.

General conclusions have also been made about coral reef fish stating that warmer water temperatures are likely to increase larval development thereby reducing the planktonic larval stage, which in turn will reduce dispersal capabilities and alter spatial scales of connectivity (Munday et al, 2009).

Resilience to change

Key points:

- Coral trout show plasticity in their life history stages and have a broad diet making them resilient to changes in local conditions.
- Although they have a moderately wide thermal tolerance range, northern areas of their range will be approaching the maximum for normal function (~30° C) in the medium term future.

Coral trout have been shown to have variable growth rates, as well as size and age at maturity and sex change depending on location and possibly population densities (Adams et al, 2000; Welch, 2001) indicating they can adapt to changing environmental and population conditions. Coral trout (*P. leopardus*) also have a broad diet with two of their major prey families (Pomacentridae and Labridae) among the most diverse and abundant on fish families on coral reefs suggesting coral trout are resilient to changes in abundances of particular prey species (St John et al, 2001). The thermal tolerances of coral trout would appear to have an upper threshold of approximately 30° C (Pratchett et al., 2013). This corresponds with known distributions for *P. leopardus*, *P. maculatus* and *P. laevis* which occur across a range of latitudes with water temperature ranges from approximately 22 – 30° C, suggesting a moderately wide temperature tolerance. Coral trout also use rising sea water temperatures as a cue for spawning (> 24°C on the GBR) (Samoilys, 1997) and so under climate change scenarios of increasing water temperatures are likely to avoid the critical thermal thresholds that negatively affect larval development described above resulting in earlier spawning.

Other

Key points:

- Future impacts on coral reef habitats will also impact coral trout populations.
- Better understanding of the ability of coral trout to adapt to increases in temperature and acidification are required, as are better estimates of recreational harvest.

<u>Ecosystem level interactions</u>

Coral trout species are one of the most abundant coral reef fish predators, particularly on the GBR. They are therefore likely to be an important functional group in the functioning of coral reef ecosystems. The interactive effects of competition and predation, particularly during early life history stages, under a changing climate are poorly understood.

Additional (multiple) stressors

Coral trout appear to have preferred micro-habitat, particularly at the juvenile stage, which may be important for early survival (Wen et al., 2012). The predicted climate change impacts on coral reef habitats (Bell et al., 2011; Pratchett et al., 2011) could therefore indirectly influence coral trout population replenishment and exacerbate the effects of more direct impacts such as temperature and water chemistry. Fishing is the major potential stressor on coral trout populations however, current management of coral trout stocks in Australia is considered to be robust and stocks considered to be sustainably fished at current levels. However, recreational catch is expected to increase as human population increases, thereby intensifying the pressure on target fish stocks.

Critical data gaps and level of uncertainty

Critical information needs are the effects of temperature and pH on the different coral trout life history stages. Research into the adaptive capacity of coral trout to predicted changes in temperature and pH would also help put current knowledge in perspective. Coral trout are a popular target species by recreational anglers across northern Australia and currently estimates of the harvest by this sector are poor. More robust estimates of recreational catch are needed.

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14. Dusky Flathead, *Platycephalus fuscus*

Authors: Richard J. Saunders and David J. Welch

The Dusky Flathead, *Platycephalus fuscus*, is a member of the family Platycephalidae (the flathead) of the order Scorpaeniformes. The species is restricted to the east-coast of Australia from eastern Victoria to north Queensland and is a very important recreational species in NSW and Qld

The fisheries

- Commercial catch is taken in inshore net fisheries in Qld and NSW.
- Recreational catch is much larger than the commercial catch.

Queensland

The dusky flathead is landed by commercial fishers in the East Coast Inshore Fin Fish Fishery (ECIFFF) and comprises <1 % of the total species composition by weight (Simpfendorfer et al., 2007). In 2009-10 there was 57 t of flathead reported in the commercial sector and the annual average over the past four years is 66 t. In the tropics dusky flathead form the bulk of flathead catches. Given the size limits in place for this species the fishery harvests predominantly females. Catches and catch rates have been stable and the species is currently considered to be sustainably fished (DEEDI, 2011a). RFISH diary surveys done to assess recreational catch in Queensland for the years 1997, 1999, 2002, and 2005 record catch of flathead ranging from 133 t in 1999 to 70 t in 2005 (McInnes, 2008). A large proportion of this catch is likely to be dusky flathead but the species composition is unknown. The species has minimum and maximum size limit and bag limits are in place for the recreational sector.

New South Wales

Commercial landings of dusky flathead are restricted to the Estuary General Fishery in NSW (Rowling et al. 2010) and are higher than the Qld commercial sector. Commercial catches in NSW since 1997/98 have generally been in the range of approximately 120 - 230 t. Commercial catches are mainly comprised of female fish (Gray et al, 2002). The catch in this fishery has varied between ~120 – 180 t in recent years after a large drop following a buy-out of many commercial fishers during 2000 (Figure 14.1). Historically, commercial catch of dusky flathead since 1952/53 has generally remained between 150 and 250 t per annum (Rowling et al. 2010).

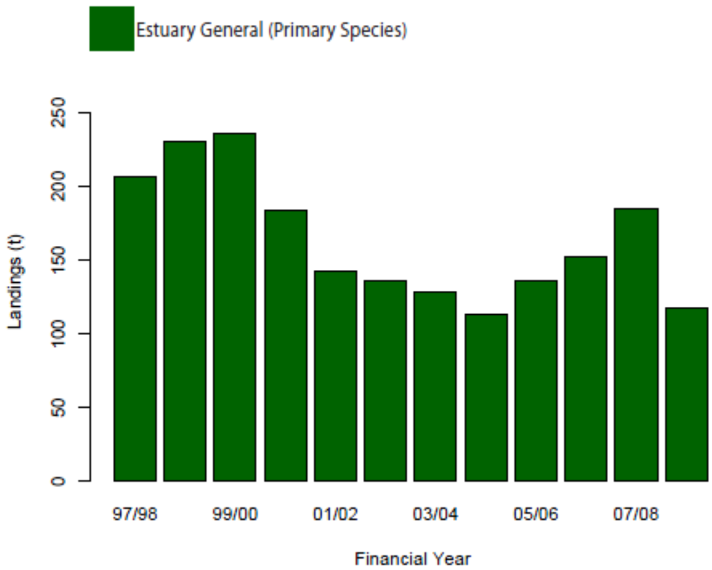

Figure 14.1. Commercial catch of dusky flathead in NSW commercial fisheries from 1997/1998 to 2008/09 (figure extracted from Rowling et al. 2010).

The commercial catch of dusky flathead in NSW is dwarfed by the recreational catch which is thought to lie between 570 and 830 t (Rowling et al. 2011). Henry & Lyle (2003) report flathead to be the second most prominent group taken by recreational fishers in Australia, however, no analysis of flathead catch by species was done. Dusky flathead are assessed as fully fished in NSW waters. They have a minimum size limit only but a restriction of one fish > 70 cm TL, with a recreational bag limit of 10 (Rowling et al. 2011).

Life history

- Commercial catch is taken in inshore net fisheries in Qld and NSW.
- Recreational catch is much larger than the commercial catch.

Life cycle, age and growth

Dusky flathead are the largest flathead species attaining 1.2 m SL and 15 kg (Gomon et al. 2008). Growth has been well described by Gray & Barnes (2008) for NSW but several studies across the range of species have also considered age and growth (e.g. Dredge 1976; West 1993; Gray et al. 2002). Gray & Barnes (2008) reported sexually dimorphic growth for dusky flathead. The von Bertalanffy growth parameters for females were: L_∞ = 127.59 mm, K= 0.084, t_o= -2.39 and for males: L_∞ = 43.21 mm, K= 0.714, t_o= -0.67 (Gray & Barnes 2008). There is some evidence that dusky flathead from Victoria attain sexual maturity at a smaller size than those from southern Queensland (*see* Kailola et al. 1993).

Spawning occurs in northern Queensland from September to March (Dredge 1976), in Moreton Bay from November to February, and January to March in NSW and Victoria (Kailola et al. 1993). These are all periods associated with an increase in day length and water temperature (Dredge 1976). The species is likely to be multiple batch spawner and has high fecundity producing between 294,000 and 3,948,000 pelagic eggs (Gray & Barnes 2008). The larvae are pelagic and are described in Neira et al. (1998).

There has been some speculation that dusky flathead are protandrous hermaphrodites (Dredge 1976, Kailola et al. 1993) but this was based on observations of sized based sex ratios and no histological or physiological studies have found evidence for this. It is now considered more likely that the species exhibits dimorphic growth between the sexes resulting in exclusively large females and a very high proportion of males in the smaller size classes (Gray & Barnes 2008).

This species was successfully reared under laboratory conditions for a pilot program of stock enhancement in south-east Queensland (Butcher et al. 2000; 2003). Eggs were developed successfully at 23°C, and as 12 mm hatchlings they were transferred to 24–26.5°C ponds prior to being released at 35–50 mm (Butcher et al. 2000; 2003). The life cycle of dusky flathead is presented in Figure 14.2 with comments on potential influences of environmental variables on the different life history stages.

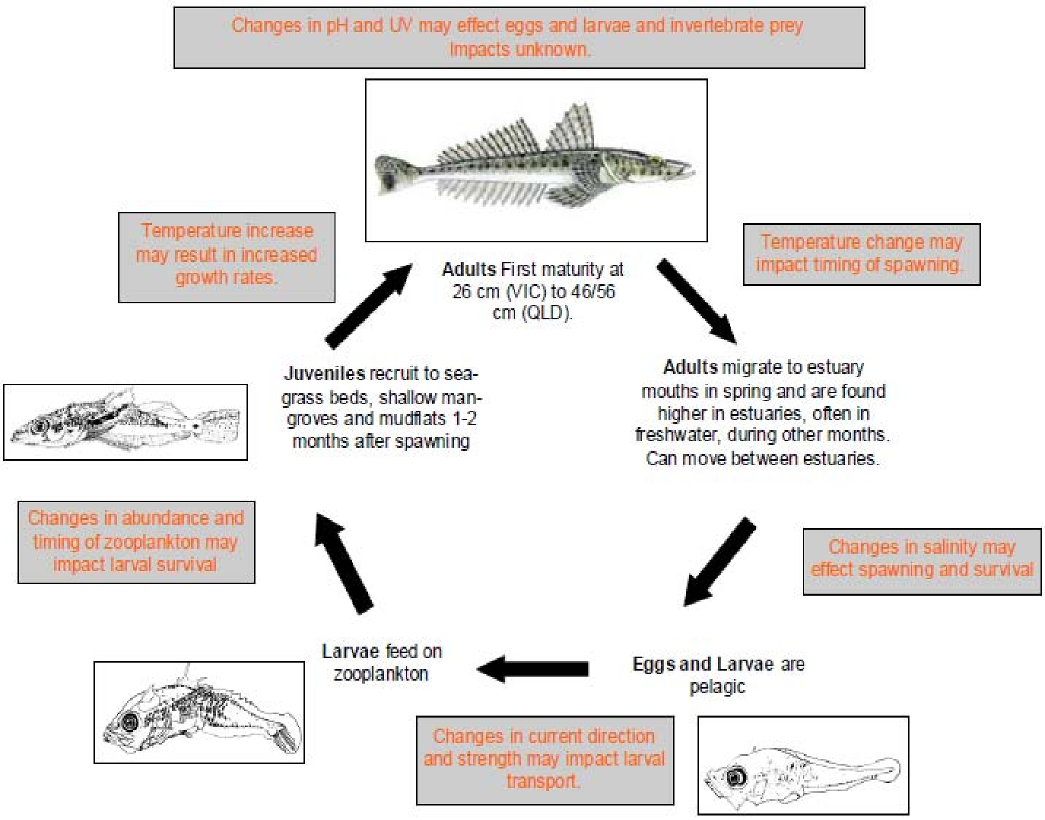

Figure 14.2. Generalised life cycle of the dusky flathead, *P. fuscus*, and the stages of potential environmental driver impacts (Source: Hutchinson, 2011).

Distribution, habitat and environmental preferences

The species is restricted to the east-coast of Australia from eastern Victoria to north Queensland (Figure 14.3). Dusky flathead occur in inshore coastal and estuarine environments usually associated with soft substrates, including mud, sand and seagrass. Movement studies show that dusky flathead are capable of moving long distances within an estuary (> 30km) and moving between estuaries (West 1993; Hindell 2008).

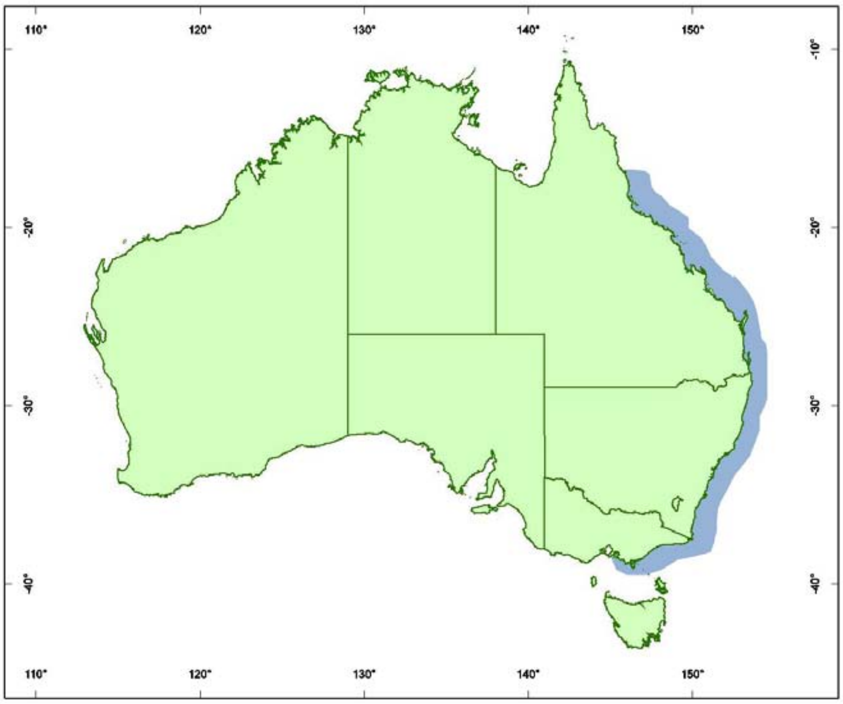

Figure 14.3. Distribution of dusky flathead.

Predators and prey

Flathead have been recorded in the diet of dolphins (Parra & Jedensjö 2009) and elasmobranchs (Walker 1989; Braccini et al. 2005; Treloar et al. 2007). As larvae they are likely to be taken by a wide range of teleosts. Dusky flatheads are primarily ambush predators (Dredge 1976; Kailola et al. 1993). The diet includes include fish, crustaceans, molluscs and polychaetes (Dredge 1976).

Recruitment

Recruitment processes of dusky flathead are not well understood. Larvae have been captured between September and May in estuaries and coastal waters of New South Wales (Gray and Miskiewicz 2000) and juveniles recruit to bays 1–2 months after spawning (Hindell 2008). Age structures of dusky flathead collected from commercial catch samples from four different estuaries of NSW collected over 2-3 years suggested that inter-annual recruitment can be highly variable (Gray et al., 2002).

Current impacts of climate change

There are no known current impacts of climate change on dusky flathead.

Sensitivity to change

- Rainfall has a positive correlation with dusky flathead catch and cpue
- Very little else is known of the sensitivity of dusky flathead to environmental variation

From a study in the Logan River, Queensland, the total catch of estuarine species in fisheries catch was been shown to be linked to the amount of freshwater runoff, particularly for flathead species (Loneragan and Bunn, 1999). A more recent study in different regions of the Queensland east coast found a significant positive correlation between annual coastal rainfall, the Southern Oscillation Index (SOI) and fisheries catch and cpue of flathead (Meynecke et al., 2006).

Resilience to change

- Given their latitudinal range they are likely to have a wide thermal tolerance, although this could be moderated if local stocks exist.

The latitudinal range of dusky flathead along almost the entire east covers a wide range in water temperatures and suggests a wide thermal tolerance for dusky flathead. It is not known, however, whether the east coast is comprised of a single stock or separate stocks. A study of dusky flathead commercial catches from four estuaries from different regions of NSW indicated differences in age, size and sex structures of the catch along with differences in mean-size-at-age suggesting the possibility of separate stocks (Gray et al, 2002). The fewer the number of stocks the more resilient dusky flathead are likely to be to changes in environmental conditions. Dusky flathead are considered to be generalist predators with a range of prey species making them resilient to changes in the availability of prey species.

Other

- Current harvest levels of dusky flathead could be nearing over-exploitation status.
- Recreational catch levels are a critical area for future assessment, as is the sensitivity of early life history stages to environmental changes.

Ecosystem level interactions

Ecosystem scale interactions are not well understood as with all species. Changes in the community structure of plankton have already been documented to have occurred in response to climate change. Jordan (1998) linked strong year class strength of southern sand flathead with peaks in the abundance of plankton. It is therefore likely that changes in the plankton will influence dusky flathead populations.

Additional (multiple) stressors

Fishing effort for dusky flathead is high in both NSW and Qld, particularly by the recreational sector. Although stock status in each state is considered to be 'sustainably fished', estimates of total mortality are considered to be high suggesting stocks may be subject to over-exploitation (Gray et al., 2002). Habitat impacts of climate change may affect all flathead species since they are benthic preferring soft substrates. Being an inshore and estuarine species dusky flathead will also be exposed to land-based impacts such as changes in water quality and salinity, and they are known to absorb a wide range of pollutants (Mondon et al., 2001).

Critical data gaps and level of uncertainty

One of the major information gaps for dusky flathead is knowledge of the sensitivity of each life history stage to changes in particular environmental variables such as temperature, salinity, pH, rainfall and extreme events. The larval and juvenile stages are potentially the most sensitive. Currently recreational harvest of dusky flathead is high and will only increase as human populations increase. Better estimates of recreational harvest levels are required to better manage the potential for cumulative impacts resulting in over-exploitation.

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15. Golden snapper, *Lutjanus johnii*

Authors: Thor Saunders and Emily Lawson

A golden snapper taken in the Northern Territory. Photo courtesy of Jenny Ovenden.

The fishery

Key points:

- The Northern Territory Coastal Line fishery is the only northern Australian fishery that takes significant quantities of golden snapper.
- Golden snapper are predominantly targeted by recreational fishers across their range.

Western Australia

A very small amount of golden snapper (2 t) was reported from Western Australia commercial fisheries in 2010. The recreational and Indigenous catch of this species in WA is unknown (Department of Fisheries 2011).

Northern Territory

The Coastal Line Fishery operates in the near-shore waters of the Northern Territory (NT) and primarily targets golden snapper (*Lutjanus johnii*) and black jewfish (*Protonibea diacanthus*) using hook and line gear. The fishery comprises commercial, recreational, charter and Indigenous sectors and there is considerable overlap in the range of species harvested. The Department of Resources (DoR), in consultation with the Coastal Line Fishery Management Advisory Committee (CLFMAC), is currently reviewing the management arrangements for the fishery to maintain the sustainable harvest of coastal fish species by all sectors. In 2010, 5 t of golden snapper was caught by the commercial sector (Figure 15.1). This species has been less targeted in recent years as operators have been able to get a better price for black jewfish (Northern Territory Government 2011).

The National Recreational and Indigenous Fishing Survey (NRIFS) conducted in 2000-01 indicated that of the ~600,000 fish harvested (i.e. caught and kept) by recreational fishers in the NT, the most common were snappers (23% of the total harvest). Golden snapper accounted for the largest portion of the snapper harvest being estimated at 68,000 fish (Coleman 2004). Fishing Tour Operators (FTOs) caught 15,382 golden snapper in 2010. Of these, 53% were released. Golden snapper harvest by the Indigenous sector is considered to be low due to the locations generally thought to be targeted by this sector (Northern Territory Government 2011).

Queensland

Golden snapper are harvested in both the Gulf of Carpentaria Inshore Fin Fish Fishery (GOCIFFF) and the East Coast Inshore Fin Fish Fishery (ECIFFF) however are not reported separately due to the very low (< 2 t) annual catch. Golden snapper are an important recreational species in Queensland, but they have not been reported as a separate species during recreational fishing surveys (DEEDI 2010a&b). Much of the targeting of golden snapper in Queensland has historically occurred in estuaries where juveniles are found, however in recent years increased targeting of larger adults on nearshore reefs and headlands has occurred due largely to the introduction of more efficient methods (eg. soft plastics) and advances in technology. The Indigenous catch of golden snapper in Queensland is unknown.

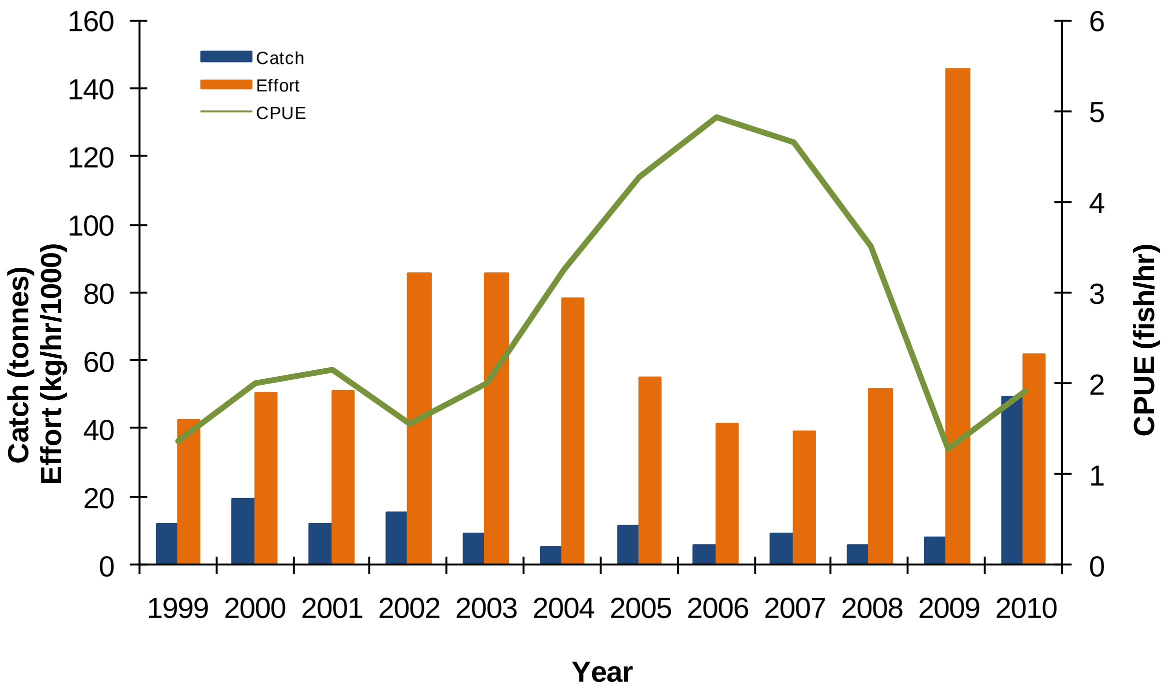

Figure 15.1. Annual catch, effort and CPUE for golden snapper in the NT Coastal Line Fishery between 1999-2010.

Life history

Key points:

- Golden snapper are slow growing and late maturing making them prone to overfishing.
- Juveniles are found in nearshore embayments and estuaries and remain in this habitat until maturity whereupon they move to nearshore reefs and headlands.

Life cycle age and growth

Golden snapper are gonochoristic (i.e. separate sexes throughout life) and can grow to at least 90 cm and 12.4 kg and live up to 20 years of age (Marriot and Cappo 2000). Despite growing reasonably quickly as juveniles (up to 30cm/year), growth slows substantially upon reaching maturity (Hay *et al.* 2005). Growth rate has also been shown to vary with latitude with quickest growth occurring at southern latitudes in the tropics (Starling and Cappo 1996). The onset of first maturity in golden snapper is also related to age, not size as faster growing southern QLD fish reach maturity at about the same age as slower growing northern QLD fish (Northern Territory Government unpublished data). Maturity for this species is reached at 63 cm or eight years of age for females and at 47cm or five years of age for males (Hay *et al.* 2005).

In the Northern Territory this species undergoes a prolonged spawning period from early September to late April (Hay *et al.* 2005). From the aquaculture experience with golden snapper, large females (72-75 cm TL) can spawn at least 2.83 million eggs over the course of four consecutive nights (Lim *et al.* 1985) suggesting that this species is quite fecund. There is also a moderate, positive, linear correlation between fish size and total egg production (Northern Territory Government unpublished data). Once hatched, golden snapper larvae are typical of most reef fishes and enter the nearshore environment to settle to benthic substrates. As larvae grow into juveniles they move to estuarine habitat where they remain until maturity whereupon they move to deeper, nearshore waters (Starling and Cappo 1996, Kiso and Mahyam 2003). Trapping surveys suggest that golden snapper are most active at night (Travers *et al.* 2006). Golden snapper have also been shown to suffer from barotrauma related mortality when they are caught from waters deeper than 15m (Northern Territory Government 2011).

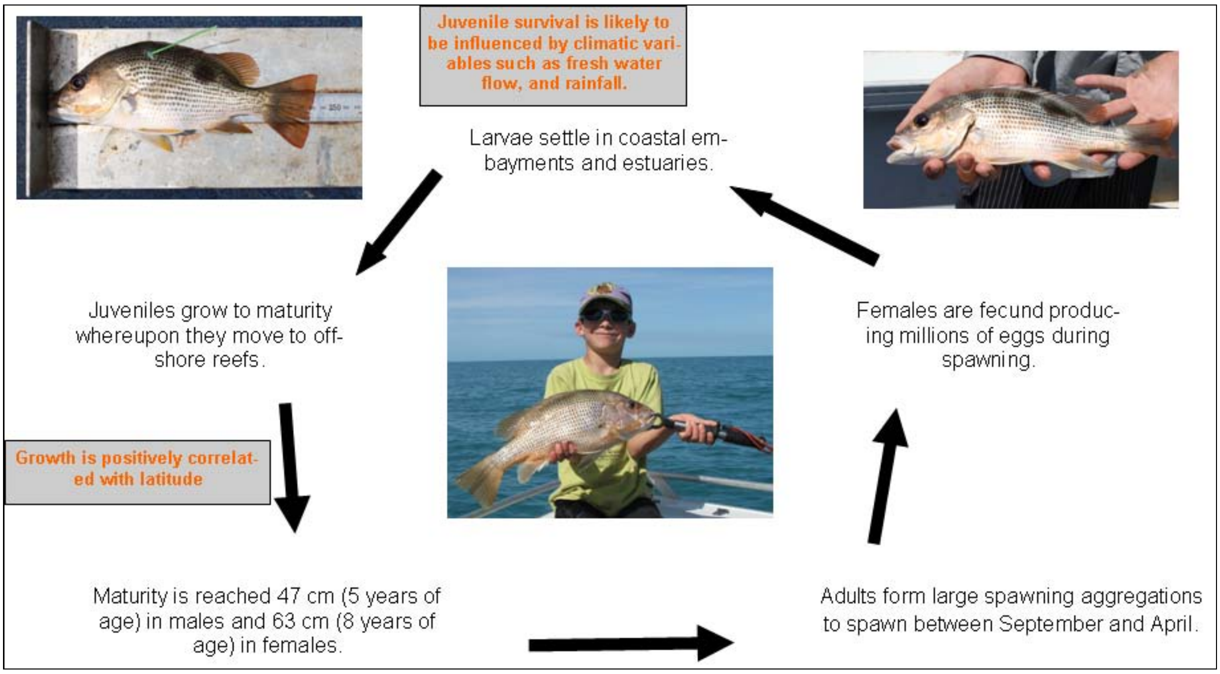

Figure 15.2. Summary of the life cycle of golden snapper, and the points of exposure to relevant climate change drivers.

Distribution, habitat and environmental preferences

Golden snapper have a wide geographic range throughout the Indo-West Pacific, inhabiting tropical inshore waters from East Africa to Fiji and northern Australia to just south of Japan (Hay *et al* 2005). In Australia they are distributed from the Kimberley region (~124°E) in north-western Australia, across northern Australia and extend down the east coast to at least 14°S (Anderson & Allen, 2001, Travers *et al* 2006, Hoese et al. 2007) and tagging studies have shown that this species is distributed to 24°S on the east coast (Bill Sawynok, unpublished data; Figure 15.3).

Their preferred habitat in deep and shallow water is around reefs, rocks, snags and pinnacles (Hay *et al* 2005, Travers *et al* 2010) but often move out onto adjacent sand areas possibly to feed (D. Welch pers. obs.). Juveniles are more regularly encountered in creek systems and mangroves, whereas the larger adult fish are encountered on coastal and nearshore reefs (Hay *et al.* 2005, Kiso and Mahyam 2003).

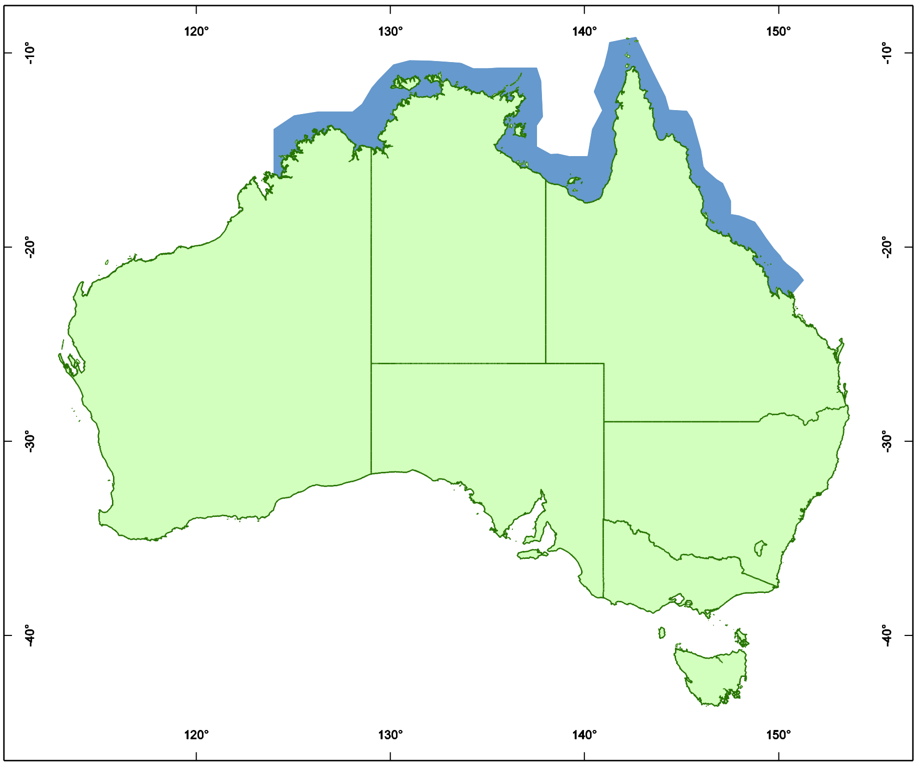

Figure 15.3. Australian distribution of golden snapper.

Predators and prey

Lutjanids are active predators feeding mainly at night on a variety of items, but fishes are dominant in the diet. Other common foods include crabs, shrimps, various other crustaceans, gastropods, cephalopods, and planktonic organisms (Randall *et al.* 1996, Travers *et al.* 2010). Juvenile golden snapper in estuaries feed on small crustaceans, and they shift their preference as size increases (Kiso and Mahyam 2003) and as adults prey mainly on fish and larger crustaceans (Druzhinin 1970). Larger fish and sharks are likely predators of golden snapper particularly as juveniles when they inhabit estuarine habitat.

Recruitment

Very little is known about the recruitment dynamics of golden snapper. Their larvae enter coastal embayments and estuaries so survival is likely to be influenced by ocean current strength and direction, river flow and rainfall and water temperature, salinity and pH.

Current impacts of climate change

Key points:

- There is recent evidence to suggest a southern expansion of this species occurring on the east coast.

Current impacts of climate change are largely unknown for this species. However, there may have been a recent southern expansion on the east coast of Australia. This evidence is based around tag recapture data over 10+ years that has indicated a higher abundance of this species a degree of latitude further south than when the study was initiated (Bill Sawynok, unpublished data).

Sensitivity to change

Key points:
- The sensitivity of golden snapper to environmental changes is unknown.

The sensitivity of golden snapper to environmental changes is unknown. Like other species with their entore life history occurring in the estuarine and nearshore environment, it is highly likely that golden snapper populations are strongly influenced by annual rainfall and river flow regimes.

Resilience to change

Although golden snapper occupy inshore habitats that are prone to high annual variability in environmental conditions, their resilience to climate-related changes are unknown.

Other

Key points:
- Information on the influence of changes in environmental variables on golden snapper life history stages is lacking.
- Better estimates of recreational harvest as well as the size characteriestics of the catch are needed to better quantify fishing impacts.

Ecosystem level interactions

The influence that fluctuations in golden snapper abundance on the ecosystem they inhabit are unknown. However, any impact is unlikely to be significant as there are a variety of other closely related species that utilise tropical coastal reefs that could readily take their place in this ecosystem.

Additional (multiple) stressors

Golden snapper are heavily targeted by recreational anglers near population centres. They are also slow growing, late maturing and suffer significant mortality from barotrauma when caught and released from deep water. These factors combined mean that any additional impacts from other factors such as climate change could result in significant population declines.

Critical data gaps and level of uncertainty

Golden snapper stock structure and correlations between environmental drivers and population dynamics are unknown. Currently management allows for high harvest rates of juvenile golden snapper across most of their range. Research that better estimates the level of this catch and the effect on population viability is required.

Acknowledgements

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16. Grey mackerel, *Scomberomorous semifasciatus*

Authors: Thor Saunders, David J. Welch and Emily Lawson

Grey mackerel, *Scomberomorus semifasciatus*, in its natural turbid water environment. Photo: David Welch.

The Fishery

Key points:

- Grey mackerel are an important commercial species across northern Australia, particularly in the Gulf of Carpentaria and western Northern Territory.
- Commercial catches since the mid 1990s has increased dramatically in all areas except Western Australia.
- The status of grey mackerel stocks in most Australian fisheries is considered 'uncertain'.

Also known as broad-barred mackerel, the fisheries targeting this species operate throughout tropical Australia. For a detailed description of these see Welch et al. (2009).

Western Australia

The Mackerel Fishery of Western Australia uses near-surface trolling gear from vessels in coastal areas to target Spanish mackerel (*Scomberomorus commerson*) around reefs, shoals and headlands while jig fishing is also used to capture grey mackerel, *Scomberomorus semifasciatus*. Grey mackerel have a total allowable commercial catch of 60 tonnes in each of three management areas (Kimberley, Pilbara, Gascoyne/West Coast), there are a limited number of permit holders able to access the fishery, all boats are required to have a Vessel Monitoring System and gear is limited to trolling or handlines. The northern shark fishery has also historically taken a small quantity of grey mackerel with pelagic gillnetting. The 2011 grey mackerel catch in the Mackerel Fishery was only 13.4 t, with grey mackerel landings from the Northern Shark Fishery much lower with an annual mean catch of 2.1 t in the period from 2006/2007 to 2008/2009, noting the Northern Shark Fishery has not operated since 2008/2009 (Fletcher and Santoro, 2012). The recreational, charter and indigenous take of grey mackerel in both fisheries is unknown but is likely to be low because of the isolated nature of this coastline.

Northern Territory

The commercial Offshore Net and Line Fishery (ONLF) targets blacktip sharks (*Carcharinus tilstoni* and *C. limbatus*) along with grey mackerel. The fishery operates from the high water mark to the boundary of the Australian Fishing Zone (AFZ), although most of the effort occurs within 12 nautical miles (nm) of the coast. The fishery is managed by limited entry (17 licences permitted to operate), individual transferable effort allocations and strict gear specifications that facilitate the selective targeting of smaller, more productive sharks species, with a lesser impact on larger, less productive shark species. The fishery is managed by the Northern Territory (NT) Fisheries Joint Authority (NTFJA), in accordance with the *NT Fisheries Act 1988*.

The reported commercial grey mackerel catch increased steadily from zero in 1983 to 766 tonnes in 2003 before declining to 401 tonnes in 2010. However, from 2003-2010 there has been substantial variation in the catch of this species and operators suggest that market forces drive variations in targeting between grey mackerel and blacktip sharks (Figure 15.1). At the point of first sale in 2010 the grey mackerel component of the fishery was valued at $1.38 million (Northern Territory Government, 2011).

The estimated retained recreational catch of grey mackerel caught every year in NT has been estimated to be approximately 8,400 fish (Crofts and de Lestang, 2004; Coleman, 2004). With an assumed average grey mackerel recreational harvest weight of 3kg (usually 1-5kg) this puts annual recreational harvest of approximately 25t from NT waters (Welch *et al.* 2009). Fishing Tour Operators (FTOs) do not record grey mackerel as a species in their logsheets. However, 1446 mackerels (other than Spanish mackerel) were caught by FTOs in 2010 which equates to approximately 4t using the 3kg/fish average (Northern Territory Government, 2011). The Indigenous catch of grey mackerel is unknown but is unlikely to be substantial since this species occupies reef habitat rarely targeted by this sector.

Queensland

Gulf of Carpentaria

The Gulf of Carpentaria Inshore Fin Fish Fishery (GOCIFFF) comprises inshore (N3) and offshore (N9) net components, commercial bait netting (N11) and recreational, Indigenous and charter boat fishing within the Queensland jurisdiction of the Gulf of Carpentaria (DEEDI 2011a). The N9 net fishery harvests almost all of the grey mackerel in the GOCIFFF and operates between 7 and 25 nm offshore. Smaller numbers of grey mackerel are harvested in the N3 fishery, which mainly targets barramundi. Both net fisheries are authorised to use set mesh nets but are restricted by limited entry, allowable net length and drop and mesh size (DEEDI 2011a).

Grey mackerel are a key target species in the GOCIFFF with catches having increased consistently since logbook reporting in 1990 (Figure 15.2). In 2010 the catch of grey mackerel reached 896 t, which is the highest level of catch ever reported. The status of grey mackerel stocks in the GOC were considered to be 'uncertain' in the most recent fishery assessment and new precautionary management arrangements were proposed to be introduced in 2012 (DEEDI, 2011a).

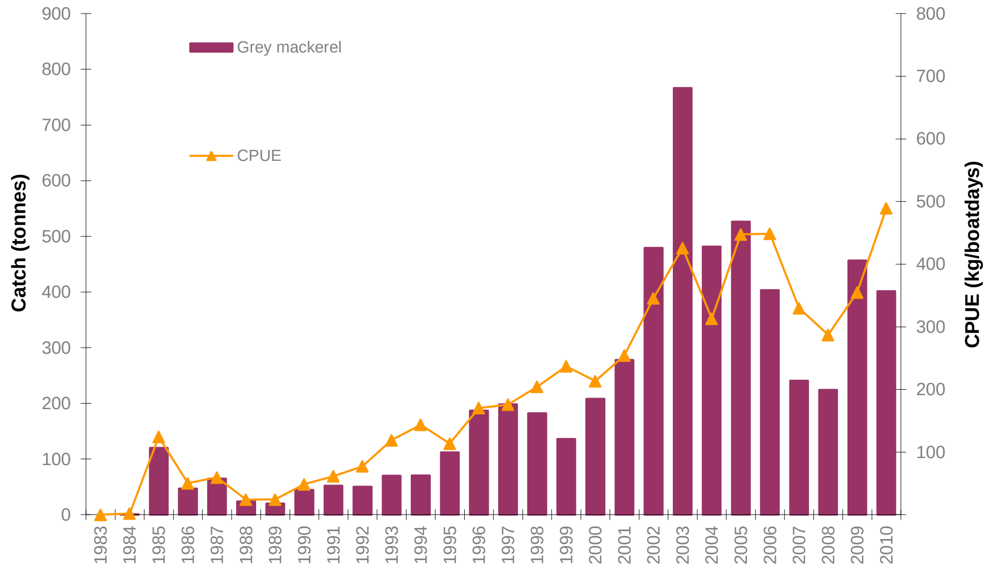

Figure 15.1. Catch and catch-per-unit-effort of grey mackerel in the NT Offshore Net and Line Fishery from 1983 to 2010.

Recreational fishers primarily use hook and line trolling methods to target grey mackerel. The most recent recreational survey conducted in the GOCIFFF during 2005 only reported on total catch so the amount of grey mackerel taken by this sector is unknown. Reported harvest of both 'grey mackerel' and 'mackerel-unspecified' by charter operators has been <1 t across the period 2004-2010 although in some years significant numbers are released (DEEDI 2011a). The Indigenous harvest of grey mackerel in the GOC is unknown but it is unlikely to be high.

East Coast

The East Coast Inshore Fin Fish Fishery (ECIFFF) comprises multi-gear commercial fisheries and recreational, charter and Indigenous fishing within all Queensland waters outside of the GOC (DEEDI 2011b). Nets represent >90% of the gear used to target grey mackerel. The number of nets permitted to be used, mesh size and length is dependent on the species being targeted and whether the fisher is operating in nearshore or offshore waters. In 2009 a total allowable commercial catch (TACC) of 250 tonnes was introduced for grey mackerel on the east coast. As a consequence the grey mackerel catch of 193t in 2009-10 was substantially lower than previous years. The stock status of grey mackerel is considered 'uncertain' due to insufficient data (DEEDI 2011b).

During the 2005 recreational fishing survey it was estimated that this sector caught 20 t of grey mackerel of which 5 t was released (DPIF 2008). Charter boats do not report grey mackerel as a separate species in their logbooks. In 2010, this group caught approximately 15 t of unspecified mackerel (DEEDI 2011b). There is currently no information on the Indigenous grey mackerel catch in this fishery.

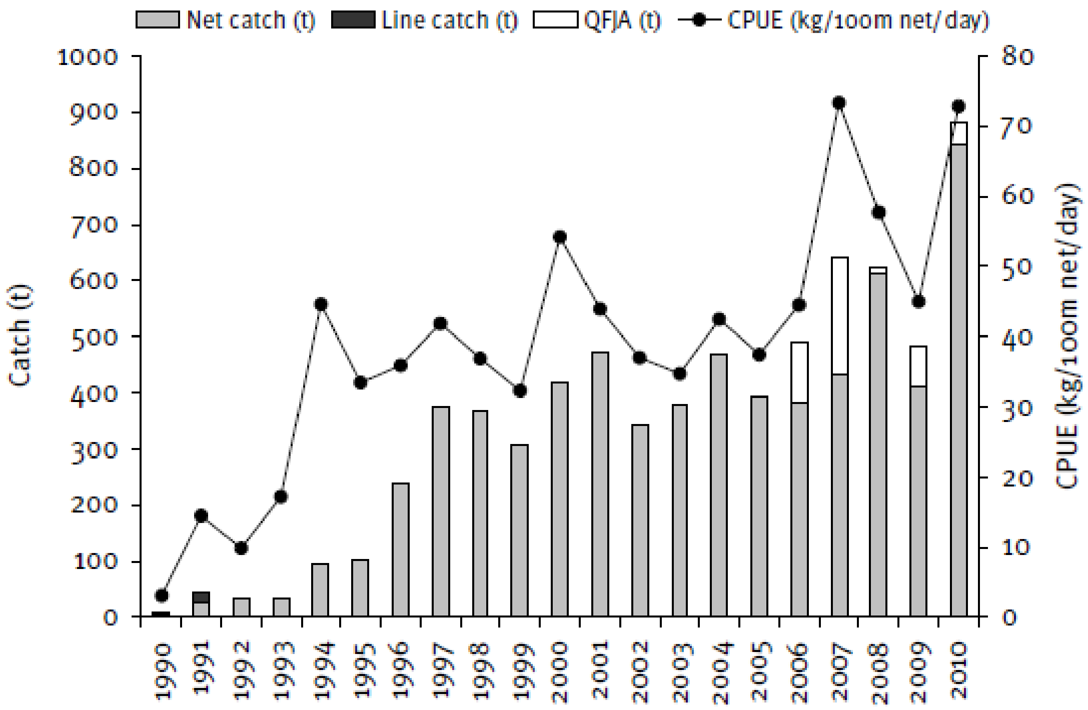

Figure 15.2. Commercial harvest (t) and catch per unit effort (CPUE) in of grey mackerel in the GOCIFFF 1990-2010 (Source: DEEDI, 2012).

Life History

Key points:

- Grey mackerel are a highly productive species with high fecundity, early maturity and quick growth.
- They exist as at least five separate stocks across northern Australia.
- Larval and juvenile phases are found in inshore coastal embayments and estuaries and consequently climatic factors such as rainfall and riverflow may influence recruitment.

Life cycle, age and growth

Grey mackerel, *Scomberomorus semifasciatus* (Macleay, 1884), is one of several species of mackerel (Family Scombridae). They have a rapid growth rate and can achieve a maximum weight of 10 kg and fork length of 120 cm, although the average size is between 2 and 5 kg (Crofts and de Lestang, 2004). The longevity of this species has been estimated to be up to 12 years of age, however, the majority of fish tend to be 2-4 years old. Estimates of 50 % maturity for male and female fish are 67 cm and 70 cm fork length respectively, and less than one year of age for both sexes (Welch *et al.*, 2009). Grey mackerel are highly fecund and produce more than 250,000 oocytes (eggs) per spawning (Cameron and Begg, 2002; Crofts and de Lestang, 2004). The primary spawning season runs between

August and December, however, there have been indications that some earlier spawning may be taking place in more northern regions such as north-western NT and the eastern Gulf of Carpentaria (Welch et al., 2009). Once hatched, larvae of this species move to the inner margins of coastal bays and also into estuaries (Jenkins *et al.*, 1985).

Distribution, habitat and environmental preferences

The species is endemic to the northern Australian region and ranges from Moreton Bay in southeast Queensland, north along the Queensland coast to the southern parts of Papua New Guinea, and then west across the top of northern Australia to Shark Bay on the mid-Western Australian coastline (Charters *et al.* 2010; Collette and Russo 1984) (Figure 15.4).

Grey mackerel is a large and highly mobile schooling fish and its known preferred habitat is inshore in the often turbid waters of tropical and sub-tropical areas where they feed on pelagic baitfish consisting of sardines and herrings, and so become seasonally available to fishing operations. At certain times of the year they can also be found around rocky headlands and inshore reefs (D. Welch, pers. obs.).

While this species is found on the continental shelf it is most abundant in shallow inshore waters, often schooling around rocky reefs and underwater structures. Grey mackerel can tolerate low salinity waters and thus can inhabit nearshore areas such as river mouths and estuaries (Jenkins *et al*. 1985; Welch *et al.* 2009). Larval and juvenile life history stages of grey mackerel are found inshore, often in estuarine environments (Jenkins *et al.* 1984).

The study by Welch *et al.* (2009) identified that a number of different stocks of grey mackerel exist across the northern coast of Australia based on differences in growth, genetics, parasites and otolith stable isotopes (Figure 15.5). There is a clear separation of broad scale fishery regions between the east coast and other areas. Evidence is also provided of smaller subdivisions occurring within these areas and of minor shared stocks within the Gulf of Carpentaria (see Charters *et al.* (2010) and Newman *et al.* (2010)) (Figure 15.5).

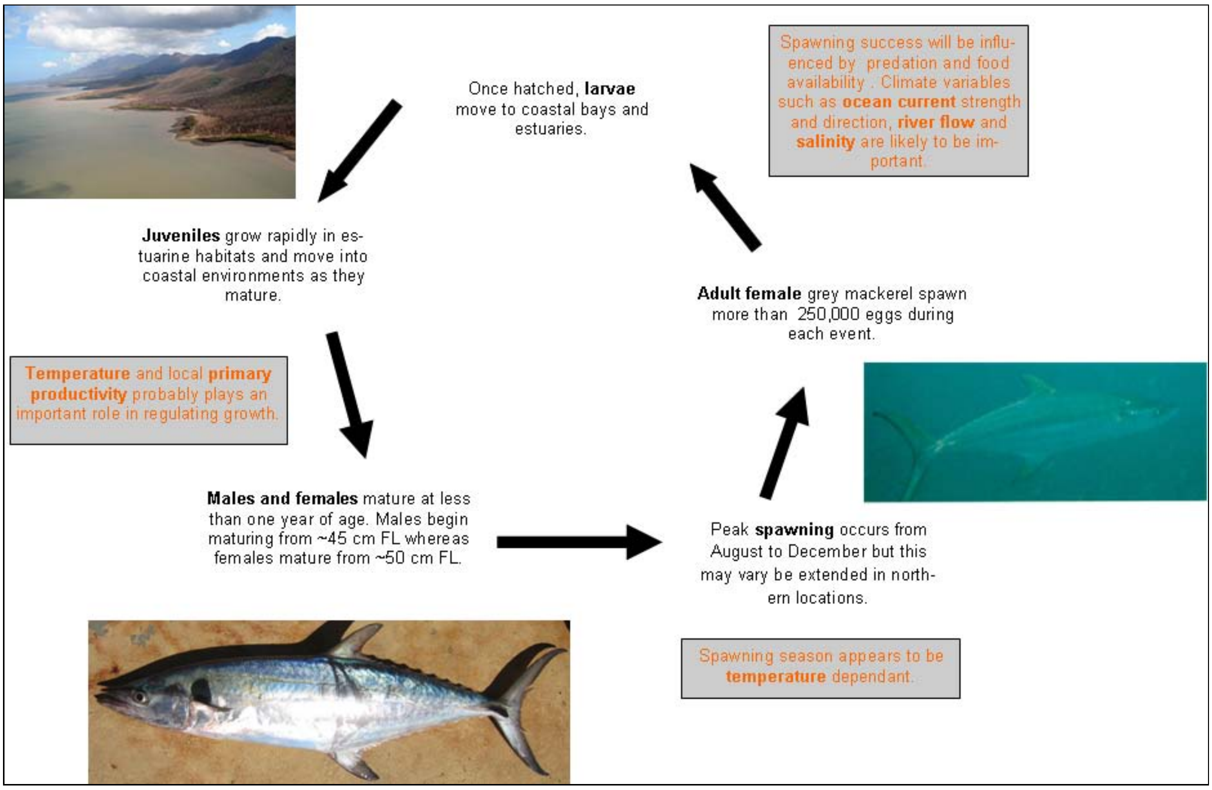

Figure 15.3. Summary of life cycle of grey mackerel and points of exposure to relevant climate change drivers. Images: D. Welch, GBRMPA.

Predators and prey

Adult grey mackerel feed primarily on pelagic baitfish such as sardines and herrings whereas larvae and juveniles feed almost exclusively on other larvae with prey sometimes reaching up to 89% of the mackerel's own body length (Jenkins *et al.* 1985; Welch *et al.* 2009).

Recruitment

Grey mackerel have a pelagic larval phase so recruitment success may be influenced by ocean current strength and direction. In addition, larvae and juveniles move into coastal embayments and estuaries so their survival is likely to be influenced by other climatic drivers such as water temperature, salinity and pH as well as rainfall and river flow.

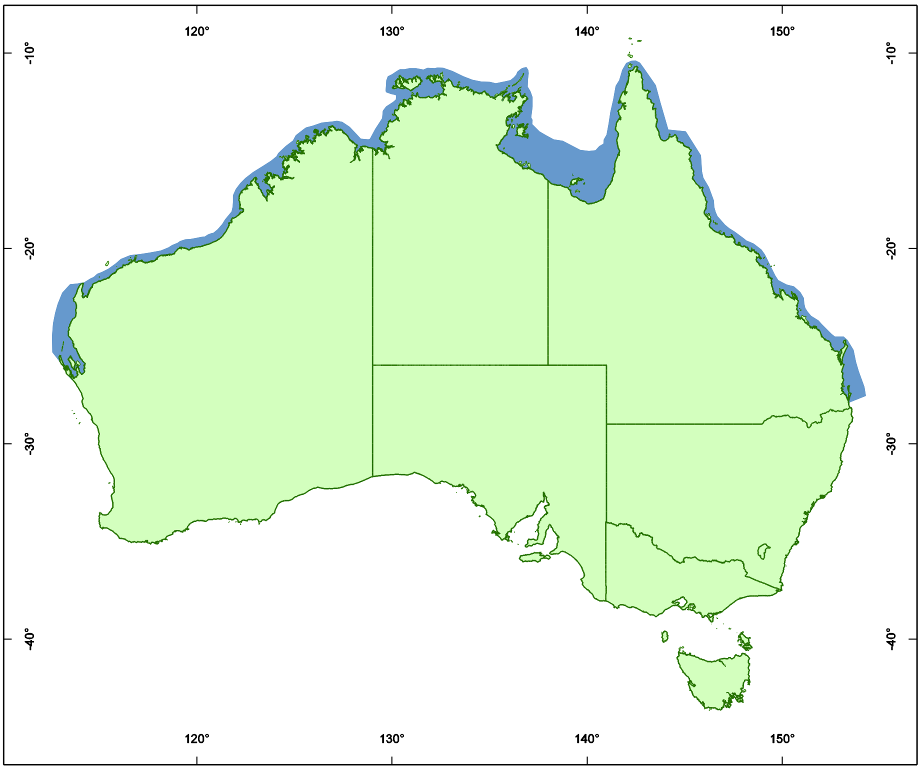

Figure 15.4. Australian distribution of grey mackerel.

Current impacts of climate change

Key points:

- Any current impacts of climate change on grey mackerel are unknown.

There are no known current climate change impacts on grey mackerel. When determining the impact of climate change on fisheries the stocks identified by Welch *et al.* (2009) should be considered separately.

Sensitivity to change

Key points:

- The sensitivity of grey mackerel to changes in environmental variables is unknown.
- Populations may be more impacted by climate change if mechanisms for stock structure inhibit large-scale migrations.
- Due to their estuarine and inshore habitats larval and juvenile phases are likely to be influenced by changes in a variety of climatic variables.

The sensitivity of grey mackerel to environmental variables is unknown. The sensitivity to climatic change by this species is likely to be related to the mechanisms driving their fine-scale stock structure. If they are structured by barriers they are unable to cross then regional changes in temperature and salinity could impact the abundance in these populations. However, if the mechanism that is driving the population structure does not prohibit large-scale movements then this species will be less sensitive to regional changes. Given that their larval and juvenile phases inhabit coastal embayments and estuaries these individuals may be more sensitive to changes in climatic variables such as ocean current strength and direction, water temperature, salinity, pH and rainfall and river flow

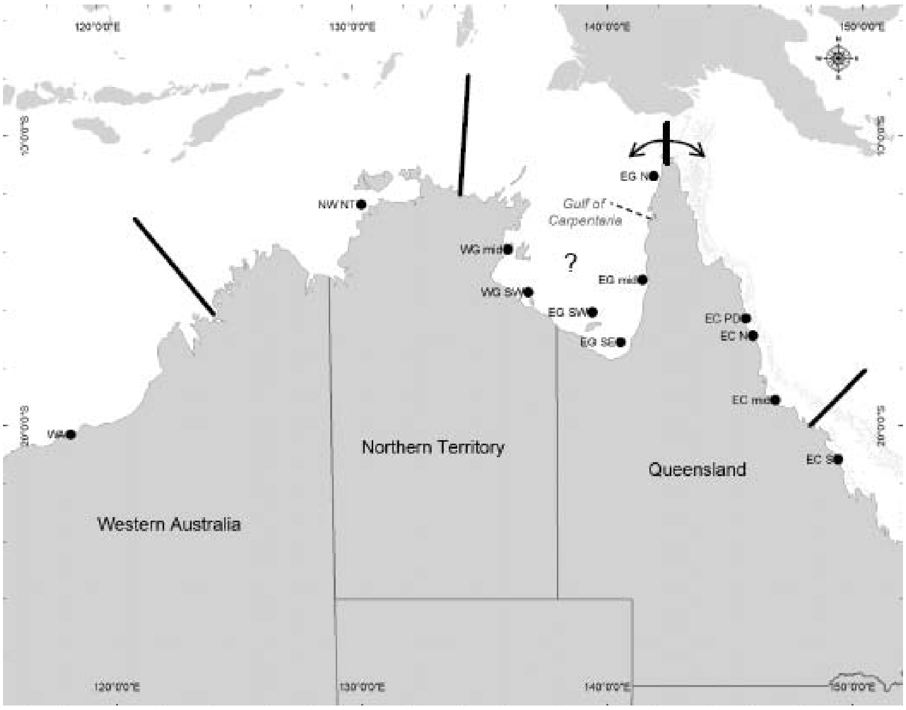

Figure 15.5. Map of northern Australia showing the approximate boundaries separating the grey mackerel stocks. Dotted lines within the Gulf of Carpentaria show where the stock division was evident and indicate the possibility of more localised stocks. Source: Welch *et al.,* 2009.

Resilience to change

Key points:

- Grey mackerel may be resilient to change in climatic variables because of their broad distribution and because they are highly productive.

Grey mackerel occur over a relatively wide latitudinal range and the species is therefore able to survive over a relatively wide temperature range. In addition, they can tolerate low salinity waters and thus can inhabit near shore areas such as river mouths and estuaries (Jenkins *et al.* 1985). They are also a highly productive species with rapid growth, early maturity and are highly fecund (Cameron and Begg, 2002; Welch et al., 2009).

Other

Key points:

- Grey mackerel are middle order predators in the food web so decreases in stocks will likely have an impact on larger predators that use them as a food source and small pelagic fish that they prey upon.
- Substantial harvest of this species over much of its range in Australia could result in substantial declines in individual populations if climate change causes reductions in stocks.
- The relationships between environmental variation and grey mackerel populations are unknown.

Ecosystem level interactions

Grey mackerel are second order predators in the tropical pelagic environment predating upon smaller pelagic fish species such as pilchards and herring while sharks, bill fish and Spanish mackerel would all predate upon grey mackerel.

Additional (multiple) stressors

Grey mackerel are harvested at significant levels from the east coast of Qld to the NT/WA border. Given their fine-scale stock structure any additional mortality associated with the impacts of climate change could cause significant localised depletions of populations in these areas.

Critical data gaps and level of uncertainty

It is unknown what specific impacts climatic factors have on the abundance of grey mackerel during all phases of their lifecycle.

Acknowledgements

We would like to thank Dr. Steve Newman for reviewing earlier drafts, which substantially improved the chapter.

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17. King threadfin, *Polydactylus macrochir*

Authors: David J. Welch and Bradley R. Moore

King threadfin, *Polydactylus macrochir*. Photo; Bradley Moore.

The fishery

Key points:

- King threadfin form the second most important species of northern Australia's inshore net fisheries after barramundi.
- King threadfin may be over-exploited in Western Australia and their status will be reviewed following a formal stock assessment.
- No formal stock assessment has been conducted in the Northern Territory or Queensland.
- Evidence of over-fishing has been observed in Queensland's Gulf of Carpentaria.

Commercial Fisheries

King threadfin form the second most important species in terms of catch and value to northern Australia's inshore net fisheries after barramundi, *Lates calcarifer*. Commercial fishers typically target threadfin using monofilament gill nets. Nets are typically set from dinghies/dories in shallow tidal waters and estuaries, or staked or anchored perpendicular to the shoreline below the high water mark. Although an important fisheries species in Australia assessment of king threadfins has been hampered in the past by a lack of good information (Welch et al., 2002, 2005) which has led to an increase in research in recent years.

Historically, threadfin caught from Western Australia and the Northern Territory has been sold to local and domestic markets as frozen fillets. Recently, interstate markets have become aware of the high quality of threadfin as a table fish and fishers are now beginning to sell whole threadfin fresh on ice to southern markets. In Queensland, the commercial threadfin catch is generally sold as frozen fillets and iced gilled and gutted fish. The majority of Queensland-caught fish are sold within the state, with smaller quantities traded on interstate markets.

In Western Australia, threadfins are targeted by commercial fishers operating in the Kimberley Gillnet and Barramundi Managed Fishery which covers a coastline from latitude 19° S all the way to the WA/NT border (Department of Fisheries, 2011). Reporting of commercial threadfin catch does not discriminate between king and blue threadfin so are collectively reported as 'threadfin'. The reported catch of threadfin from Western Australia's waters in 2010 was 83 t, which comprised 55 % of the total catch for the inshore gillnet fishery (Department of Fisheries, 2011). Most of this catch was taken from the Broome and Pilbara Coasts. Threadfin catch in Western Australia has varied between approximately 50 and 110 t from 1999 - 2010 (Figure 17.1). A minimum legal length of 45 cm TL is in effect for Western Australia. A preliminary assessment suggests that populations of *P. macrochir* in Western Australia may be over-exploited (Pember et al., 2005) though no formal stock assessment has been carried out. The data required for a formal stock assessment are currently being collected.

In the Northern Territory, king threadfin forms the bulk of the reported commercial threadfin catch, with approximately 296 tonnes harvested in 2010 (Figure 17.1) (Northern Territory Government, 2009). Changes in the distribution of commercial fishing effort have been observed over the last 15 years, with effort moving away from areas in which commercial fishing has been constrained or excluded (such and the Mary River Fish Management Zone, Kakadu National Park and the Adelaide and McArthur Rivers) to more remote areas, such as the western Gulf of Carpentaria and Arnhem Land. There is no minimum legal length requirement for *P. macrochir* in the Northern Territory. The status of populations in the Northern Territory is uncertain, with no formal stock assessments conducted in this jurisdiction.

The vast majority of the Queensland reported commercial catch of threadfins is taken by the Gulf of Carpentaria (GoC) (N3) and East Coast Inshore Net Fisheries (N1 and N2), although a small proportion is taken by hook and line across the state. The GOC N3 fishery operates from the coastline out to a distance of 7nm from the coast. Along with the Northern Territory the GoC has historically been the most important fishery region for king threadfin nationally (Figure 17.1). The bulk of catch from Queensland's GoC waters is generally taken from the south-eastern Gulf, near the population centres of Burketown and Karumba. In 2009, 289 tonnes of king threadfin were harvested from Queensland's GoC waters (DEEDI, 2009a). In 2009 there were 86 commercial fishing licences for the N3 fishery in the Gulf, of which approximately 80 were active. On Queensland's east coast, the bulk of the commercial catch is taken from around the Fitzroy River and the Narrows near the cities of Rockhampton and Gladstone. In 2009 approximately 135 tonnes of king threadfin were taken from Queensland's east coast waters (Figure 17.1) (DEEDI, 2009b).

A minimum legal length of 60 cm TL is in effect for capture of *P. macrochir* in both Queensland's Gulf and east coast waters. The status of *P. macrochir* populations in Queensland's Gulf of Carpentaria and east coast waters is uncertain, with no formal stock assessments conducted in these jurisdictions. However, evidence of overfishing has been observed in Queensland's Gulf waters, with significant age truncation and reductions in length and age at sex change compared with samples collected 10–15 years ago (Moore, 2012).

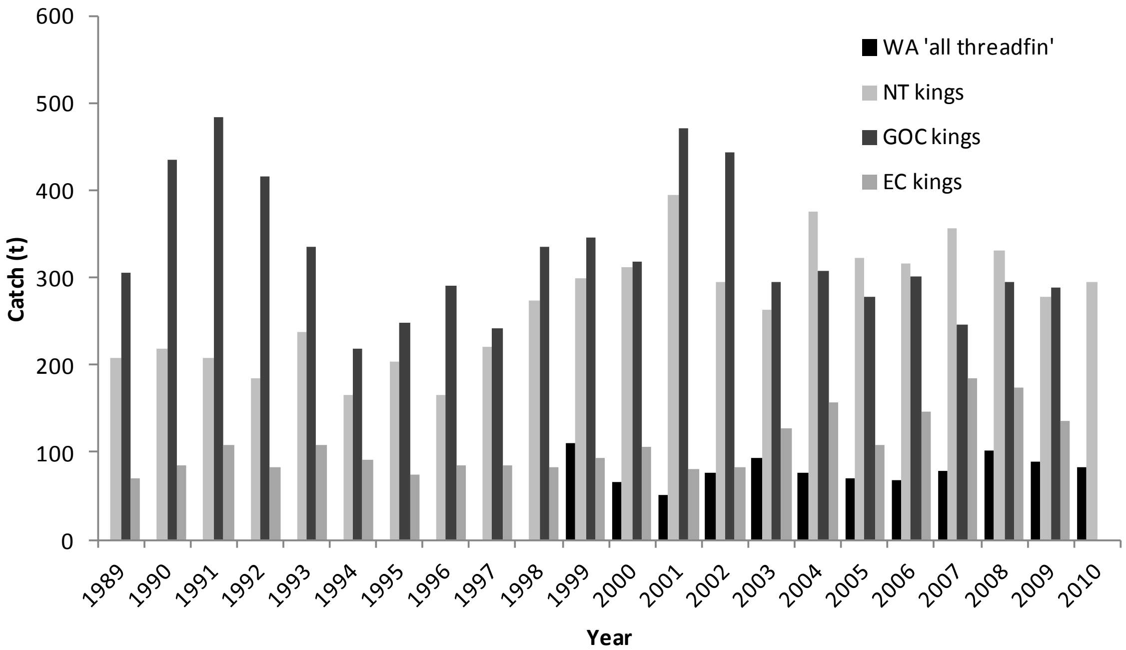

Figure 17.1. Commercial catch of king threadfin from for Western Australia (WA) which includes blue threadfin (1999 – 2010), Northern Territory (NT; 1989 – 2010), Queensland Gulf of Carpentaria (GOC; 1989 – 2009), and the Queensland east coast (EC; 1989 – 2009). Sources: Department of Fisheries, 2011; Northern Territory Government, 2011; DEEDI, 2011a, 2011b). (NB. From 2006 catch figures for the Queensland EC are reported by financial years, ie. 2006/07).

Recreational Fisheries

Recreational anglers catch king threadfin throughout the species' distribution, although fishing pressure is greatest on accessible coastlines and estuaries near population centres. Although historical information on catch and effort for the recreational fisheries across the various Australian states is limited, it is accepted that recreational fishing for threadfins has increased over the years, particularly with improved access to the more remote fishing areas in Queensland and the Northern Territory. In 2000-01 it was estimated that the total recreational catch of threadfins (all species combined) across Queensland, Western Australia and the Northern Territory was 185,000 individual fish with a further 118,000 released (Henry and Lyle, 2003).

Recreational fishing regulations vary across state jurisdictions, but are typically based on spatial closures, minimum legal size limits and bag limits. In addition to the minimum legal length requirements outlined above, a recreational daily bag limit of two fish exists in Western Australia, while a bag limit of 30 fish exists in the Northern Territory. A recreational bag limit of 5 fish is in effect for *P. macrochir* in Queensland's Gulf and east coast waters. Unlike other protandrous species, such as barramundi, there is no maximum legal size for king threadfin in any jurisdiction in Australia.

Life history

Key points:

- King threadfin across northern Australia consist of multiple stocks and exhibit highly variable demography.
- King threadfin change sex from male to female and the size and age at both maturity and sex change varies among regions.

Life cycle, age and growth

King threadfin are protandrous hermaphrodites meaning that they first mature as males and change sex during their life to become females (Pember et al., 2005). Peak spawning occurs around August to September for populations in Queensland's Gulf of Carpentaria, and between October and January for populations in Western Australia and on Queensland's east coast (Garrett, 1997; Pember et al., 2005; Moore et al., 2011). Spawning in east coast populations occurs at lower reaches of estuaries and associated coastal foreshores (Moore et al., 2011), and it is likely that the pelagic eggs require salinities near that of seawater for high survival rates (Rod Garrett pers. comm.). Little is known of the trigger for spawning, although there is some evidence to suggest it is related to water temperature and new moon phase (Pember et al., 2005).

A number of recent studies have revealed that *Polydactylus macrochir* exhibit considerable demographic variation across northern Australia, with variation in longevity, growth rates, length and age at maturity and length and age at sex change profiles over relatively small spatial scales (Pember et al., 2005; Moore et al., 2011; Moore et al., 2012). For example, 50% of *P. macrochir* at one location in Western Australia attain maturity at approximately 23 cm TL. In contrast, the length at 50% maturity for populations on the east coast of Queensland was estimated to be 85–92 cm TL (depending on the population sampled) (Moore et al, 2011), well above the current minimum legal limit of 60 cm TL in effect for these waters. In Western Australia 50% of *P. macrochir* change sex between 79 and 116 cm, depending on region (Pember, 2006), at around 4.3–6.7 years of age (Pember et al., 2005). On the east coast of Queensland, 50% of *P. macrochir* change sex at approximately 112–136 cm TL, when fish are between 7.5–9.3 years old (Moore et al., 2011).

Considerable variation in longevity has also been observed across northern Australia. In the Fitzroy River on the east coast of Queensland, *P. macrochir* is known to reach up to 160 cm TL and live for at least 22 years (Moore et al., 2011). In contrast, individuals in Western Australia rarely live for more than 10 years (Pember et al., 2005; Moore et al., 2012). In Queensland's Gulf of Carpentaria, fish over 8 years old in the commercial catch are now virtually non-existent, despite such individuals being historically recorded in this region (Kailola et al., 1993; Garrett, 1997). The observed geographic differences in demography likely reflect regional and local variation in environmental factors and fishing pressure.

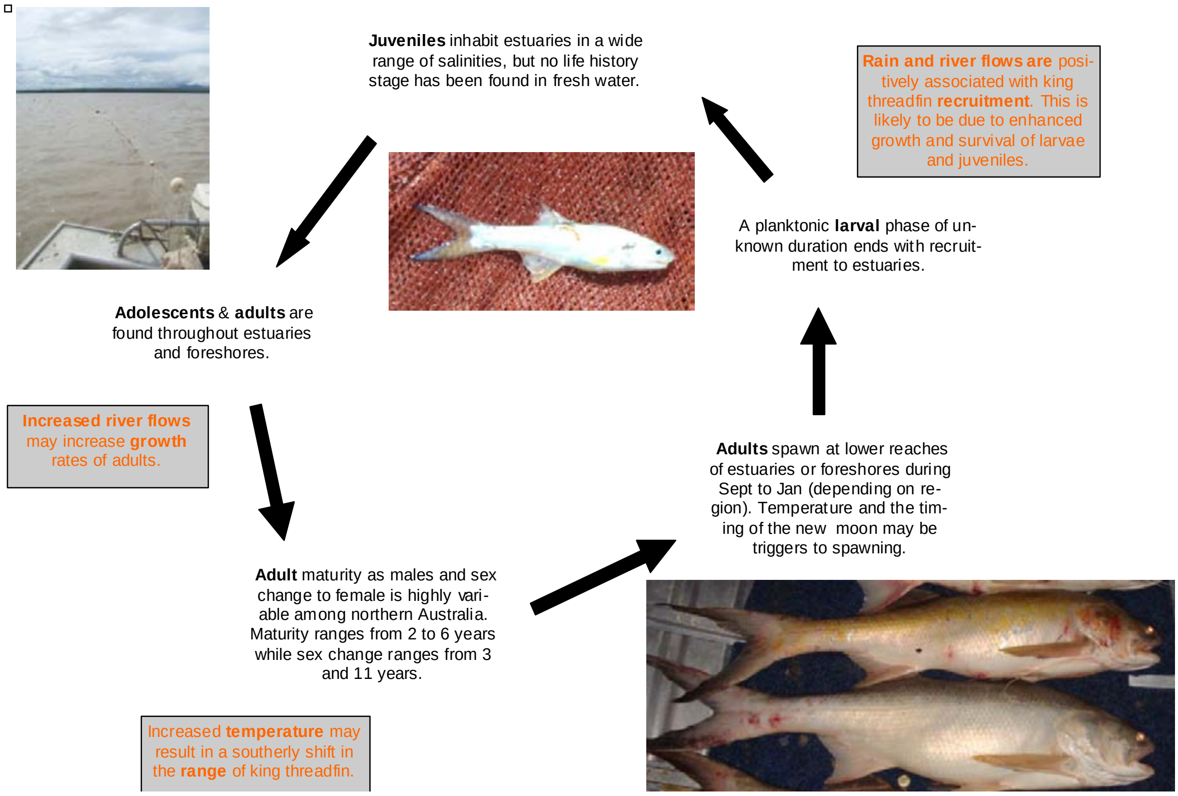

Figure 17.2. Generalised life cycle diagram for king threadfin and the stages of potential environmental driver impacts. Images: Brad Moore, Ian Halliday.

Distribution, habitat and environmental preferences

King threadfin are endemic to tropical and sub-tropical northern Australia, southern Papua New Guinea and Irian Jaya (Motomura et al., 2000; Motomura, 2004). In Australia, the species' distribution extends across tropical and sub-tropical northern Australia from the Ashburton River in Western Australia to the Brisbane region in southeast Queensland (Figure 17.3; Motomura, 2004). King threadfin inhabit estuaries and turbid coastal waters typically less than 5 m in depth (Blaber et al., 1995; Motomura et al., 2000). King threadfin do not use freshwater during any life history stage, although adults can be found upstream during winter, as saline waters intrude up the estuary (Ian Halliday pers. obs.). No king threadfin were recorded in temporary supralittoral pools in the Gulf of Carpentaria (Russell and Garrett, 1983), suggesting that king threadfin restrict their use of estuarine habitats to permanent water areas in the main channels and tributaries of creeks and rivers.

Young-of-the-year juveniles (30–100 mm FL) have been observed in north Queensland estuaries from December to May in salinities ranging from 2.0 to 37.8, suggesting a high degree of euryhalinity of these life history stages. Post-larval (i.e. juvenile and adult fish) are largely sedentary. This means that king threadfin tend to form discrete stocks over relatively small areas that are demographically, and often genetically, distinct and separate to adjacent fish (Newman et al., 2010; Welch et al., 2010; Moore et al, 2011; Horne et al., 2012). Conventional tagging data from the Australian Sport Fishing Association supports the notion of fine-scale stock structure and showed that only 4% individuals tagged in estuaries on the east coast of Queensland travelled outside of the estuaries in which they were tagged (Moore, 2012; Welch et al., 2010).

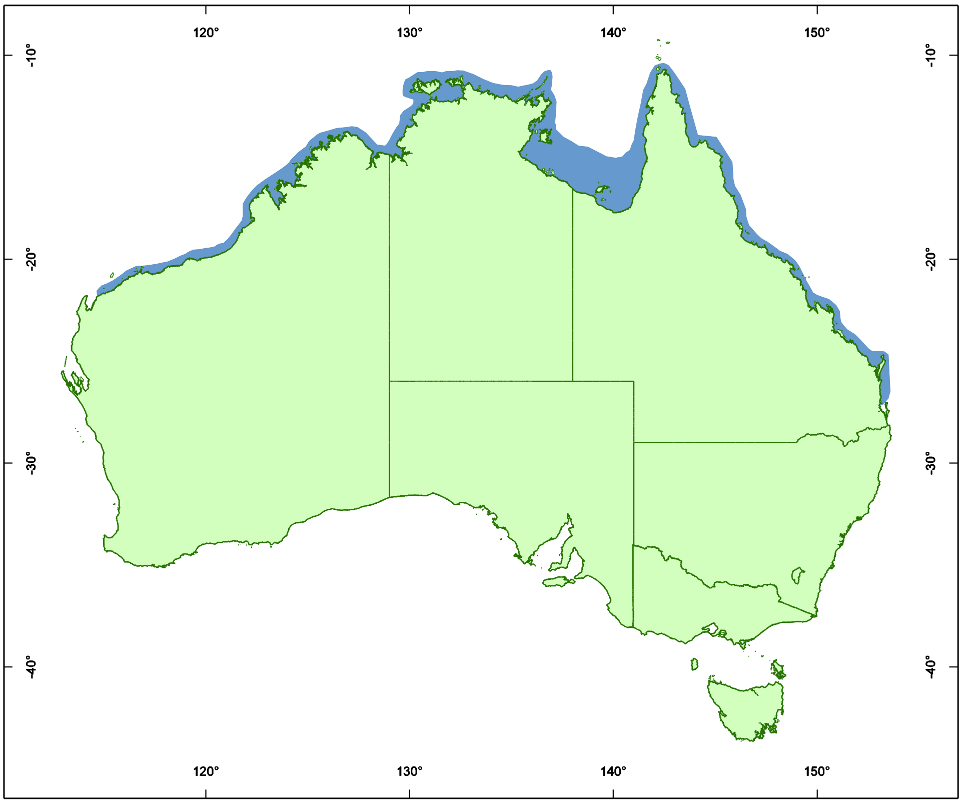

Figure 17.3. Distribution map for king threadfin.

Predators and prey

King threadfin form an important component of estuarine and coastal ecosystems, with dietary studies showing they are a significant predator of small fishes and crustaceans, in particular penaeid prawns (Brewer et al., 1995; Salini et al., 1998). Juvenile of *P. macrochir* are commonly observed in the stomachs of adult fish (B. Moore, pers. obs., Pember, 2006). Other large carnivorous fish, crocodiles and elasmobranchs prey on juvenile and adult fish (Kailola et al., 1993).

Recruitment

Little is known of the duration of the pelagic larval stage, or the sensory and swimming abilities of *P. macrochir* larvae. However, these life history stages appear to settle exclusively in estuaries (Halliday et al., 2008) or nearshore waters with estuarine characteristics (Pember, 2006), suggesting that they may be able to locate these systems, orientate themselves and take directed movements. Young-of-the-year juveniles (30–100 mm FL) have been observed in north Queensland estuaries from December to May.

Year-class strength of *P. macrochir* in Queensland estuaries is significantly and positively correlated with the timing and duration of spring and summer freshwater flow, which has been suggested to be due to greater food availability, an alteration of energy budgets in areas of decreased salinity, and/or a reduction in predation, with turbid waters enhancing juvenile survival rates (Halliday et al., 2008).

Current impacts of climate change

There are no known current impacts of climate change on king threadfin.

Sensitivity to change

Key points:

- Reduced rainfall may depress king threadfin recruitment and growth rates.
- Highly localised adult assemblages may be vulnerable to changes in local conditions.

King threadfin populations have been shown to be strongly influenced by rainfall and freshwater river flows (Halliday et al, 2008), although this relationship may vary regionally (Halliday et al., 2012). By examining age structures from commercial fishery catches over consecutive years they found that variation in year-class strength (as an indicator of the overall recruitment and survival of juvenile king threadfin) was consistently and positively correlated to the amount of freshwater flowing or coastal rainfall delivered into the Fitzroy River estuary in central Queensland during spring and summer. They hypothesised that this may be due to either increased biological productivity of the estuary system thereby increasing availability of food and enhancing growth, decreased salinity resulting in lowered energy budgets, or increased turbidity increasing juvenile survival through reduced predation (Halliday et al, 2008). The first hypothesis is supported by the documented evidence that major food sources of king threadfin, penaeid prawns and *Acetes*, show a significant positive correlation between catch and river flows (rainfall), however this relationship can vary regionally (Vance et al, 1985; Halliday and Robins, 2007; Meynecke and Lee, 2011).

Robins et al (2006) demonstrated that barramundi growth rates were significantly and positively correlated with freshwater flow rates (rainfall). Given the remarkable similarities between the life histories of the two species, notwithstanding the freshwater phase in barramundi (Halliday and Robins, 2007), it is very possible that king threadfin may also show increased growth rates in response to higher freshwater flows.

Resilience to change

Key points:

- Fine scale stock structure of king threadfin reduce the species resilience to localised changes that impact the stock.
- Demonstrated plasticity in life history changes make them more resilient to changed environmental conditions.

King threadfin form discrete stocks that may be associated with river systems and therefore show fine spatial scale separation (Welch et al, 2010). This disjunct in connectivity may make individual stocks less resilient to local changes resulting in localised population effects. Conversely, king threadfin stocks have been shown to exhibit wide variation in key population traits including growth and size-/age-at-maturity and sex change (Moore et al, 2010; Moore, 2012). This demonstrates phenotypic plasticity that suggests the flexibility of populations in responding to changing environmental conditions. Although fishing pressure may affect such parameters, these characteristics may also be determined by different temperature and primary productivity regimes experienced in the respective regions of each stock (Moore, 2012).

Other

Key points:

- Climate change impacts on key prey items such as penaeid prawns will have flow-on impacts to king threadfin.
- King threadfin are exposed to coastal perturbations and will be particularly sensitive to increased water extraction especially on the east coast where rainfall is projected to decrease.
- Nothing is known of the thermal and pH tolerances of early life history stages.

Ecosystem level interactions

King threadfin are an important estuarine and coastal predator of small fishes and penaeid prawns (Brewer et al., 1995; Salini et al., 1998). Factors affecting productivity of lower order food web animals will affect survival and growth, and therefore productivity, of king threadfin populations.

Additional (multiple) stressors

King threadfin are closely linked with estuarine and nearshore habitats throughout their life cycle. As such they are likely to be highly exposed to and impacted by land-based influences on water quality such as agriculture, farming and development. The life history characteristics and localised stock structure of king threadfin mean they are potentially sensitive to high levels of fishing. Localised depletion of stocks from cumulative impacts are a potential risk with evidence of such a case recently documented in the south eastern region of the Gulf of Carpentaria (Moore, 2012).

Additionally, as with barramundi, where is a strong link between river flow/rainfall and population productivity, the management of water resources by authorities may influence fisheries production of king threadfin. This will be particularly pertinent under future scenarios of lower rainfall where water allocations may be preferentially directed towards human use (Halliday and Robins, 2007).

Critical data gaps and level of uncertainty

There is good evidence that king threadfin populations are influenced by river flows and rainfall (Halliday et al., 2008). However, given the localisation of populations and the high level of uncertainty in downscaled climate predictions, future climate impacts on king threadfin are highly uncertain, especially the effects of increasing temperature and decreasing pH on early life history stages. Further uncertainty will be due to the effects of cumulative impacts and food web interactions.

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18. Mangrove jack, *Lutjanus argentimaculatus*

Authors: Richard J. Saunders and David J. Welch

The mangrove jack, *Lutjanus argentimaculatus*, is a member of the family Lutjanidae (the tropical snappers). The species has a wide distribution in the Indo-West Pacific from East Africa, the Red Sea and east to Samoa. It has also invaded the eastern Mediterranean via the Suez Canal. The species occurs throughout the northern half of Australia from the northern half of Western Australia throughout the Northern Territory and Queensland into central New South Wales, and sometimes as far south as Sydney. Juveniles and sub-adults are found in nearshore reefs and islands, coastal estuaries and freshwater streams. Adults tend to migrate further offshore to reefs and occur to depths of at least 180 m. The mangrove jack is a particularly significant species for recreational fishers throughout its Australian distribution particularly in nearshore environments.

The fisheries

- Mangrove jack are not a major target species for commercial fisheries in Australia but are captured as by-product species in reef line and trap fisheries and barramundi net fisheries.
- They are a significant target species for recreational fisheries throughout their northern Australian range particularly in riverine and coastal areas.

Western Australia

Mangrove jack is not a major component of any commercial fisheries in Western Australia with a total of 8 t landed across the state’s commercial fisheries in 2010 (Department of Fisheries, 2011). There are no estimates of recreational harvest for Western Australia. Traps are used to capture this species off the northern coast.

Northern Territory

Mangrove jack is not a significant part of any commercial fisheries in the Northern Territory. They are, however, recognised as a by-product species of recreational fishers targeting barramundi. A small number are taken in the Aquarium Fishing / Display fishery: 281 individuals in 2010 (Northern Territory Government, 2011). There are no estimates of the recreational harvest for the Northern Territory.

Queensland

Mangrove jack is captured as by-product species in the Queensland Coral Reef Fin Fish Fishery. No data on numbers or catch weight is published for this fishery however it is likely to be insignificant (DEEDI, 2011a). The species is also landed as part of the East Coast Inshore Fin Fish Fishery (ECIFF) which has both net and line sectors but is < 1% of the total catch by weight (Simpfendorfer et al., 2007). Catch in the ECIFF has been 2, 7, 12 and 5 t for the 2006/07 – 2009/10 financial years respectively (DEEDI, 2011b). Estimates of recreational harvest by number in Queensland are 117,000, 107,000 and 77,000 for the years 1999, 2002 and 2005 respectively with similar numbers recorded as released (McInnes, 2008). There may be an underreporting of the total harvest in the commercial logbook scheme as this species is often reported in generic categories such as mixed reef fish. This species is also caught incidentally in fish trawls in the Gulf of Carpentaria.

Life history

- Mangrove jack occupies freshwater, estuaries and nearshore areas as juveniles and move offshore as adults.
- They mature late as old as 10 years or more.
- They have a very broad distribution across tropical Australia and down into temperate waters on a seasonal basis.

Life cycle, age and growth

The life history of the mangrove jack has been well investigated, particularly in Queensland (see Russell et al. 2003). This research confirmed that mangrove jack has a complex life history with juveniles and sub-adults occurring in inshore coastal and estuarine systems, and freshwater environments, with mature adults found further offshore areas (Russell et al., 2003; Russell & McDougall, 2005). Mangrove jack are a long-lived species. In freshwater and estuarine environments age estimates ranged in age from 0 to 11 years and in offshore environments from 2 to 39 years (Russell et al., 2003).

The species is gonochoristic, with mature fish primarily found in offshore environments. Males mature at a smaller size than females with a length at 50% maturity of 47 cm FL and 53 cm FL for females and can be 10 years old or more (Russell et al., 2003). Gonad development occurs between October and March with a peak in gonadosomatic index occurring in December suggesting a Spring-Summer spawning season in northern Queensland (Russell & McDougall, 2008). However, there is evidence in lower latitudes that the species spawns throughout the year (Anderson & Allen, 2001). Mangrove jack also form spawning aggregations in some parts of the world (eg. Palau: Johannes, 1978). In Australian waters spawning sites and behaviour are not well known although based on the distribution of mature fish it is assumed that spawning occurs offshore.

They are highly fecund broadcast spawners and larvae become free swimming by the time they reach 12 mm TL (Doi et al., 1998; Russell and McDougall, 2008). Recruitment of juveniles to inshore riverine environments occurs at 20-30 mm from February (Russell et al. 2003). Mangrove jack leave the estuarine and inshore environments between approximately 325 and 430 mm CFL at ages between three and eleven years (Russell et al. 2003).

Age and growth of mangrove jack has been extensively described by Russell et al. (2003). This study encompassed the distribution of the species within Australia but the data is best for the Queensland east coast. Some evidence for higher somatic growth rate of juveniles when able to utilise freshwater systems was identified. Furthermore, growth did vary between regions with faster growth evident in fish from northern New South Wales and southern Queensland than further north. von Bertalanffy growth parameters are provide in Table 18.1 for the Queensland East Coast.

Table 18.1. Von Bertalanffy growth parameters for Queensland east coast adapted from Russell et al. (2003). Population genetic studies across northern Australia indicate a high level of gene flow and that they are likely to belong to the same genetic stock (Ovenden & Street 2003).

Location	Sex	L_∞ (mm)	K	t_o (years)
North of Cooktown	♀	632.7	0.164	1.77
	♂	616.2		
Ingham to Cooktown	♀	673.7	0.136	1.051
	♂	644.2		2.364
Queensland East Coast combined	♀	681.2	0.126	2.893
	♂	650.6		1.761

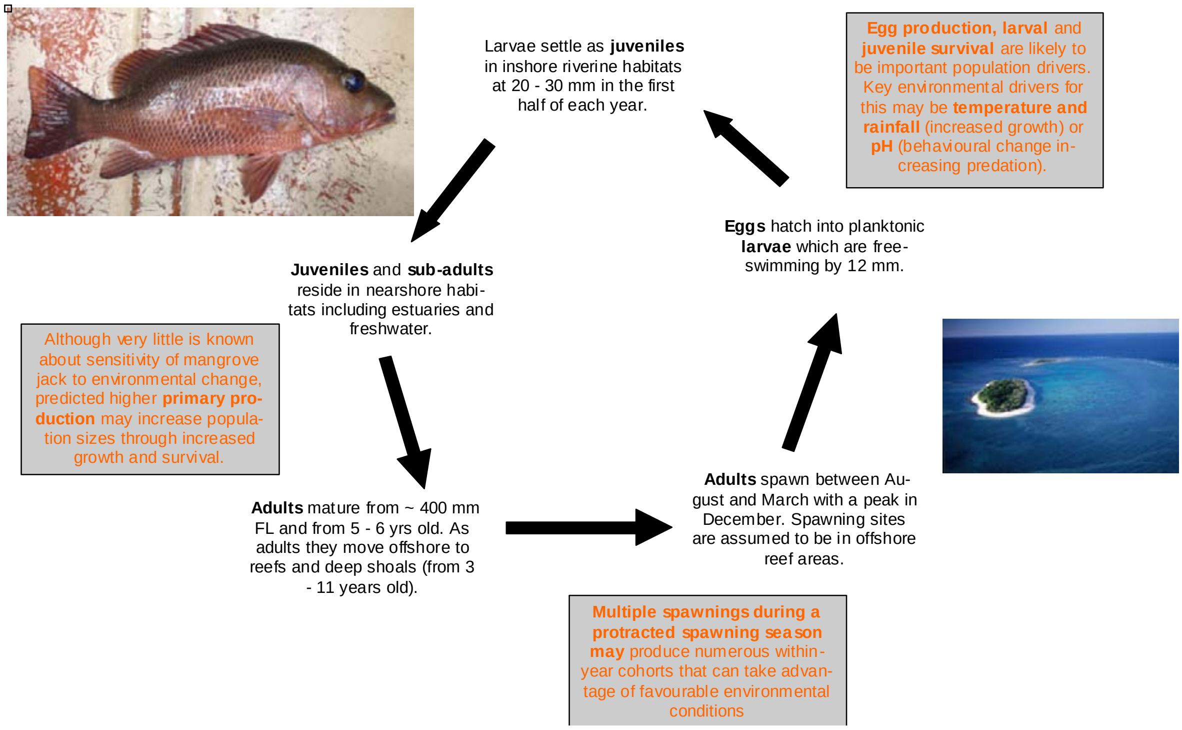

Figure 18.1. Generalised life cycle of the mangrove jack, *L. argentimaculatus*, and the stages of potential environmental driver impacts.

Distribution, habitat and environmental preferences

Mangrove jack occur throughout the Indo-West Pacific from Australia to southern Japan, west to East Africa and the Red Sea (Allen 1985). In Australia, it is widespread ranging from central New South Wales on the east coast to Geraldton on the west coast (Figure 18.2). It is, however, most common in the northern parts of its Australian range. The species utilises a wide range of habitats throughout its life cycle. It is commonly associated with reef environments in shallow near-shore waters to depths of at least 180 m (Kailola et al. 1993).

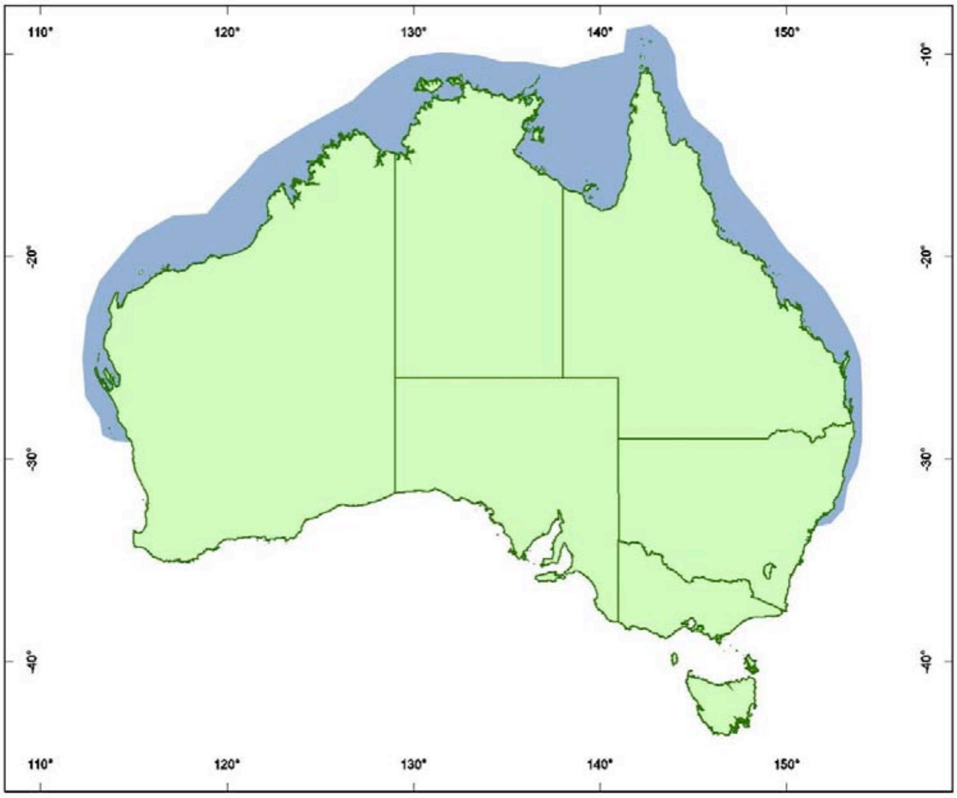

Figure 18.2. The Australian distribution of mangrove jack. This represents their usual occurrence and sometimes they can be found outside this range.

Predators and prey

Mangrove jack are carnivorous. As juveniles in creeks, mangrove jack take fish (Robertson & Duke, 1990) but crabs, particularly *Sesarma* sp., are also a significant component of the juvenile and sub-adult diet (Sheaves & Molony, 2000). As adults' mangrove jack diet is poorly documented however as a large reef predator is likely to comprise largely of a variety of fish species.

Recruitment

Young of the year mangrove jack recruit seasonally to estuaries and rivers in the first half of each year (Russell et al. 2003). Significant inter-annual recruitment variation occurs and this can occur at a large spatial scale. For example, recruitment in 2000 was generally poor for mangrove jack in several large river systems in far north Queensland across a large geographical range (Russell et al. 2000). The reasons for such inter annual variations are unknown.

Current impacts of climate change

Currently, there are no documented impacts of climate change available. A study in the US on the gray snapper, *Lutjanus griseus*, found that population sizes had increased over a 30 year period and was correlated with increasing water temperatures in estuaries. This was suspected to be because of increasingly higher winter water temperature minimums due to changes in the North Atlantic Oscillation. They postulated that the lower winter temperatures provide favourable over-wintering conditions for juvenile fish thereby enhancing recruitment (Tolan and Fisher, 2009).

Sensitivity to change

- The sensitivity of mangrove jack to environmental change is unknown.

There are no documented studies on the sensitivity of mangrove jack to changes in environmental variables. One study using an ecosystem modelling approach found that over the next 50 years under plausible climate change scenarios (IPCC A2 emission scenario), primary production across northern Australia will increase. This was due to increases in nutrients and also temperature. They predicted that this would result in increases in fisheries catches by 10 % in NW Western Australia and up to 60 % in parts of the east coast region (Brown et al., 2009). The results of this study suggest that mangrove jack catches under future climate change is likely to increase, however, these predictions are not species-specific and so it is impossible to say what the future impact on mangrove jack would be.

Resilience to change

- Mangrove jack use a remarkable array of habitats and environmental conditions during their lifetime, however they have life history characteristics that suggest their capacity to recover from population impacts is poor.

Mangrove jack occupy many different habitat types across a wide range of latitudes and therefore appear resilient to a range of environmental conditions. Furthermore, they are reported to be a single genetic stock across the entire northern Australian range (Ovenden and Street, 2003) meaning they are more resilient to localised changes.

Other

- Mangrove jack are likely to be highly exposed to climate change impacts during their pre-adult stage since they occupy estuarine areas and associated habitats.
- Although heavily targeted by recreational fishers, estimates of the harvest levels are unknown and are a high priority for future research.

Ecosystem level interactions

Climate change is predicted to have potentially profound effects on estuarine and coastal environments through a variety of physical, biological and ecological mechanisms (Sheaves et al., 2007). The complexities of the interaction of changes and their subsequent impacts on individual species makes sensible and accurate predictions challenging.

Additional (multiple) stressors

Mangrove jack represent a significant target species for recreational fisheries across all of northern Australia and increasing human populations are likely to increase this targeting. Mangrove jack rely on estuarine habitats for their juvenile and sub-adult life history stages and as such are likely to be impacted. Anthropogenic influences that effect estuarine environments (eg. water quality) are likely to affect mangrove jack populations however no data are available to determine the key variables of influence nor the extent or direction of their potential impact. Gehrke et al (2011) concluded that fisheries in estuarine areas will become increasingly vulnerable to climate change, particularly temperature increases, where catchments have been modified by riparian clearing, agriculture, forestry or mining.

Critical data gaps and level of uncertainty

Estimates of recreational harvest are very poorly known for mangrove jack despite being a major recreational fisheries target species. Better estimation should be a key future research priority. The sensitivity of mangrove jack to environmental influences, particularly those relevant to estuarine habitats, should be investigated. Key variables of interest include temperature, rainfall, sea level rise, acidification and extreme events (Sheaves et al., 2007).

Acknowledgements

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19. Red Emperor, *Lutjanus sebae*

Authors: David J. Welch and Richard J. Saunders

An adult red emeperor from the Great Barrier Reef. Photo: Mick de Rooy.

The red emperor, *Lutjanus sebae*, is a member of the family Lutjanidae. The species has a wide distribution from east Africa to the western Pacific. It occurs in the northern half of Australia from mid Western Australia, across the Northern Territory and down the Queensland coast, primarily in reef habitats. The red emperor is a significant species for both recreational and commercial fishers throughout its Australian distribution.

The fisheries

- Commercial catches are taken in Western Australia, Northern Territory and Queensland.
- The majority of the Australian catch is by commercial and recreational fishers in the Queensland Coral Reef Fin Fish Fishery and in north-western Western Australia.
- Recreational catch levels of red emperor are poorly understood in all northern Australian fishery jurisdictions.

Western Australia

Red emperor is an important commercial and recreational species in Western Australia (Department of Fisheries, 2011). The species is taken as part of the Gascoyne Demersal Scale Fishery, the Pilbara Demersal Scalefish Fisheries and the North Coast Demersal Fishery with each fishery comprising recreational, commercial and charter fishing operations. In the Gascoyne Demersal Fishery red emperor are a non-target species and catches have ranged over the past 10 years from 9.8 t (2009/10) to 24.4 t (2000/01). In the North Coast Demersal Fishery catches are more significant, with red emperor being the second most important species by weight within this fishery. Total catch taken in both the Pilbara and Kimberley regions in 2010 was 308 t (Department of Fisheries, 2011).

The recreational catch was estimated for the area between Onslow and Broome in 2002 (Newman et al., 2004). In boat ramp surveys *Lutjanus sebae* ranked in the top ten fish kept in only one of the seven districts considered with an estimated 355 fish kept in the Point Samson district. By weight, however, the species was more significant with catches in top ten by weight in four of the seven districts; Dampier at 2,956 kg, Karratha at 190 kg, Point Samson at 1,309 kg and Port Hedland with 937 kg. The species did not feature in the catch of shore based fishers in the region (Newman et al., 2004). In 2010 the charter catch of red emperor in Western Australia was 12.7 t. Stocks in Western Australia are considered to be sustainably fished at current levels of effort (Department of Fisheries, 2011).

Northern Territory

Red emperor are a major part of the by-product catch in the Northern Territory Demersal fishery which mainly targets gold band snappers (*Pristipomoides* spp.), saddletail snapper (*Lutjanus malabaricus*) and crimson snapper (*L. erythropterus*) using drop lines and traps. Total commercial catch in this fishery was 208 t in 2010, down from 505 t in 2009. Red emperor contributed 3.5% (7.3 t) of the total catch in 2010. Red emperor is also taken as part of the Timor Reef Fishery which uses baited traps and vertical lines (NT Government, 2011). The only recreational estimate of red emperor catch was in 2002 by Henry and Lyle (2003) who estimated that 9.5 t were kept. Catches of red emperor in the Northern Territory recreational and Fishing Tour Operator sectors is currently considered to be negligible.

Queensland

Red emperor is captured as part of the Queensland east coast Coral Reef Fin Fish Fishery. The fishery is managed with spatial and temporal closures, size limits and gear restrictions. In 2003/04, a commercial catch quota was introduced for Coral Trout, Red Throat Emperor and “Other Species”. Red emperor catch is included in the “Other Species” with the quota set at 956 t (DEEDI, 2011) and their minimum legal size limit was increased from 45 cm TL to 55 cm TL. Commercial catch of red emperor was estimated to be 104 t in the year prior to the introduction of quota (2003/04). In 2004/05 catch was 26 t and has steadily increased each year since and was estimated to be 60 t in 2009-10 (DEEDI, 2011).

The best estimates for the recreational catch in Queensland are from the DEEDI RFISH diary programs. The RFISH surveys estimate the retained catch of red emperor in 2002 was 88,000 fish and in 2005 there were 52,000 retained. If we assume an average weight of 4.45 kg for retained red emperor (as in Henry and Lyle, 2003), this equates to approximately 392 t in 2002 and 231 t in 2005. The reduction in catch over these survey periods corresponds with the timing of the increase in the MLS to 55 cm TL introduced during 2003.

The stock status is considered “uncertain” as there is limited understanding of the recreational catch and age structure of the population (DEEDI 2011).

Life history

- Red emperor is vulnerable to over-exploitation having a low production potential; long-lived, slow growing, low natural mortality, large size and age at maturity.
- Juveniles and sub-adults frequent inshore reefs and islands while adults prefer shoals and inter-reef areas usually > 15 m depth.
- Red emperor has a protracted spawning season throughout their range.

Life cycle, age and growth

A series of recent publications on life history of red emperor based primarily in Western Australia have improved the understanding of the species considerably. Red emperor are gonochoristic but there is considerable growth difference between the sexes with males generally attaining a larger size than females (Newman & Dunk, 2002). Growth has been studied in both north-western Western Australia and Queensland (Table 19.1). Red emperor are capable of reaching sizes of approximately 100 cm (Allen, 1985) and can attain weights up to at least 15 kg however their growth rates are relatively slow (Table 19.1) and their asymptotic length is reached between 10 and 15 years of age, although growth can continue throughout their life (Newman and Dunk, 2002). The species is relatively long lived with the oldest reported specimen from the Great Barrier Reef being 32 years, one specimen from New Caledonia was 35 years and the oldest reported was from deep water off north-west Western Australia at 40 years (Loubens, 1980; Newman et al. 2010). The age-at-maturity for both sexes has been estimated to be approximately 8 years (Newman et al., 2001).

From a Western Australian study estimates of natural mortality for red emperor are low (0.104 – 0.122 $year^{-1}$) (Newman and Dunk, 2002). Red emperor are therefore considered to have a low production potential, being long-lived, relatively slow growing, low natural mortality, and large size and age at maturity, making them vulnerable to over-exploitation (Newman and Dunk, 2002).

Table 19.1. Von Bertalanffy growth parameters for Qld and WA Red Emperor.

Location	Sex	L_∞	K	t_o	Reference
Kimberley (WA)	♀	482.62	0.27	0.07	Newman & Dunk 2002
	♂	627.79	0.15	-0.60	
Queensland	♀ & ♂ combined	792.1	0.14	-0.92	Newman et al. 2000

Multiple stocks of red emperor have been found to occur along the west coast (Stephenson et al. 2001) and it is likely that multiple stocks are present across northern Australia. However, a lack of genetic difference within or between the east and west coast of Australia suggests the widespread dispersal of red emperor larvae resulting in high levels of gene flow (van Herwerden et al 2009), since adults exhibit little movement (Stephenson et al. 2001).

On the GBR red emperor have an extended spawning season of approximately 7 months duration during the Austral spring-summer period (McPherson et al, 1992) while in the Northern Territory females are reported to spawn year round with males only spawning at limited times (Kailola et al, 1993). They are known to be broadcast spawners with a pelagic larval phase (Allen, 1985).

Distribution, habitat and environmental preferences

Red emperor occur throughout the Indo-West Pacific from Australia to southern Japan, west to East Africa and the Red Sea (Allen 2009). In Australia it occurs from northern NSW around the northern Coast to as far south as Cape Naturaliste in south-west WA (Figure 19.2) (Newman et al. 2010). It is, however, most common in the northern parts of its Australian range. It is most commonly associated with reef environments in shallow near-shore waters to depths of at least 180 m (Kailola et al. 1993). On the GBR juveniles and sub-adults were frequently observed in nearshore habitats. Cross-shelf differences were also observed in their relative abundance with significantly more red emperor present on inshore reefs, mid-shelf reefs, and inter-reefal shoals compared with outer-shelf reefs. They were also more likely to be found in depths greater than 15 m (Newman and Williams, 1996). They are commonly associated with habitats that have both sandy and hard substrate types.

Predators and prey

A study in the Gulf of Carpentaria during 1990 found that the most common prey item by weight found in stomach content samples of red emperor were teleosts (73.0 %). The next most common by weight was crustaceans (14.1 %; not including Penaeidae and Stomatopoda) (Salini et al, 1994). Other than the above prey types, red emperor will eat a variety of prey types with annelids, cephalopods, penaeids, stomatopods, and mollusc found in stomach content samples. However, the size of the red emperor sampled during this study (n = 113) did not exceed 387 mm SL and it is possible that diet will change as fish get larger. Predators of red emperor are likely to be those of higher order (eg. sharks) and/or much larger predators.

Recruitment

There is no published information on the recruitment dynamics of red emperor however it is likely that larval survival will be variable form year to year due to inter-annual variation in favourable environmental and biological conditions, although this may be tempered by protracted spawning seasons.

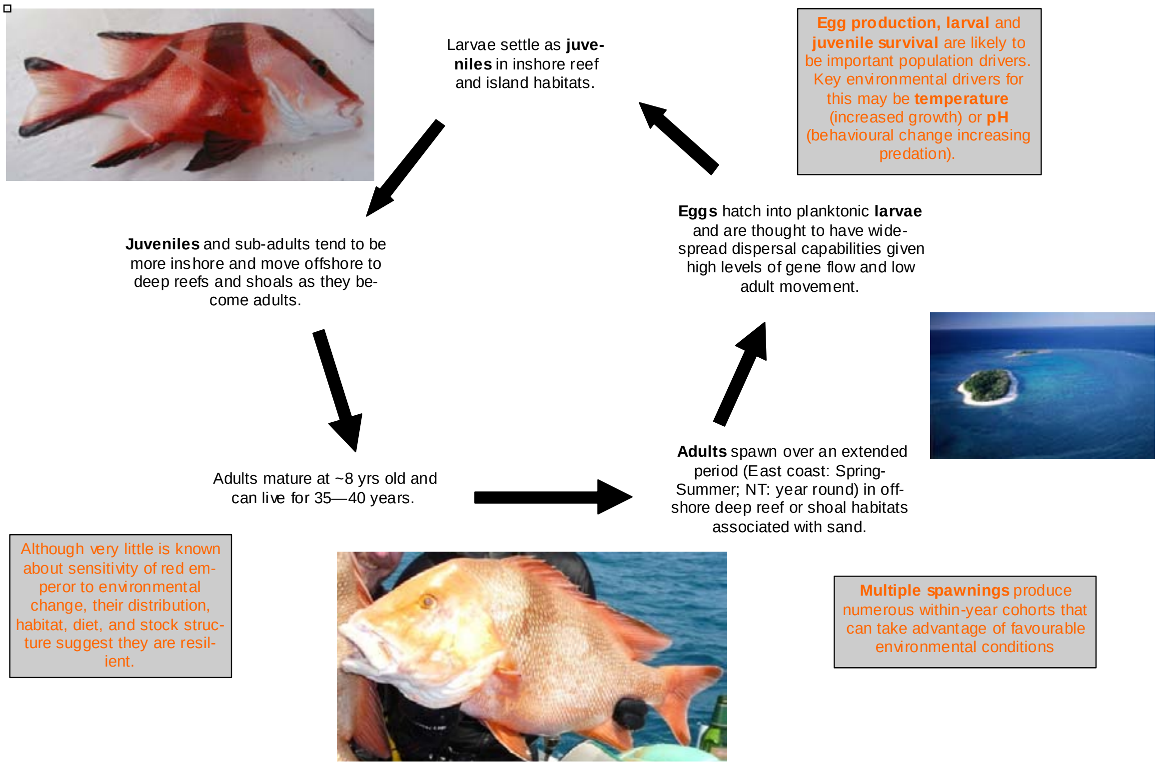

Figure 19.1. Generalised life cycle of the red emperor, *L. sebae*, and the stages of potential environmental driver impacts. Images: Michael de Rooy, GBRMPA, Fishing & Fisheries Research Centre (JCU).

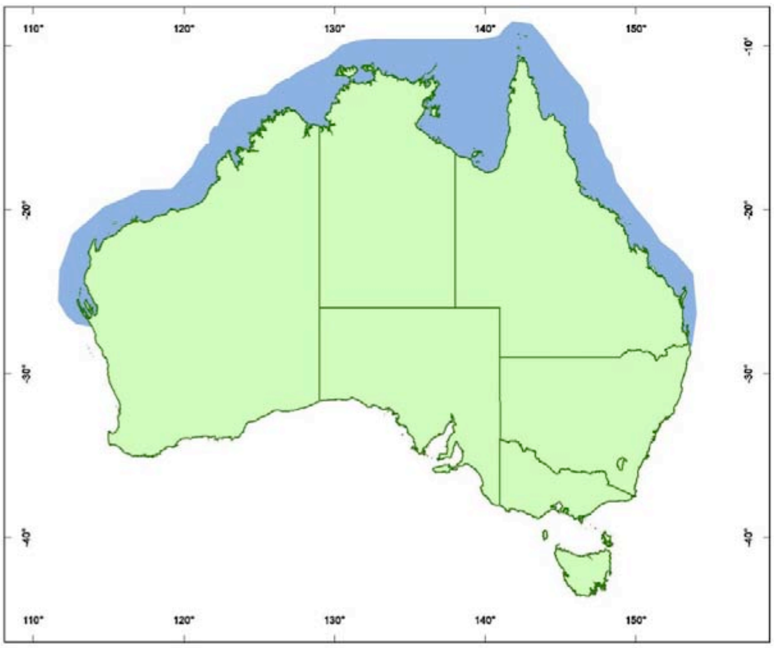

Figure 19.2. The Australian distribution of Red Emperor.

Current impacts of climate change

There are no known current impacts of climate change on red emperor.

Sensitivity to change

- Knowledge of the sensitivity of red emperor to environmental variability is very poor.

Juveniles appear to favour nearshore environments (though not exclusively) and may therefore be more influenced by land-based and anthropogenic impacts. However, very little is known of the sensitivities of red emperor to environmental factors. In other tropical lutjanid species spawning seasonality has been linked to temperature and for nearshore spawners, to rainfall also (Freitas *et al.*, 2011). However, these authors acknowledged that there was latitudinal and species-specific variation in apparent spawning patterns making generalisations about environmental spawning cues for lutjanids difficult to make. The cues for red emperor may be varied and have wide ranges since they have a protracted spawning season.

Resilience to change

- Red emperor has a broad distribution across many different habiata types and environmental conditions. They also have a protracted spawning season. These characters suggest a high potential resilienc to climate change.
- Low productivity potential represents a low resilience character however.

Red emperor is found over a wide latitudinal and temperature range and their distribution extends across the continental shelf from shallow inshore waters to deep offshore waters. They appear to prefer reef/shoal habitat associated with sand but this is variable, and their diet appears to be varied. Across northern Australia they are reported to be a single genetic stock comprising multiple separate adult stocks. They are also known to be hardy in aquariums. All of these attributes suggest that red emperor are a resilient species to differences in environmental conditions and therefore change.

Other

- Key information gaps for red emperor are recreational harvest levels and the sensitivity of the different life history stages to changes in environmental variables.

Ecosystem level interactions

Juvenile red emperor are reported to be frequently found in association with sea urchins (Allen, 1985), however the significance of this is unknown.

Additional (multiple) stressors

Although current levels of fishing effort for red emperor is considered to be sustainable in WA and the NT, in Qld it is considered uncertain due to a lack of information. Recreational catch is prominent on Qld in particular and is likely to increase in the future with increasing human populations. Further, red emperor has life history characteristics that make them relatively vulnerable to over-exploitation. The discard rate for red emperor on the GBR is known to be high given the large MLS limit, however despite often being caught from deep water post-release survival is estimated to be high (Brown et al, 2008).

Critical data gaps and level of uncertainty

Better estimates of recreational harvest of red emperor are required to better assess stock status in all jurisdictions of northern Australia. Critical gaps that need to be investigated is the sensitivity of red emperor to environmental variation including pH and temperature, particularly for early life history stages.

Acknowledgements

The authors gratefully acknowledge the constructive comments on an earlier draft of this review.

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20. Red throat emperor, *Lethrinus miniatus*

Authors: David J. Welch and Ashley J. Williams

Red throat emperor. Photo source: GBRMPA.

Red throat emperor, *Lethrinus miniatus*, is a medium-sized coral reef fish of the Family Lethrinidae reaching a maximum size of approximately 60 cm fork length (FL) and a maximum weight of around 3 kg. They are widespread throughout the tropical and subtropical regions of the Indian and western Pacific Oceans. In Australia they are an important fishery target species on both the east and west coasts.

The fishery

Key points:

- Catches in Northern Territory and the Gulf of Carpentaria are negligible.
- Red throat emperor is taken in Western Australia but mostly in the Great Barrier Reef line fishery.
- Recreational catch is poorly estimated.
- Red throat emperor is considered sustainably fished in WA and on the GBR.

Western Australia

Red throat emperor is taken by the commercial sector in the Western Demersal Scalefish Fishery (WDSF) which uses hand lines and drop lines. The fishery is multi-species with over 70 different species taken. In 2010 there was 45 t of red throat emperor harvested which constituted ~12 % of the total catch (Department of Fisheries, 2011). The commercial fishery is limited entry and managed primarily by spatial effort restrictions and gear restrictions.

The recreational catch of red throat emperor is unknown however the 2009/10 estimate of catch of the top 15 species, which includes red throat emperor, was 155 t of which 128 t was the three fishery indicator species (West Australian dhufish, pink snapper, baldchin groper). Management is through input and output controls including spatial and temporal closures, size limits, bag and possession limits (Department of Fisheries, 2011). Estimates of catch of red throat emperor from the charter sector are not given however are less than 10 t. Assessment of the WDSF is by monitoring estimates of fishing mortality (F) for the three indicator species and is assumed to reflect the status of all other species taken in the fishery. The most recent assessment (2007/08) determined the three indicator species to be 'recovering' (Department of Fisheries, 2011).

Northern Territory

Red throat emperor is not reported from Northern Territory waters.

Queensland

For the Queensland Great Barrier Reef line fishery (RLF) coral trout are the predominant target species historically comprising approximately 50% of the total catch (Welch et al, 2008), with red throat emperor the secondary target species. The fishery is multi-species with in excess of 125 species taken, and the fishing methods used are handlines (all sectors) and rod and reel (recreational and charter), with fishers operating from small vessels on individual coral reefs usually in depths usually less than 20 m (Welch et al, 2008). The 2009-10 estimate of the commercial gross value of production of the RLF was $45 million fishery due to increased profitability with live fish, which are almost exclusively coral trout. Currently there are 369 commercial fishing endorsements for the RLF (RQ symbol) of which approximately 205 are active (DEEDI, 2011).

Prior to 2004 the commercial sector was regulated mainly by effort controls, and the recreational and charter sectors had daily or trip bag limits. For all sectors a minimum size limit (MSL) of 35 cm total length (TL) was applied to red throat emperor for all sectors. In 2003–2004 management of the fishery changed substantially with the introduction of an annual total allowable commercial catch (TACC) allocated as individual transferable quotas (ITQs) for the key fishery species groups (coral trout, red throat emperor and 'Other' species). The red throat emperor TACC introduced was 700 t. Other management changes included increasing the MSL to 38 cm TL, introduction of a seasonal (spawning) closure and new spatial closures, gear and boat restrictions, and some effort restrictions. Since the introduction of the quota management system the TACC has not been realised in any year and in 2009/10 the reported commercial harvest of red throat emperor was 267 t (38% of the TACC) (Figure 20.1) (DEEDI, 2011).

Line fishery catches of red throat emperor are known to occur from waters of the Gulf of Carpentaria. No estimates are reported however they are almost certainly negligible. Minor quantities are also taken in the Rocky Reef fishery (SE Qld) (DEEDI, 2010). Most of the Australian catch of red throat emperor is reported to come from the Reef Line fishery (RLF) on the Great Barrier Reef from commercial, recreational and charter fishing sectors.

Harvest estimates of red throat emperor by the GBR charter sector in 2009/10 was 80 t while in the recreational sector for the years 1999, 2002 and 2005 catch was estimated to be 171,000, 155,000 and 89,000 fish respectively (DEEDI, 2011). An initial stock assessment for red throat emperor was carried out in 2006 that assessed stocks to be sustainably fished (Leigh et al., 2006). The most recent assessment also considered stocks to be sustainably fished (DEEDI, 2011).

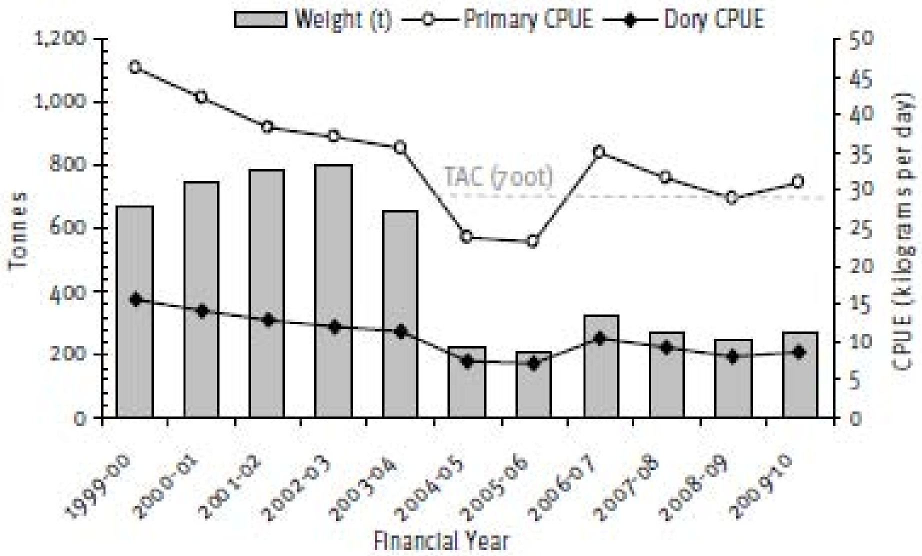

Figure 20.1. Commercial catch of red throat emperor from the Great Barrier Reef line fishery for the financial years (quota years) 1999-00 to 2009-10. Catch-per-unit-effort for primary vessels and dories are also indicated. (Source: DEEDI, 2011).

Life history

Key points:

- Red throat emperor is a moderately productive species with a narrow distribution on the east and west tropical/sub-tropical continental shelf areas.
- Knowledge of the early life history is completely lacking, including juvenile habitat.

Life cycle, age and growth

Red throat emperor is a medium-sized coral reef fish reaching a maximum size of approximately 60 cm FL and a maximum weight of around 3 kg (Williams et al., 2003; 2007). Reports of red throat emperor reaching 90 cm FL and 9 kg in weight (Carpenter, 2001) are likely to be other emperor species, such as *Lethrinus nebulosus*, *L. laticaudis*, *L. erythacanthus* and *L. xanthochilus*, which have been misidentified.

The early life history of red throat emperor is poorly understood. The eggs and larvae have not been identified in plankton samples and juveniles (< 15 cm FL) have not been observed so their preferred habitat is unknown. Growth is better understood and is relatively fast in the first few years of life. Red throat emperor can reach their maximum size at around 6 years of age, with a maximum age in excess of 20 years (Brown and Sumpton, 1998; Williams et al., 2003; Williams et al., 2007). Patterns of growth vary significantly among regions of the GBR, with fish in the southern GBR reaching a larger maximum size than those in the northern GBR (Brown and Sumpton, 1998, Williams et al., 2003; 2007).

Red throat emperor is a protogynous hermaphrodite, whereby individuals mature first as females before changing sex later in life (Bean et al., 2003; Sumpton and Brown, 2004). However, some of the oldest red throat emperors are female, suggesting that not all individuals change sex and highlighting the plasticity of sex change in this species (Williams et al., 2006). The peak spawning season for red throat emperor occurs between July and November on the GBR (Sumpton and Brown, 2004; Williams et al., 2006). It is not known whether there are intra-seasonal peaks in spawning associated with the lunar cycle. However, the frequency of eggs at different developmental stages in the ovaries of spawning females suggests red throat emperor are batch spawners and may spawn more than once during the spawning season (Williams et al., 2006).

The spawning behaviour of red throat emperor is not known, but occasional large commercial catches during the spawning season suggests that they may form relatively large aggregations. The proportion of females that spawn during the spawning period varies among regions of the GBR, with up to 100% of females spawning in the northern GBR and less than 43% spawning in the southern GBR (Williams et al., 2006).

Sumpton and Brown (2004) estimated that females in the Swains and Capricorn-Bunker (southern) regions of the GBR were first capable of spawning at age 3 years and 35–40 cm FL. In a more recent study, Williams et al. (2006) estimated the average size and age of mature females from the Capricorn-Bunker region to be 28 cm FL and 1–2 years. Sex change occurs over a wide size and age range, but 50% of fish become male by about 43 cm FL and 7 years of age (Sumpton and Brown, 2004; Williams et al., 2006).

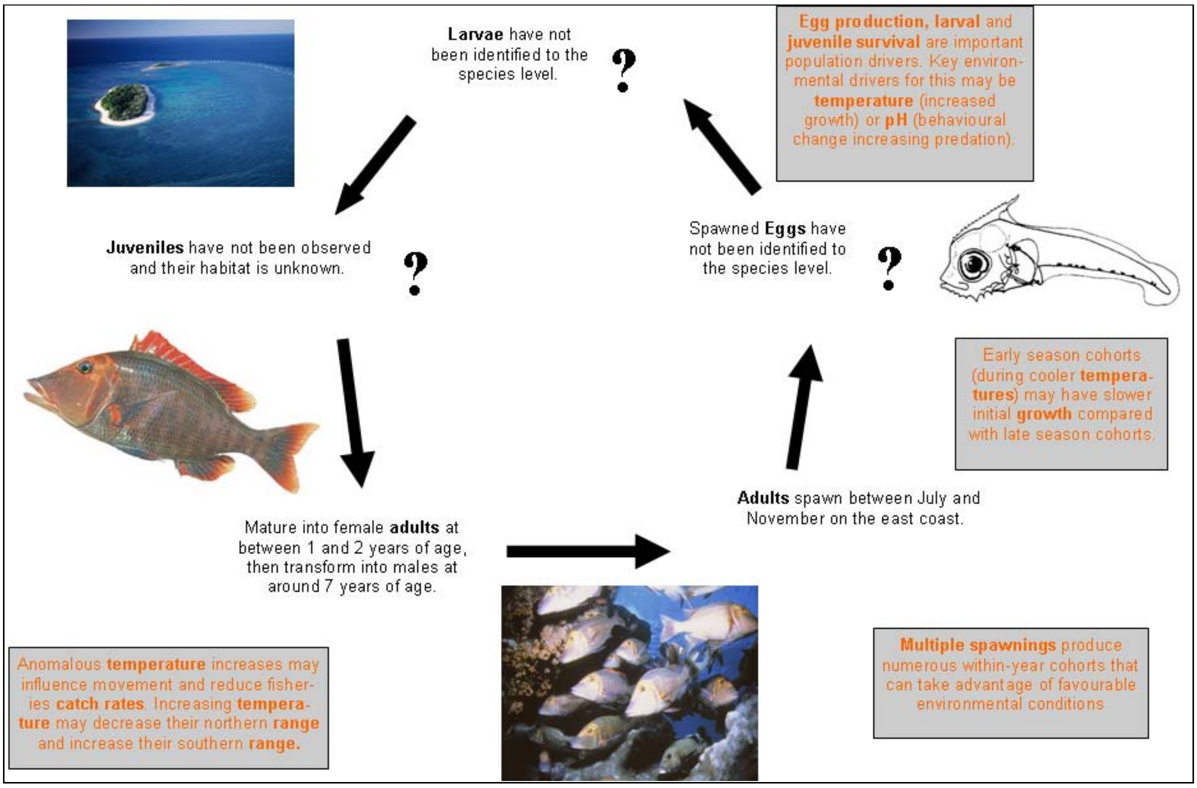

Figure 20.2. Generalised life cycle of the red throat emperor, *L. miniatus*, and the stages of potential environmental driver impacts. Images: Leis and Rennis, 1983; GBRMPA.

Distribution, habitat and environmental preferences

Reports of red throat emperor are widespread throughout the tropical and subtropical regions of the Indian and western Pacific Oceans (Figure 20.3). However, it is more likely that red throat emperor has a much more restricted distribution, as many reports of the species have been misidentifications or cannot be confirmed. Red throat emperor is confirmed to occur along the tropical and subtropical coasts of eastern and western Australia (Figure 20.3), New Caledonia, and the Ryukyu Islands of southern Japan. These confirmed reports reveal a disjunct distribution separated by the equatorial zone, and a narrow longitudinal range between approximately 110 °E and 170 °E (Carpenter, 2001).

In Australia, red throat emperor occurs along the west coast from the Dampier Archipelago in the north to the Houtman Abrolhos Islands in the south. On the east coast of Australia, red throat emperors have been found from Cooktown to Norfolk Island. However, their usual GBR distribution on the Queensland east coast lies between approximately 17 °S (Cairns) and 26 °S (Fraser Island) (Figure 20.3) (Williams et al., 2006).

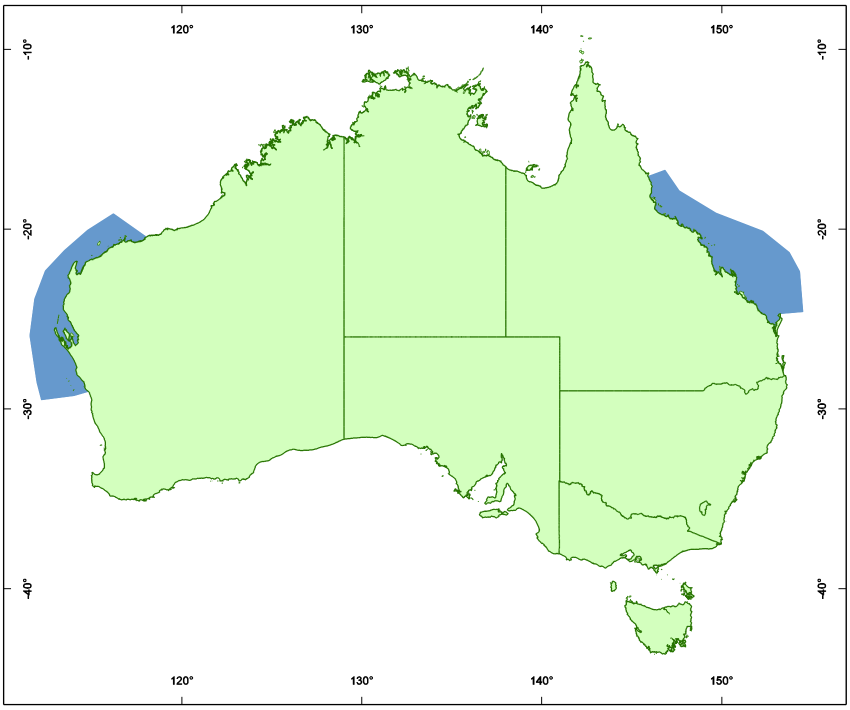

Figure 20.3. Australian distribution of red throat emperor.

Red throat emperor is a demersal species that is typically associated with coral or rocky reefs, although it is also commonly encountered on shoal and rubble habitats between reefs (Newman and Williams, 1996). Along the GBR, red throat emperor is mostly found on mid and outer shelf reefs in depths from 2 m to at least 128 m, and is rarely found on inshore reefs (Newman and Williams, 1996). There are also reports of them occurring off the continental shelf in deep water.

Predators and prey

Red throat emperor is a demersal carnivorous predator consuming mainly crustaceans, echinoderms, molluscs and fish (Walker, 1978). Within this wide range of taxa, red throat emperor appears to exercise some selective feeding, preferring particular species of crab, sand dollar and sea urchin, all of which are in relatively low abundance and are typically red or purple in colour (Walker, 1975; 1978).

Recruitment

Little is known about the early life history of red throat emperor due to difficulties in identifying emperor larvae to the species level and a lack of information about the juvenile habitat. Red throat emperor eggs are approximately 0.6 to 0.9 mm in diameter (Walker, 1975), but the appearance of larvae has not been described. The duration of the larval phase and the size at settlement is also unknown. The juvenile habitat of red throat emperor is unknown, as individuals less than 15 cm FL have not been collected or observed from anywhere throughout their distribution. Williams and Russ (1994), however, hypothesised that juveniles occur in relatively deep water (> 40 m) adjacent to coral reefs, based on the fact that juveniles have not been observed during extensive surveys of shallow reef and seagrass habitats.

Current impacts of climate change

Key points:

- The passing of cyclones has resulted in dramatic increases in catch rates of red throat emperor, apparently due to a re-distribution of populations possibly due to incursions of cool water on to reef areas.

In 2009 a very large (Category 5) tropical cyclone, Cyclone Hamish, crossed over parts of the Great Barrier Reef and was immediately followed by changes in fishery catch rates of red throat emperor in the RLF (Tobin et al., 2010). These changes varied among regions however predominantly involved increases in catch rates. In 1997 a less intense but long-lived cyclone, Cyclone Justin, also resulted in significant increases in catch rates of red throat emperor (by up to ~200%) and a northerly expansion in their usual distribution (Tobin et al., 2010). Underwater visual surveys conducted following Cyclone Hamish documented structural reef damage as high as 66 % on some reefs, however observed no change in red throat emperor abundances. For Cyclone Hamish an analysis of sea surface temperature and catch rates could not determine a clear correlation. For Cyclone Justin however, a distinct cool water anomaly was found to be the most likely driver of increased red throat emperor catch rates (Tobin et al., 2010). The impacts were spatially and temporally highly variable for each Cyclone making general statements about likely impacts of cyclones highly uncertain.

Sensitivity to change

Key points:

- Temperature appears to be an important driver of red thorat emperor populations based on the apparent effects of cyclones and their narrow latitudinal range.

Red throat emperor behaviour and movement appear to be influenced by temperature given increases in fishery catch rates and range demonstrated by Tobin et al (2010) following severe weather events and associated negative temperature anomalies, as well as their relatively narrow latitudinal range. With climate change predicting increasing water temperatures red throat emperor may show a southerly range shift in the future or be more common in deeper waters of their current range. Occasional sightings have been made as far south on the east coast as North Solitary Island near Coffs Harbour, northern New South Wales.

Resilience to change

Key points:

- Red throat emperor shows some phenotypic plasticity providing some resilience to change, however they may have narrow thermal tolerances that reduces their resilience.

Red throat emperors demonstrate phenotypic plasticity with variability in sex change documented (Williams et al., 2006). They are also concluded to be batch spawners with some evidence that females may spawn more than once during the seasonal spawning period (Williams et al., 2006).

These attributes are likely to provide red throat emperor some level of resilience in the face of climate change.

However, they do have attributes that make them less resilient to changes. They appear to have relatively restricted latitudinal distributions on the east and west coasts of Australia compared with many other key species. This is possibly determined by their thermal tolerances although they do inhabit a range of depths also. Also, despite willing to feed on a variety of prey items, they also have preferred food items that are naturally in low abundance (Walker, 1975).

Other

Key points:

- A key critical knowledge gap for red throat emperor is their early life history including larval distribution and settelement, juvenile distribution and ecology, and how climate change will affect this critical life history stage.
- More accurate estimates of the recreational harvest of red throat emperor are also required.

Ecosystem level interactions

Red throat emperor is relatively abundant within their usual range, particularly on the GBR, and therefore adults may play an important functional role in coral reef ecosystems. The recruitment dynamics are poorly understood and, like all species with a pelagic larval phase, are likely to be influenced by spatial and temporal variability in primary productivity.

Additional (multiple) stressors

Fishing effort is a potential stressor on red throat emperor despite being assessed as "under-utilised" at current levels on the east coast, and probably at similar levels on the west coast. Current estimates of recreational harvest are poor and there is potential for increased targeting in the future particularly as human populations increase.

Critical data gaps and level of uncertainty

There are several key gaps and uncertainty in the current knowledge of red throat emperor. One of the major gaps is knowledge of their early life history, particularly larval distribution and settlement, and juvenile distribution and ecology. Very little is known on the effect that climate variables have on red throat emperor life history stages. Key variables of interest are temperature and pH and experimental studies would be beneficial for this species. Uncertain estimates of recreational harvest remains a key issue.

Acknowledgements

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21. Scalloped hammerhead, *Sphyrna lewini*

Authors: Alastair Harry & Andrew Tobin

The fishery

Key points:

- Scalloped hammerheads are captured in a range of fisheries and at various life stages in Australian waters
- There is currently no species-specific management of scalloped hammerheads and monitoring of catch is difficult since hammerheads are rarely identified below family level.
- Complex and poorly understood behaviour, migration and stock structuring make managing this species a challenge.

The scalloped hammerhead is caught in a variety of state and commonwealth managed fisheries, where it is typically a by-catch or by-product species rather than directly targeted. Shark catch is poorly documented in many of these fisheries and hammerhead species are frequently only identified to family level. This means the occurrence of the scalloped hammerhead specifically in some fisheries is difficult to determine. No formal stock assessments have been undertaken on scalloped hammerheads in Australian waters, although there is some indication that hammerhead populations in general may be declining off the east coast of Australia (Noriega *et al.*, 2011; Simpfendorfer et al, 2011).

The scalloped hammerhead is a wide-ranging, migratory species. Since there is some level of genetic mixing with nearby countries, such as Indonesia (Ovenden *et al.*, 2009), overfishing in these areas may also affect Australia. Despite evidence for genetic mixing at large scales, evidence for fine-scale stock structuring has also been found on the east coast of Queensland suggesting a need for re-evaluation of management for this species across northern Australia (Welch *et al.*, 2010).

This species displays strong sex and size segregation, with males, females and juveniles residing in different areas and thus potentially different management jurisdictions. For example, most coastal fisheries in Australia have a bias towards catching juveniles and male scalloped hammerhead (Harry *et al.*, 2011a; Harry *et al.*, 2011b). The implications of sex-biased harvesting on this species are not well understood (Harry, 2011).

Queensland

The largest catches of hammerheads in Queensland occur in the East Coast Inshore Fin Fish Fishery (ECIFFF) and the Gulf of Carpenteria Inshore Fin Fish Fishery (GOCIFFF)(DEEDI, 2010; 2011). The vast majority of sharks harvested in both these fisheries are in the commercial sector and are caught using gillnets. The recent introduction of a total allowable catch of 600t for sharks in the ECIFF has reduced the quantity of hammerheads caught (47t were landed in 2009/10 compared to 152t in 2008/09). Until recently the majority of the hammerhead catch in these fisheries was assumed to be scalloped hammerheads (Rose *et al.*, 2003). However, Harry *et al.* (2011b) found that great hammerhead, *S. mokarran*, was a slightly larger component of the catch by weight in the ECIFF due to its larger average size at capture. Indeed, most scalloped hammerheads caught by both these fisheries are likely to be small juveniles (<1000mm TL). For example, 11,892 hammerheads were reported in the GOCIFFF catch in 2009 for a weight of 12t an average size of < 1kg (DEEDI, 2010). Understanding trends through time are complicated by poor species-specific recording in commercial fisher logbooks. Figure 21.1 demonstrates the changes that have occurred in the Gulf of Carpentaria fishery as a result of changed logbook format and fisher education. Unfortunately, the data is not sufficiently robust to make any comment about changes through time and many fishers still group scalloped and great hammerheads in their logbook entries.

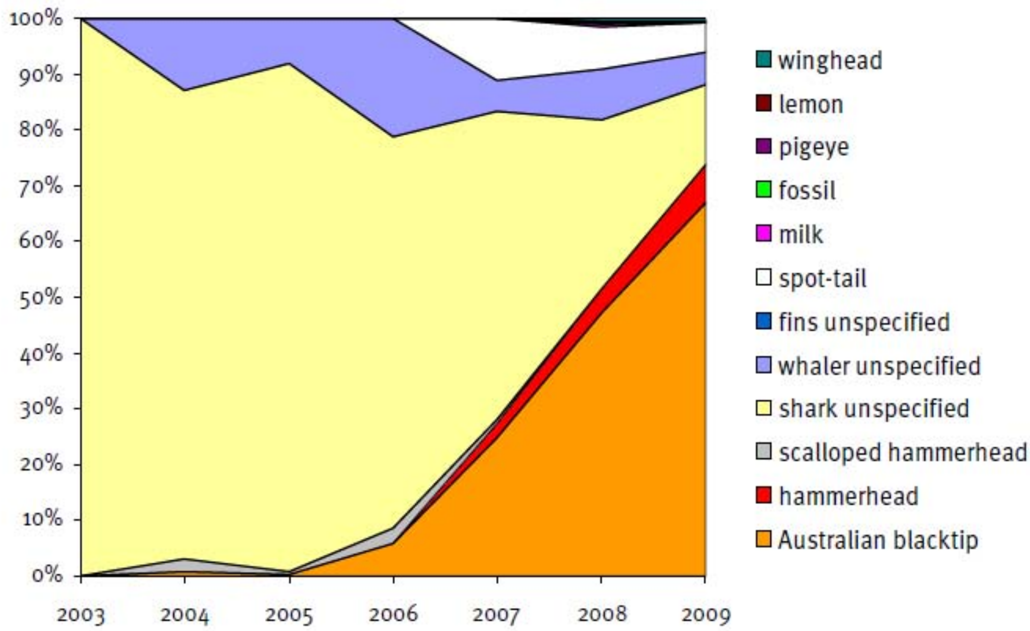

Figure 21.1. Changes in recording of shark species in commercial net fisher logbooks from 2003 to 2009 (Source: DEEDI, 2010).

Scalloped hammerhead are also caught as bycatch in Queensland trawl fisheries (Stobutzki *et al.*, 2002), however the introduction of turtle excluder devices, bycatch reduction devices and restrictions on the possession of sharks are likely to have reduced this substantially. Recreational and charter fishers also interact with hammerheads in Queensland waters (Lynch *et al.*, 2010), however size restrictions within the Great Barrier Reef World Heritage Area and current fishing behaviour (most sharks are released alive) mean that the effect of recreational fishing on scalloped hammerheads is likely to be small compared to the commercial sector.

While the majority of Queensland's fisheries almost exclusively capture juvenile scalloped hammerheads, adults are captured and killed by the Queensland Shark Control Program (QSCP) (Noriega *et al.*, 2011). Between 2000 and 2010 the annual catch of all hammerhead species taken in the entire QSCP was between 48 and 92 individuals (Source: DEEDI, 2012). Since its inception in the 1960s, there has been a dramatic drop in the catch of hammerheads by the QSCP. For example, in north Queensland hammerheads were >50% of the catch at the beginning of the QSCP, but are now fewer than 10% of the catch (Simpfendorfer *et al.*, 2011). However, it is unclear to what extent trends in catch are related to trends in abundance, as opposed to other factors (e.g. changing gear types, localised depletion)(Simpfendorfer *et al.* 2011).

Northern Territory

The largest catch of hammerhead sharks in the Northern Territory is within the Offshore Net and Line Fishery that targets mackerel and shark (Handley, 2010). Hammerhead species made up approximately 9% (118 t) of the total catch in 2009. Although current catches are not distinguished to species level, previous observer surveys of this fishery suggests similar catch characteristics to the east coast of Queensland, with juvenile scalloped hammerheads dominating the catch, and a general bias towards catching males (Stevens and Lyle, 1989).

Western Australia

Hammerhead sharks are caught in a number of Western Australian gillnet and demersal longline fisheries termed the 'northern shark fisheries'. Due to unsustainable levels of fishing on sandbar sharks, this fishery ceased to operate and no catch has been reported since 2009/10 (Department of Fisheries, 2011).

New South Wales (NSW)

Historical commercial landings of hammerhead sharks in NSW averaged 4t between 2005 and 2010, and the highest recorded catch was 15.7t in 1993/94 (Rowling *et al.* 2010). Most of the commercial catch of hammerheads occurs in the NSW Ocean Trap and Line fishery where there has been increased targeting of sharks in the past 10 years for their fins (Macbeth *et al.*, 2009). Scalloped hammerheads make up a relatively small component of the catch in this fishery (which also catches *S. mokarran* and *S. zygaena*), and larger individuals (adult males and sub-adult females) are predominantly captured (Harry *et al.*, 2011a). Hammerheads are also captured in the NSW shark meshing program and by recreational anglers although the specific occurrence of scalloped hammerheads is not well documented (Reid *et al.*, 2011). The total number of hammerheads caught by recreational anglers and the NSW shark meshing program was around 250 sharks per year between the 1970s and 2000s (Rowling *et al.* 2010).

Commonwealth Fisheries

Commonwealth managed tuna and billfish fisheries also catch hammerheads (potentially scalloped), of which a relatively small number are retained. For example in 2006, 188 hammerheads weighing 6.2t were retained in the Eastern Tuna and Billfish Fishery (Evans, 2007), with a further 117 not kept. In 2003, 59 hammerheads weighing 833kg were retained in the Western Tuna and Billfish Fishery, while a further 613 were not kept (Lynch, 2004). Australian tuna and billfish fisheries currently have a bycatch discard workplan and management measures for mitigating risks to sharks including a trip limit of 20 and a ban on the use of wire traces.

Illegal, unregulated and unreported (IUU) fishing

There has been a rapid rise in IUU for sharks off northern Australian waters, and this is likely to affect scalloped hammerheads (Field *et al.*, 2009; Marshall, 2011).

Life history

Key points:

- Scalloped hammerheads have a relatively low fecundity, occupy many different habitats and have a wide distribution.
- They are a migratory species with males, females and juveniles potentially occurring in and crossing different management jurisdictions and fisheries.
- Their general biology is poorly understood and there is considerable uncertainty in many areas of their life history.

Life cycle, age and growth

The scalloped hammerhead has a reproductive mode of placental viviparity; young are born live at 465-563 mm TL (Harry *et al.*, 2011a). Nineteen pregnant females recorded in the Queensland Shark Control Program had an average of 15 pups (range 1–28) and larger females were more fecund (Harry, 2011). Although female scalloped hammerheads appear to have an asynchronous reproductive cycle in Australian waters; pups are born year-round however there is a peak during late-spring, early summer (Stevens and Lyle, 1989; Harry *et al.*, 2011a). The timing and frequency of reproduction in scalloped hammerheads is not known with certainty. While some authors have suggested an annual reproductive cycle (White *et al.* 2008), most other large carcharhiniform sharks have a biennial or longer reproductive cycle. Pups are born in coastal estuaries and embayments and juveniles remain inshore for the first few years of life before migrating offshore. The timing of migration offshore differs between sexes (females migrate offshore earlier) and this appears to be the cause of the strong patterns in sex-segregation often observed for this species (Klimley, 1987).

There is increasing evidence to suggest that *S. lewini* is a relatively long-lived species, living to at least 30 years of age (Piercy *et al.*, 2007; Harry *et al.*, 2011a; Kotas *et al.*, 2011). However, since the majority of growth studies have used vertebrae for age determination, and none have been able to validate the vertebral banding pattern, there is a high level of uncertainty about longevity in the species. Parameters of a von Bertalanffy growth model fitted to both sexes of *S. lewini* from the east coast of Australia were L_∞ = 3,305 mm TL, K = 0.077 yr^{-1}, and t_0 = -2.516 yr. Female *S. lewini* grow to at least 3,460 mm TL in Australian waters (Stevens and Lyle, 1989). Female life history is poorly documented in Australian waters; maturity in females appears to occur at lengths > 2,200 mm TL in Australian waters at an age of 10–15 years (Stevens and Lyle, 1989; Harry *et al.*, 2011a).

Distribution, habitat and environmental preferences

The scalloped hammerhead is found in tropical and warm-temperate seas worldwide (Compagno *et al.*, 2005). This coastal-pelagic species is typically found on the continental shelf from close inshore to well offshore, and may use deepwater and meso-pelagic habitats (to at least 1,000m) to some extent (Jorgensen *et al.*, 2009). Pups and juveniles prefer coastal estuaries and embayments for the first few years of life before migrating offshore.

In Australian waters scalloped hammerheads occur across northern Australia from Sydney on the east coast to Geographe Bay in Western Australia (Figure 21.2; Last and Stevens, 2009). Tropical coastal embayments are used as a nursery habitat for this species off eastern Australia, and neonates have been recorded as far south as Moreton Bay on the east coast. Juveniles of both sexes and sexually mature males can be found in close inshore habitats of the GBR (<25m depth) (Harry *et al.*, 2011b). The absence of females > 2 years old suggests they have begun to migrate offshore by this age. Some males do not appear to migrate offshore at all (Harry *et al.*, 2011a). Catch characteristics in the Gulf of Carpentaria and Arafura Sea are similar to the east coast of Australia (adult females absent, male-biased sex-ratio) and indicate this species may have similar behaviour across northern Australia (Stevens and Lyle, 1989).

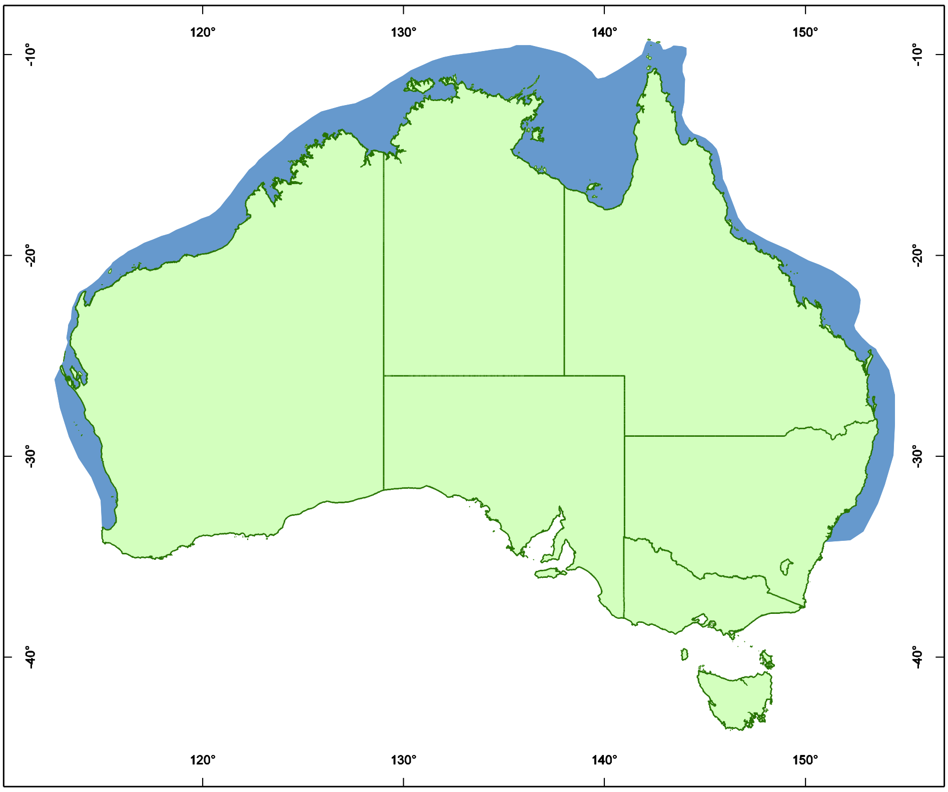

Figure 21.2. Australian distribution of scalloped hammerhead shark.

Predators and prey

This species has a broad diet that probably changes during different stages of ontogenetic development (Stevens, 1984; Klimley, 1987; Stevens and Lyle, 1989). Off northern Australia the diet of scalloped hammerheads consisted predominantly of teleost fish (80% of individuals) and molluscs (24% of individuals) (Stevens and Lyle, 1989).

Recruitment

Little is known about survival in sharks, however since young are born live and do not have a larval phase, interannual recruitment may be relatively stable and less affected by fluctuations in environmental conditions than broadcast spawners (Walker, 1998).

Current impacts of climate change

Key points:

- There are no known current impacts of climate change on scalloped hammerheads.

There has been no investigation into the effects of climate change on this species. Any changes in the distribution and abundance of the scalloped hammerhead specifically would be difficult to discern from fishery catch records, if they exist, since hammerheads are typically only identified to family level. Shark control programs in Queensland and New South Wales are the only long-term fishery-independent records of hammerhead abundance in Australia, and have not identified hammerheads to species level either (Reid *et al.*, 2011; Simpfendorfer et al, 2011).

Sensitivity to change

Key points:

- Very little is known on the sensitivity of scalloped hammerheads to environmental changes however one study suggests that higher water temperatures will effect their metabolic functioning.

Little is known about the sensitivity of shark populations to environmental changes. An integrated risk assessment for climate change on sharks in the Great Barrier Reef World Heritage area identified scalloped hammerhead as a low-risk species in both coastal habitats and shelf habitats (Chin *et al.*, 2010). The semi-quantitative assessment considered various climate change scenarios, included biological information about each species, and ranked species' rigidity and sensitivity to a variety of factors to determine their exposure to climate change. Like many large sharks, scalloped hammerhead was considered to have a relatively high adaptive capacity, and thus was not highly vulnerable to climate change. However, vulnerability increased when other synergistic factors such as fishing and coastal development were considered.

While risk assessments may give some indication of how sensitive a species is to change, there have been few experiments to provide supporting evidence. In one experiment, however, the metabolic rate of juvenile scalloped hammerheads was found to increase with temperature in Hawaii. This also increased daily food requirements and led to many animals starving during summer (Lowe, 2002). Contrary to what was expected, growth rate was determined by foraging ability and was highest when temperatures were lower. This may suggest that an increase in water temperatures could lead to greater rates of juvenile mortality in scalloped hammerheads.

Long-term fisheries datasets can also provide information on the effects of climate change on demography. While no such data has been published for scalloped hammerhead, a study of the spiny dogfish, *Squalus acanthias*, over a 60 year period found that age at 50% maturity decreased by

11 years and there was an increase in fecundity from 5.9 to 6.7 pups on average (Taylor and Gallucci, 2009). Although the authors concluded that this change was largely due to fishing rather than increasing water temperatures, the study demonstrates that many long-lived sharks may have considerable plasticity in life history traits.

Harry *et al.* (2011a) noted similar plasticity in life history traits of male scalloped hammerhead, including off the east coast of Queensland specifically. Growth rates and length and age at maturity were significantly different between two samples from two different locations off eastern Australia, suggesting that phenotype can be greatly influenced by local environmental conditions.

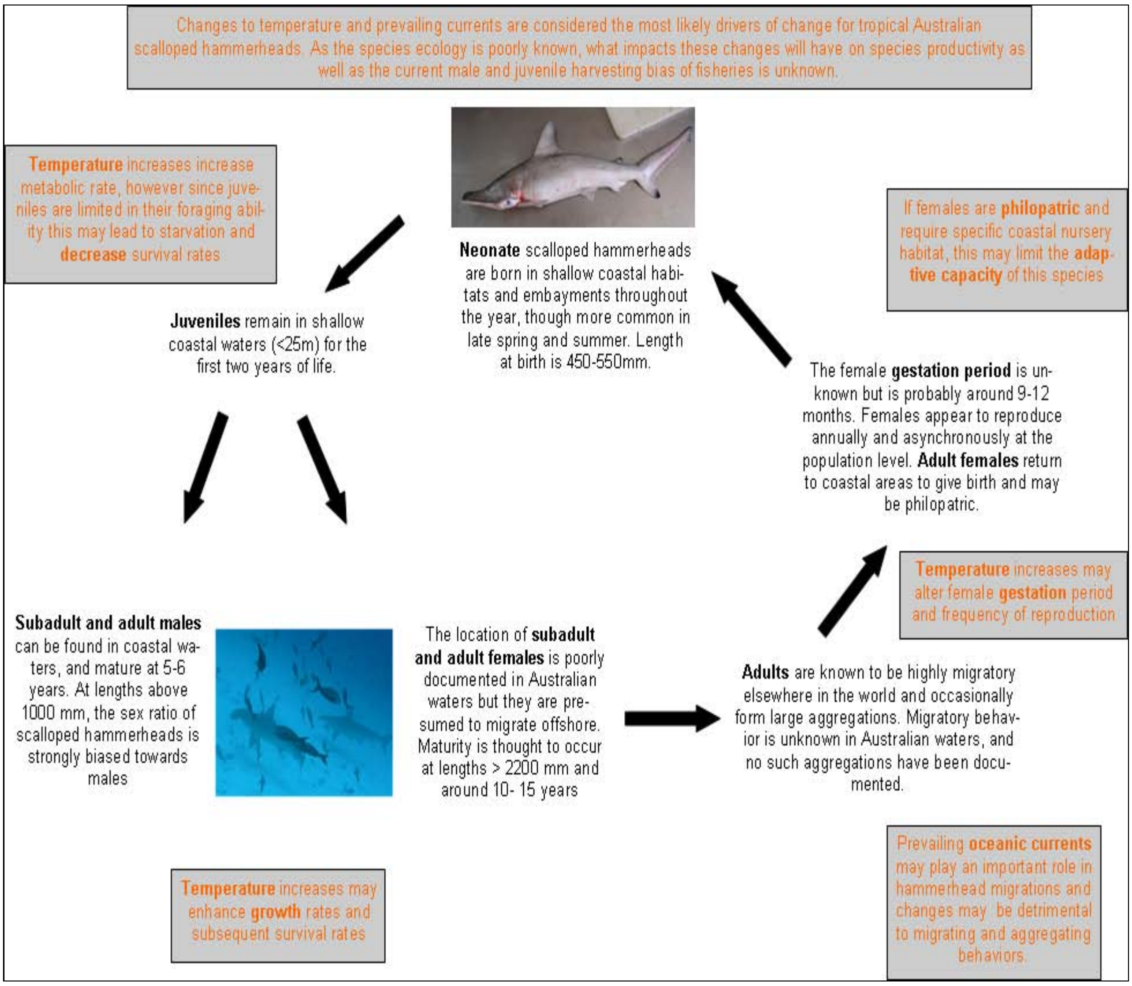

Figure 21.3. Summary of life cycle of scalloped hammerhead shark (*Sphyrna lewini*), and points of exposure to relevant climate change drivers.

Resilience to change

Key points:

- Scalloped hammerhead are likely to be resilient to climate change due to their cosmopolitan distribution across a range of habitats, as well as evidence for phenotypic plasticity.

Scalloped hammerhead sharks live in a wide range of habitats across a wide range of latitudes and through many different oceans. On this basis they are likely to be relatively robust to climate changes.

Other

Key points:

- Key information gaps exist in basic life history of scalloped hammerhead especially the validation of age and longevity.
- Fisheries monitoring and reporting programs need to begin recording hammerheads to species level to better understand background pressure on populations.

Ecosystem level interactions

Sharks constitute a major fraction of the predator biomass in tropical waters (Blaber et al. 1989, 1990a, Salini et al 1992) and as a consequence exert an important top down influence impact on tropical coastal ecosystems.

Additional (multiple) stressors

Like most large marine predatory species, sharks are vulnerable to overexploitation (Ovenden et al. 2010).

Critical data gaps and level of uncertainty

Despite its cosmopolitan distribution and abundance in many areas, the general biology and ecology of the scalloped hammerhead remains poorly understood. Since growth and longevity have never been validated in this species, it is very difficult to anticipate how populations of scalloped hammerheads are likely to respond to disturbances such as climate change and fishing. There is also a critical need for fisheries and shark control programs to begin recording catch of hammerheads to the species level.

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22. Spanish mackerel, *Scomberomorus commerson*

Authors: David J. Welch, Thor Saunders and Emily Lawson

The fishery

- Spanish mackerel are a key northern Australian species with fisheries in Western Australia, Northern Territory, the Gulf of Carpentaria, Torres Strait and the east coast (Queensland & New South Wales).
- Management is generally by imposing catch limits and/or catch sharing arrangements among sectors.
- Fisheries are considered to be fully fished and/or at sustainable levels.

Fisheries for narrow-barred Spanish mackerel (referred to hereafter as Spanish mackerel) extend across northern Australia from the east coast to the west coast. Fish are taken by commercial and recreational fishing sectors by line fishing methods (see Tobin and Mapleston 2004 for a detailed description). The vast majority of the catch across Australia is taken using trolling methods using lures or baits. The fisheries are managed based on state and Commonwealth jurisdictions while also conforming to known stock structure. These key fisheries/stocks are: Queensland/New South Wales east coast, Torres Strait, Gulf of Carpentaria, north-western Northern Territory and Western Australia (Buckworth *et al* 2007). Product is sold predominantly to domestic markets.

<u>Western Australia</u>

In Western Australia the Spanish mackerel fishery extends from the WA/NT border and south to Perth however the majority of the catch is reported from the northwest coast. Catch from the fishery is reported separately for each of three regions: Area 1 in the north (Kimberley); Area 2 on the midwest coast (Pilbara); and Area 3 to the south (Department of Fisheries 2011). Since 2006 an

Individual Transferable Quota (ITQ) management system has been in place with a Total Allowable Commercial Catch (TACC) for each of the three Areas. The TACC for each Area is currently: Area 1 – 205 t; Area 2 – 126 t; and Area 3 – 79 t. A total of 3, 4 and 7 boats operate within each of Areas 1, 2 and 3 respectively, and boat positions are monitored by a Vessel Monitoring System (VMS). A minimum legal size limit of 90 cm total length is also applied (Department of Fisheries 2011).

The majority of the catch is from Area 1 which is a reflection of the more tropical distribution of the species. Total catch increased from 1980 and peaked in 2002 and 2003. Since then effort reductions through management intervention has caused a drop in catches to be approximately 284 t in 2010 (Figure 22.1) (Department of Fisheries 2011).

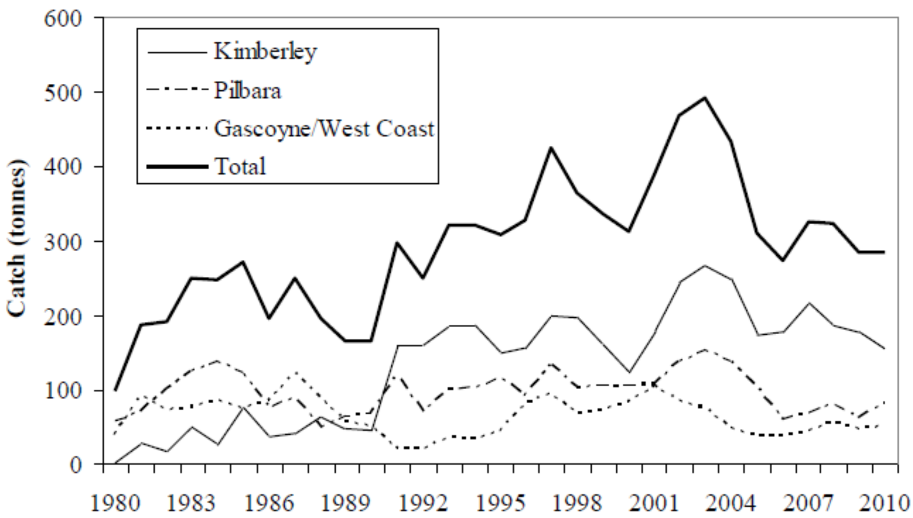

Figure 22.1. Catch of Spanish mackerel for each of the three management areas (Area 1 – Kimberley; Area 2 – Pilbara; Area 3 – Gascoyne/West Coast) for the period 1980 to 2010. Source: Department of Fisheries, 2011.

There are no recent estimates of the recreational catch of Spanish mackerel in WA however they are known to be a popular target species. Currently the effort in the fishery is considered to be at an acceptable level (Department of Fisheries 2011).

North-western Northern Territory

In the Northern Territory (NT) Spanish mackerel are taken in the Spanish mackerel fishery that operates from the coast to the outer limit of the Australian Fishing Zone and mostly around headlands, shoals and reefs. Some incidental catch is taken in the Offshore Net and Line and the Finfish Trawl fisheries (Northern Territory Government 2011). Fishers operate from a main vessel with up to two dories for each licence with each of the dories and the main vessel fishing. In 2010 there were 16 licences issued however only 12 were actively fishing. Catch is either filleted on board or trunked (head, viscera and tail removed) and stored on board. Spanish mackerel are also keenly sought-after by recreational anglers and Fishing Tour Operator (FTO) clients with most effort around the major coastal population centres of Darwin, Nhulunbuy and Borroloola (Northern Territory Government 2011). Catch limits are set for all sectors as reference points to trigger a management action if they are exceeded.

Historically, there were significant landings of Spanish mackerel by the Taiwanese gillnet fleet off northern Australia between 1974 and 1986, with annual catches perhaps as high as 1,000 tonnes in the late 1970s. Since the mid 1990s, the fishery has stabilised as a small, tightly-controlled NT-based troll fishery with a steadily increasing CPUE, possibly due to recovering populations after the period of heavy foreign harvest as well as increasing efficiency of the fishing operations (Northern Territory Government 2011).

The commercial Spanish mackerel catch has shown an increase from 1983 to 2006 with a peak of approximately 400 t and since then has stabilised at around 250 t with 254 t taken in 2010 (Figure 22.2). Catch levels have generally followed effort levels which have been influenced by price and operational factors such as availability of skilled skippers and crew (Northern Territory Government 2011).

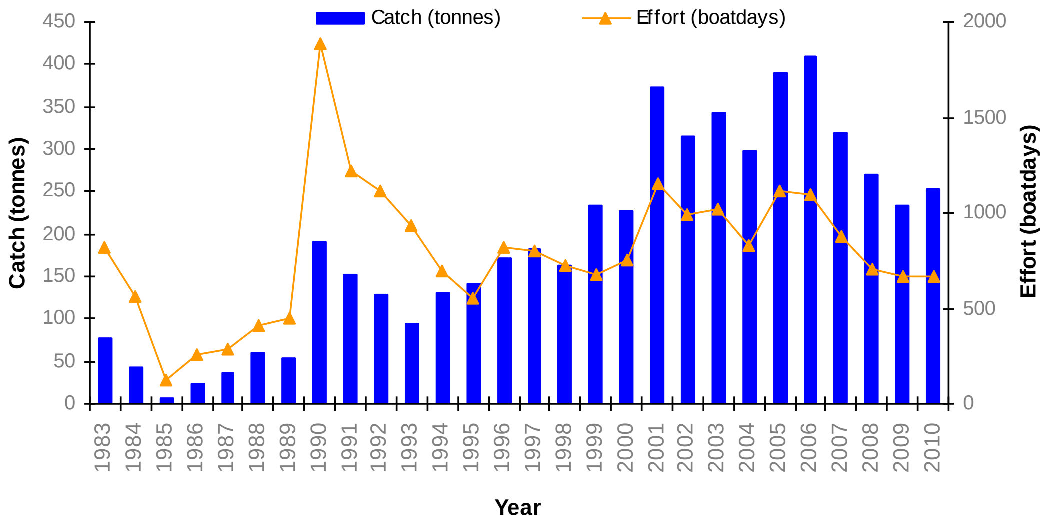

Figure 22.2. Annual catch (tonnes) and effort (boatdays) in the NT Spanish Mackerel Fishery, 1983 – 2010. Source: Northern Territory Government 2011.

Catch from the recreational and FTO sectors are reported in numbers and recent estimates put the catch of these sectors at approximately 62 t and 15 t respectively (Northern Territory Government 2011). An unknown quantity of Spanish mackerel are released after capture by these sectors in particular and this will result in a “cryptic” mortality component of total catch levels since the release mortality rate for Spanish mackerel is estimated to be approximately 54% (Northern Territory Government 2011). Indigenous catch levels are estimated to be very low (Henry and Lyle 2003). The current low harvest compared to high catches from the Taiwanese fleet in the 1970s and 1980s suggests that current harvest rates are well within sustainability limits which is supported by none of the management trigger reference points being exceeded in 2010 (Northern Territory Government 2011).

Table 22.1. Allocation of the allowable catch among the different fishery sectors (SPM = Spanish mackerel fishery; ONL = Offshore net and line fishery; FT = Finfish trawl fishery). Source: Northern Territory Government, 2011.

Sector	Sector allocation	Weight (t)
Commercial SPM licensees	76%	342
Commercial ONL licensees	3%	13.5
Commercial FT licensees	1%	4.5
FTO licensees	3%	13.5
Recreational fishers	16%	72
Indigenous	1%	4.5
Totals	***100***	***450***

Management of the Spanish mackerel fishery in the NT is by a catch sharing arrangement based on historical catch estimates for each of the commercial, recreational, FTO and Indigenous sectors. The allowable catch level across all sectors is 450 t per year and there are trigger points for the total catch level and for catch within each sector that require management review (Northern Territory Government 2011). See Table 22.1 for the current catch sharing arrangements.

Gulf of Carpentaria

Spanish mackerel account for the vast majority of the total catch taken in the Gulf of Carpentaria (GOC) Line fishery that operates throughout Queensland GOC waters. Fishers operate generally from a main vessel with a number of smaller tender vessels (DEEDI 2012a). The fishery is managed under the Queensland Fisheries Joint Authority through the *Fisheries Act 1994* and applies a variety of input and output management controls. These include limited entry to the commercial fishery, gear restrictions, some spatial closures, and a minimum legal size limit of 75 cm TL. During 2010 there were a total of 47 licences in the fishery however only 22 were active during the reporting period. Currently the stock status is listed as 'uncertain' due to a lack of data (DEEDI 2012a).

Commercial catch of Spanish mackerel in the GOC has gradually increased during the period 2000 to 2008 where it has peaked at 287 t, while for 2009 and 2010 the catch dropped to 189 t and 183 t respectively (Figure 22.3). A significant volume of Spanish mackerel is landed as a by-product in nets set to target grey mackerel by fishers in the GOC inshore finfish fishery. In 2010, 48 t of Spanish mackerel was taken in the nets set by the inshore net fishery. During this period (2000 – 2010) catch-per-unit-effort increased (DEEDI 2012a). Most of the commercial catch in the past two years at least has come from two main fishing areas: around Weipa in the north-eastern GOC, and in the area to the northeast of Mornington Island in the southeastern part of the GOC. Effort in the charter operator sector has been decreasing over the past 5 years with catches also decreasing. In 2010 the Spanish mackerel catch by the charter sector was estimated to be 2.9 t (DEEDI 2012a).

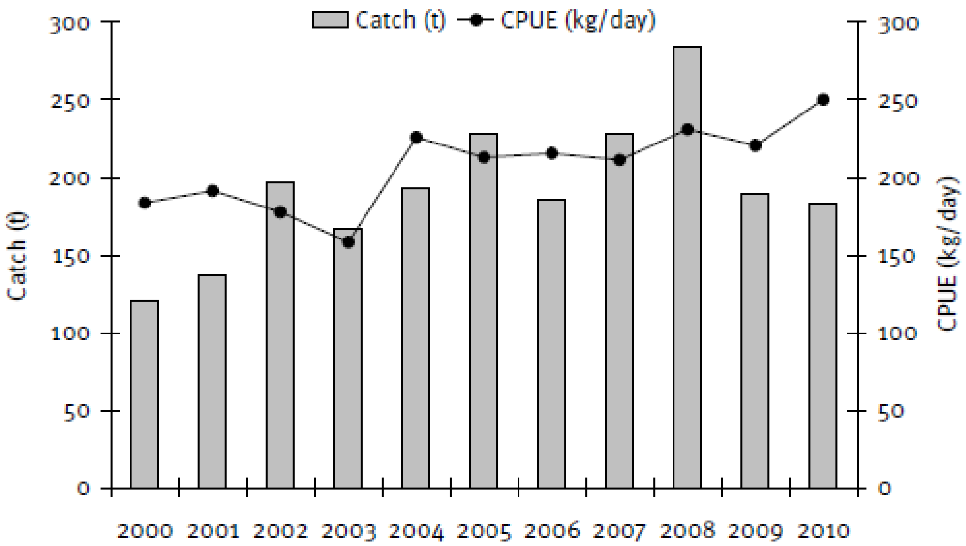

Figure 22.3. Annual total catch (tonnes) of Spanish mackerel taken in the Gulf of Carpentaria from 2000 – 2010. Source: DEEDI 2012a.

Torres Strait

Spanish mackerel is one of the key target species in the Torres Strait Finfish fishery. The fishery for Spanish mackerel is seasonal and principally targets fish near Bramble Cay in the northeastern Torres Strait between August and March (Marton *et al* 2011). The fishery is made up of fishers in two licence categories: the Traditional Inhabitant Boat (TIB) licences and the Transferable Vessel Holder (TVH) licences. As part of negotiations with the Federal Government, in 2008 all TVH endorsements were bought out and surrendered to the Torres Strait Protected Zone Joint Authority with a few still operating through leasing arrangements under quota only. In 2010 there were 5 TVH licenses with mackerel endorsements with only 4 active, and there were 161 TIB licenses with mackerel endorsements with 55 active (Marton *et al* 2011).

Despite catch restrictions, the TVH sector of the fishery accounts for most of the effort and catch and have mandatory logbook reporting requirements while the TIB sector do not. Therefore the reported catch from the fishery is always an under-estimate, as it does not include the TIB sector. Estimates of recreational catch are also not available. The most recent years of total reported commercial catch was lower than previous years reflecting the reductions in active TVH fishery licences and in 2009 was 88 t, down from its peak of approximately 250 t in 2005 (Figure 22.4; Marton *et al* 2011).

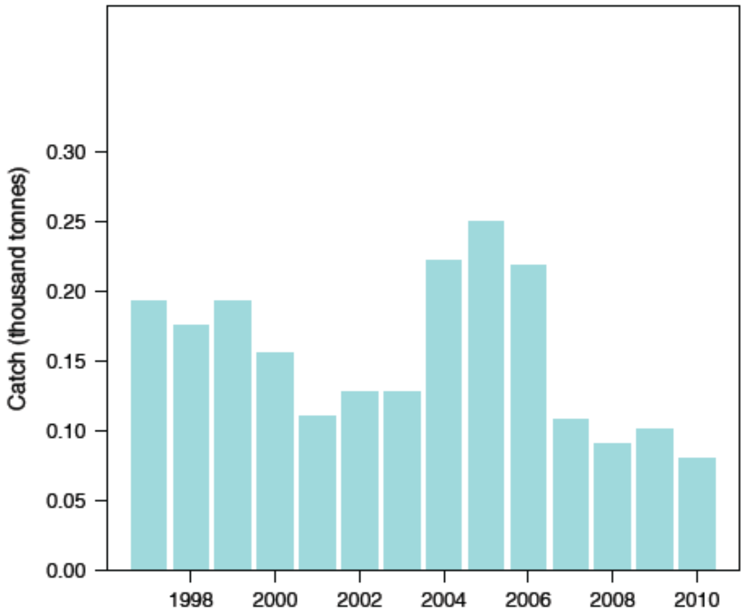

Figure 22.4. Annual total catch (thousand tonnes) of Spanish mackerel taken in the Torres Strait from 1997 – 2010 as reported by the TVH sector (non-Traditional Owners). Source: Marton *et al* 2011.

Queensland/New South Wales

On the east coast fisheries for Spanish mackerel span Queensland and northern New South Wales waters and are managed separately based on state jurisdictions despite current knowledge suggesting a single stock (Shaklee *et al* 1990). The New South Wales (NSW) fishery is highly seasonal with fish mainly only available during the summer/autumn months during a southerly migration associated with feeding and apparently linked with sea water temperatures. Commercial catches in NSW were higher during the period 1984/85 – 1993/94 (range: 15 – 51 t) and since then have tended to be lower ranging from 2 – 30 t annually (Rowling *et al* 2010). Estimates for the recreational sector are very coarse ranging from 10 – 100 t (Henry and Lyle 2003). Management in NSW uses output controls and includes a minimum size limit of 75 cm and a recreational bag limit of 5 (combined Spanish and spotted mackerel limit). NSW have adopted the Queensland assessment that Spanish mackerel is sustainably fished (Rowling *et al* 2010).

In Queensland the fishery generally extends throughout the year however historically the majority of the annual catch comes from a known spawning region near Townsville during the months of October and November (Welch *et al* 2002). The fishery is managed under a range of input and output management controls including a minimum size limit of 75 cm TL and a recreational bag limit of 3 fish. In 2004 a Total Allowable Commercial Catch (TACC) of 544 t was introduced. Since compulsory logbook reporting in 1988 reported commercial catch increased slowly to peak at approximately 800 t in 2003. With the introduction of the TACC annual reported catch has been from 200 – 400 t in the period 2004/05 to 2009/10 (Figure 22.5) (DEEDI 2012b). Reported catch from the charter boat sector has been between 20 and 30 t since 1999/00 and increased to 44 t in the 2009/10 reporting year (DEEDI 2012b).

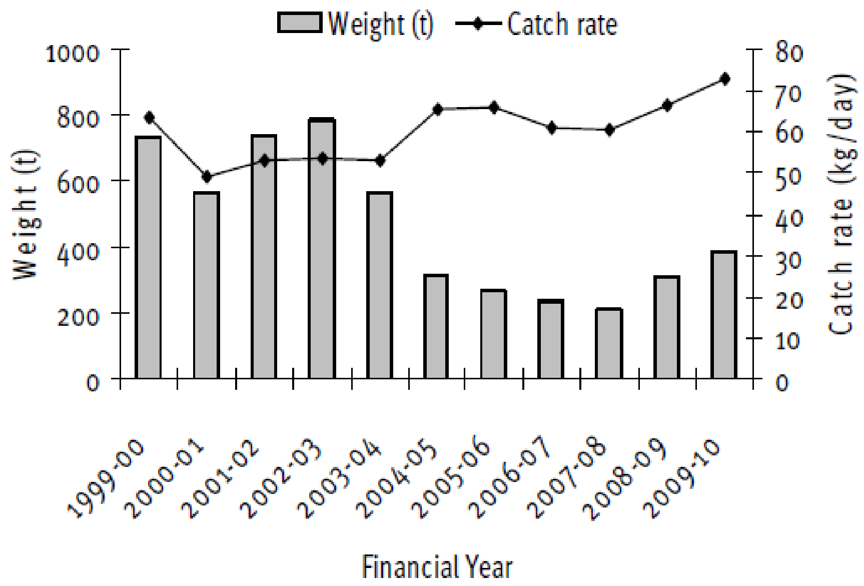

Figure 22.5. Annual total commercial catch (tonnes) and catch rate of Spanish mackerel taken on the Queensland east coast from 1999/00 to 2009/10. Source: DEEDI 2012b.

Life history

Key points:

- Spanish mackerel are highly productive being fast growing and mature at an early age. They are also highly fecund.
- They aggregate over large areas for spawning which appears to be triggered by SST.
- Spanish mackerel have seasonal movements possibly linked with SST, and migrate farther south during summer on the east and west coasts.

Life cycle, age and growth

Spanish mackerel are fast growing and highly mobile epi-pelagic species found in tropical and sub-tropical waters across northern Australia usually associated with reefs, shoals or current lines (Collette and Nauen 1983). Growth is rapid to a large size, with record fish exceeding 2 m in length and 100 kg in weight (McPherson 1992; Buckworth and Clarke 2001). Differential growth between sexes occurs with the females showing faster growth, greater maximum length and higher longevity reaching at least 17 years on the east coast (McPherson 1992; Tobin and Mapleston 2004) and up to 22 years on the north west coast (Mackie *et al* 2003).

Much of the following life history knowledge documented below is sourced from studies conducted on the east coast, and particularly the Great Barrier Reef. Similar life history patterns are assumed for other parts of northern Australia. Spanish mackerel are known to aggregate in large numbers to spawn. During the 1970's aggregations of spawning fish on the east coast were reported to occur between Lizard Island and Townsville. In recent years the only aggregation of spawning fish has occurred over a much smaller area on several reefs east of Ingham, north of Townsville. Fish gather on these reefs in large numbers between September and December each year. Spawning is determined by a combination of environmental factors particularly temperature, but can be observed over much of the two month period particularly during new moon phases (McPherson 1981a). Females in pre-spawning condition are common in troll catches during the morning hours of the day of spawning. Spawning appears to take place during late afternoon and early evening during which time the fish cease feeding. Feeding behaviour resumes immediately after spawning (McPherson 1981a; McPherson 1993). *S. commerson* is a serial-spawning species and females can spawn every few nights during a spawning run. In the tropics at least, spawning may be repeated over a protracted spawning season (Buckworth and Clarke 2001). Female Spanish mackerel are highly fecund (Moltibano *et al* unpublished data).

An unknown proportion of fish older than two years of age undertake post-spawning migrations into southern Queensland and northern NSW waters on the east coast, and on the west coast a similar seasonal migration is documented. These large-scale migrations are thought to be linked to seasonal warmer currents moving southwards (Donohue *et al* 1982; McPherson 1981b). On the east coast migratory fish return northwards near to the coast and inshore islands where small localised fisheries have developed for these larger fish. Patterns in water temperature and baitfish distribution are likely to affect adult distributions throughout the year.

Eggs are released into the plankton where they develop and hatch as larvae at approximately 2.5 mm in length (Munro 1942). They develop minute teeth by the time they are 5.6 mm long and become juveniles at approximately 14.5 mm (Jones, 1962). Larval duration is two to four weeks (Ovenden 2007). Larval *S. commerson* feed almost exclusively on larval fish and invertebrates (Jenkins *et al* 1984). Larvae are found on continental shelf waters and settle as juveniles in inshore nursery grounds. The absence of Spanish mackerel larvae in coastal and estuarine habitats suggests direct movement inshore by juvenile fish rather than passive transportation of eggs and larvae by currents and tides (Jenkins *et al* 1985). Juvenile fish inhabit shallow estuaries and intertidal flats for approximately the first six months of life (McPherson 1981a). Juvenile fish between 15 and 40 cm length are found in shallow coastal waters during February and March (Williams & O'Brien 1998). By May, juveniles leave inshore areas for offshore waters where fish around 50 cm begin to be represented in the catches of commercial fishers (McPherson 1981).

Growth of juvenile Spanish mackerel is typically rapid, reaching approximately 65cm fork length (FL) in the first year. They reach the current minimum legal size early in their second year of growth and attain approximately 80 cm FL by 2 years of age. Sexual maturity for males and females occurs around 2 years of age from about 79 cm FL (McPherson 1993; Montilbano *et al* unpublished data).

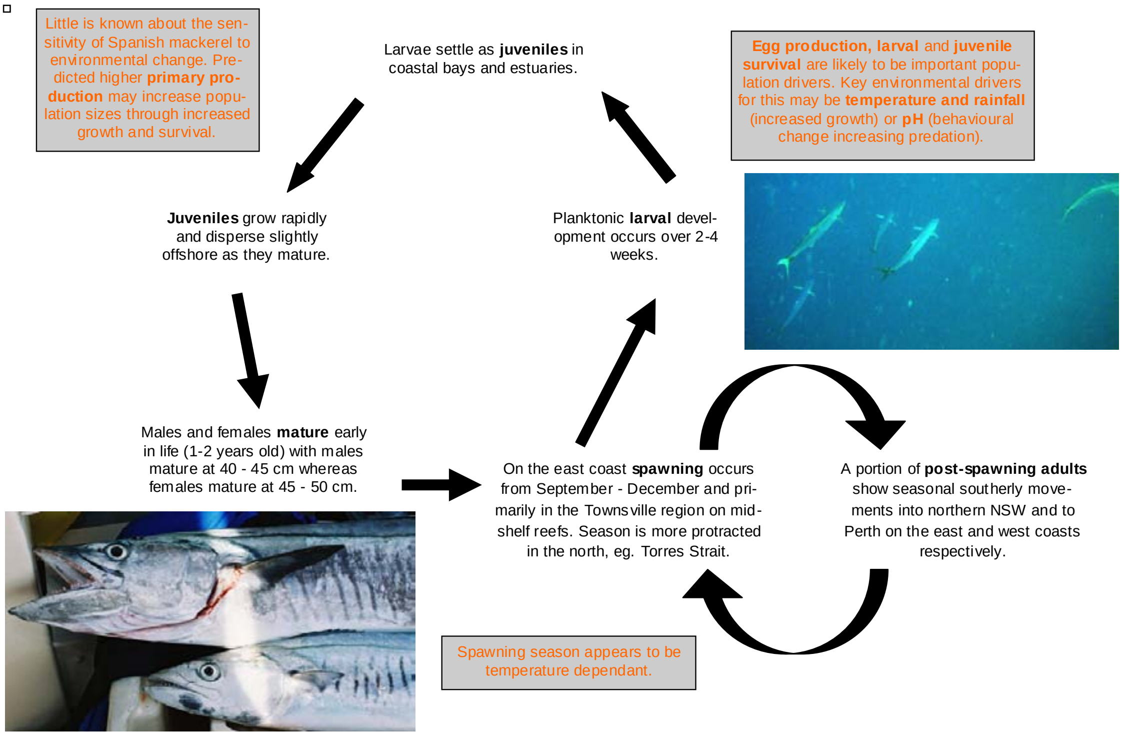

Figure 22.6. Generalised life cycle of the narrow-barred Spanish mackerel, *S. commerson*, and the stages of potential environmental driver impacts. Images: Mike Hanks, Michael de Rooy.

Distribution, habitat and environmental preferences

Spanish mackerel are found throughout tropical and sub-tropical areas of the Indo-west Pacific from Africa to Fiji. In Australia they extend across the northern coastline throughout continental shelf waters to approximately 30°S on both the east and west coasts (McPherson 1981; McPherson 1992). Their usual range has a southerly limit of the central NSW coast in the east, and at least as far south as Perth on the west coast (Figure 22.7). They are a highly mobile pelagic fish commonly associated with reef edges and headlands and have a preference for shallow coastal and continental shelf waters (Quinn 1993). They are usually associated with water temperatures of approximately 20° C or warmer (Buckworth and Clarke 2001; McPherson 1992).

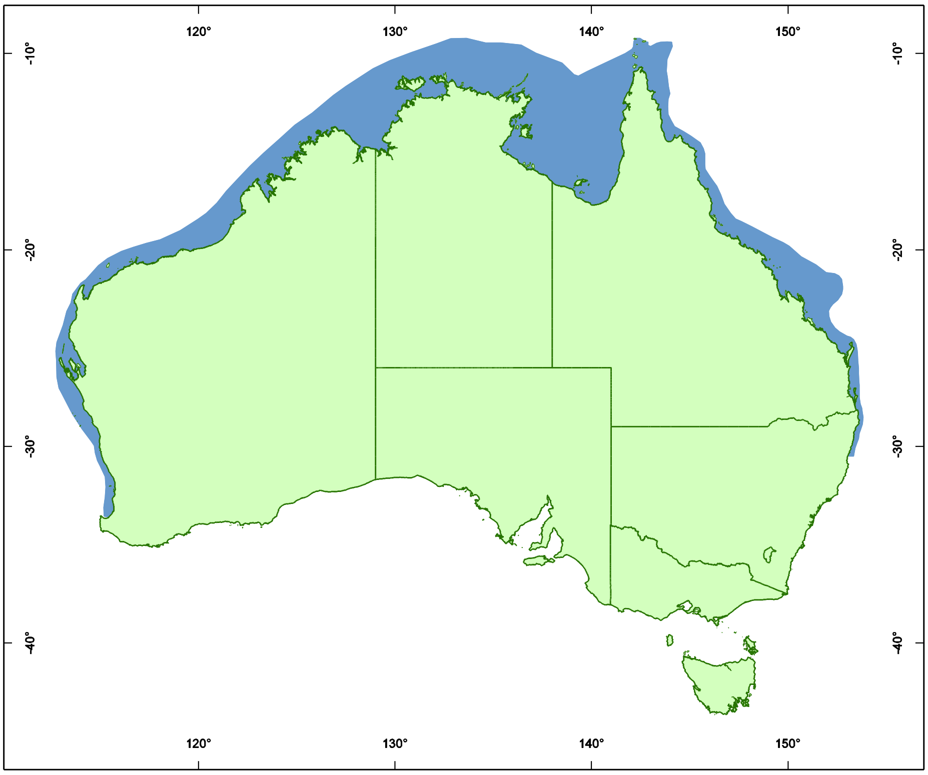

Figure 22.7. Australian distribution of Spanish mackerel.

Spanish mackerel is usually seasonally abundant (Collette and Nauen 1983). In the Northern Territory, this seasonality is apparently related to reproductive activity (Buckworth and Clarke 2001). Observed seasonal variations in availability of Spanish mackerel probably reflect cycles of seasonal aggregation and dispersal (Buckworth *et al* 2007). For example, on the east and west coasts a portion of the Spanish mackerel stock migrate to the southern extent of their usual range during Austral Summer/Autumn months (Welch *et al* 2002; Tobin and Mapleston 2004). Between-sex differences in dispersal rates is evident, with males likely to be the most active dispersers (Buckworth *et al* 2007; Ovenden *et al* 2007).

Predators and prey

Prey of Spanish mackerel are mostly smaller fish (including other *S. commerson*), and squids (Kumaran 1964; Rao 1964; McPherson 1987). Fisher anecdotes also report that penaids are often a dominate gut item (A. Tobin pers. comm.).

Recruitment

Juvenile *S. commerson* are known to recruit to nearshore environments including estuaries (Jenkins *et al* 1984). From examples of age structure population 'snapshots' and from the very few time series of age structure data available, there is evidence of variable strength in year classes among years. Tobin & Mapleston (2004) were first to identify this characteristic in Spanish mackerel from the Queensland east coast and continued age structure sampling by Fisheries Queensland (QDAFF) has confirmed this trait. Variable annual larval growth and survival is to be expected given natural variation in environmental conditions and primary production. The collection of more robust time series of age structure samples would inform more about recruitment variability. Inter-annual variation in catches of Spanish mackerel also suggests recruitment variation, though the quality of logbook data may compromise catch related analyses.

Current impacts of climate change

There are no documented impacts of climate change on Spanish mackerel.

Sensitivity to change

Key points:

- The sensitivity of Spanish mackerel to environmental variation is not well investigated, however annual spawning and southerly migrations on the east and west coasts appear to be temperature driven.
- Juveniles live in estuarine and nearshore waters during the Austral wet season and so rainfall/riverflow, and associated primary production, are likely to be important drivers of juvenile survival.

The sensitivity of Spanish mackerel to changes in the environment is poorly understood, although temperature has been postulated to strongly influence spawning seasonality and annual migrations. The East Australian Current has been shown to have increased in strength and has extended further southward over the past 60 years (Ridgeway and Hill 2009) and this may have influenced the annual southerly migrations of Spanish mackerel into NSW during this time but has not been investigated. With future predicted warming of the oceans Spanish mackerel may become a far more important species in NSW with the possibility of increasingly southwards migrations and/or an increasing presence through range shifting.

Given that Spanish mackerel settle as juveniles in inshore and estuarine nursery areas (McPherson 1981a; Williams and O'Brien 1998), their early survival and growth are potentially influenced by local rainfall and river flows as has been documented for other species with inshore early life history stages (eg. Halliday *et al* 2008, 2011).

Resilience to change

Key points:

- Spanish mackerel are highly mobile, highly fecund and fast growing making them generally resilient. They also have a wide distribution across arnge of habitats. The availability and abundance of baitfish as prey may be the key limiting factor.

Spanish mackerel have a broad distribution range covering the entire northern Australian coastline. This, and the fact they are a highly mobile pelagic species, suggests they may be resilient to changes in the environment. They are also a highly productive and fast growing species, which makes them resilient to relatively high levels of fishing pressure.

Other

Key points:

- Spanish mackerel are known carriers of ciguatera. The effects of climate change on the incidence of ciguatera are poorly known but may be significant.
- Research on the importance of temperature and riverflow (rainfall) as population drivers needs to be conducted.
- Research on the sensitivity of early life history stages to altered sea temperatures and pH should also be conducted.

Ecosystem level interactions

Spanish mackerel are known carriers of ciguatera. Ciguatera poisoning is caused by a microscopic organism that attaches itself to algae growing in the warm waters of coral reefs. Small fish eat the algae, and are in turn eaten by larger fish such as Spanish mackerel. This food chain effect means that larger fish can accumulate enough of this organism to make their flesh toxic to humans when eaten. Ciguatera poisoning has been noted to be particularly prevalent in areas that have experienced some form of ecosystem disruption. Some examples of this may be pollution from industry, agricultural and human effluent, reef damage from cyclones, or coral bleaching triggered by rising water temperatures through the insidious effects of climate change. However, not all damaged reef environments exhibit outbreaks of ciguatoxic fish (Lewis and King 1996).

Additional (multiple) stressors

While harvest levels appear sustainable for most Spanish mackerel fisheries (Holmes *et al* 2012) there has been historical evidence of unsustainable harvest levels (see Begg *et al* 2006; Grubert *et al* 2013) suggesting this species is sensitive to poorly regulated fishing pressure.

Given the juvenile preference for nearshore waters, the survival of annual cohorts may be more affected by land-based influences on estuarine and nearshore conditions, such as changes in water quality and runoff that may negatively impact preferred habitats and/or prey.

Critical data gaps and level of uncertainty

Better estimates of recreational harvest levels for all stocks across northern Australia are needed given the importance of Spanish mackerel to this sector and the fully fished status of all fisheries. The sensitivity of Spanish mackerel early life history and adult stages to increases in temperature should be investigated since the spawning times and seasonal movements appear to be linked to certain times and places. The effect of rainfall/river flows on early life history survival and subsequent recruitment to the fishery should be investigated via recruitment indices and commercial catch data.

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23. Spotted mackerel, *Scomberomorus munroi*

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The Australian spotted mackerel, *Scomberomorus munroi*, (hereafter referred to as the spotted mackerel) is a member of the family Scombridae (the tunas and mackerels). The species is distributed in the northern half of Australia, from the Abrolhos Islands in Western Australia (WA) to central New South Wales (NSW), and southern Papua New Guinea. The spotted mackerel is particularly significant to both recreational and commercial fishers in the Queensland East Coast Inshore Fin Fish Fishery (ECIFFF).

The fisheries

- Catches in Western Australia, Northern Territory and the Gulf of Carpentaria are poorly known but are likely to be relatively low.
- The majority of the catch is from the Queensland east coast but significant commercial and recreational catch is also made in NSW.
- Commercial catch on the Qld east coast is regulated by a total allowable catch quota however, recreational catch in this fishery is not known.

Western Australia and Northern Territory

Commercial catches of spotted mackerel are negligible in Western Australia and are reported under "other mackerel" at 0.9 t in 2010 (WA Government 2011). There is no reported commercial catch of spotted mackerel in the Northern Territory however it is most likely taken and mixed in with other mackerel. In both Northern Territory and Western Australia most spotted mackerel landings are likely to be from the recreational fishing sector.

Queensland

In the Queensland Gulf of Carpentaria Inshore Fin Fish Fishery the commercial catch of spotted mackerel is low. In 2007, the only year for which data can be reported due to confidentiality reasons (less than 5 vessels), only 4 t was landed (DEEDI 2011a). The commercial catch in the Queensland Gulf of Carpentaria Line Fishery is not known but is unlikely to be high as the total commercial catch of all mackerel was 185 t in 2009 and was almost entirely comprised of Spanish mackerel (*Scomberomorus commerson*) with only 0.2 t of by-product species (DEEDI 2011b). The recreational catch in the Gulf of Carpentaria is not known. Spotted mackerel are landed in the Torres Strait Finfish Fishery but are reported under by-product species which is a minor component of the total catch (Marton et al. 2010).

The Queensland ECIFFF is a multi-species fishery comprising of charter, commercial, Indigenous and recreational fishing sectors. It is Queensland's largest and most diverse fishery. Fishing methods used are hook and lines (all sectors) and nets (commercial). Until 2002/03, commercial ring netting of spotted mackerel was legal and commercial catch was considerably larger than current levels (Figure 23.1). As of 2003/04, commercial landing of spotted mackerel in the ECIFFF has been restricted to a total allowable catch of 140 t and the combined catch for all sectors is recommended not to exceed 296 t (DEEDI 2011b). Commercial landings were 100 t in 2009-10 and have been highly variable over the past four years (average annual catch: 65 t). Charter landings were 11 t in 2009/10 (DEEDI 2011b). The most recent estimate of recreational harvest from the statewide RFISH diary surveys was 148 t in 2005 (DEEDI 2008). Begg *et al*. (2005) re-analysed all RFISH data in a standardised manner, and obtained estimates of total annual recreational catch from Queensland of between 52 t and 265 t (mean of 175 t).

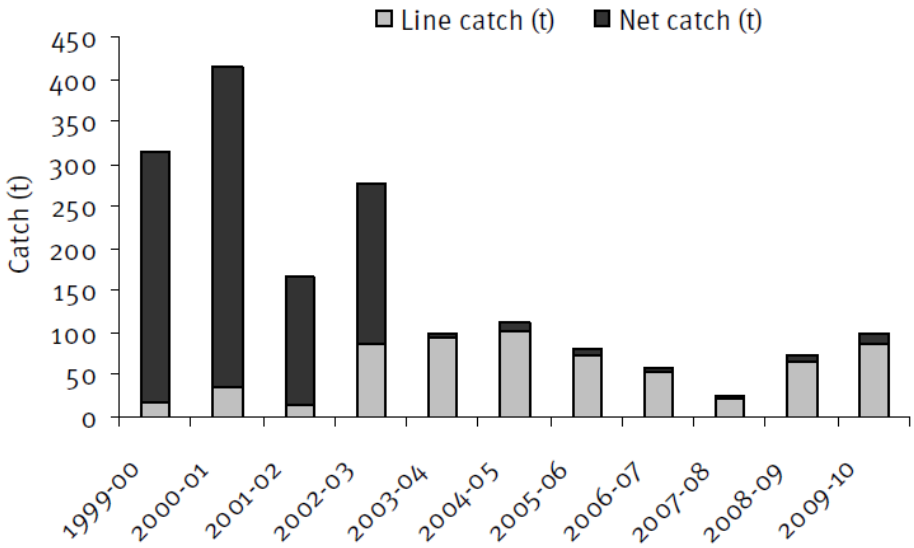

Figure 23.1. Commercial catch (t) of spotted mackerel caught by line and net in the ECIFFF, reported in logbooks 1999-00 to 2009-10. The substantial net catch prior to 2003-04 was the result of ring netting, which was banned from 2003-04 (Figure extracted from DEEDI 2011b).

Monitoring of spotted mackerel catches on the east coast since 2008 indicate that the commercial sector tend to take more fish in smaller size classes relative to the recreational sector. Very few fish over 95 cm TL are taken in either sector. The age structure taken by each sector is very similar and the majority of the catch by both sectors are comprised of 1- and 2-year old fish with fish older than 5 yrs being rare. The oldest fish sampled during monitoring was an 8-year old male (http://www.dpi.qld.gov.au/28_21410.htm, accessed 12/04/2012).

New South Wales

Spotted mackerel are landed commercially in the ocean trap and line fisheries in New South Wales as a key secondary species. The annual commercial catch ranges from less than 10 t to nearly 60 t (Figure 23.2). The species is also landed in the NSW recreational fishery and is thought to be between 10 t and 100 t (Rowling et al. 2010).

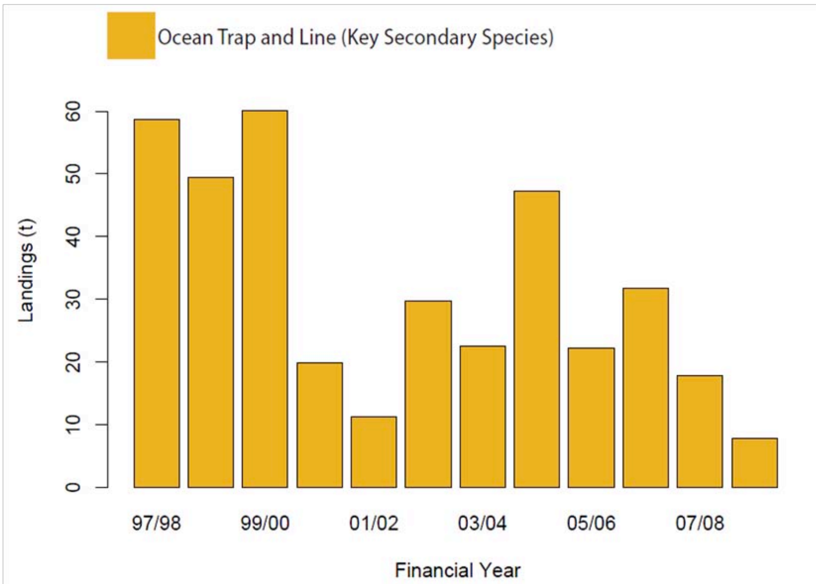

Figure 23.2. Reported landings of spotted mackerel by NSW commercial fisheries from 1997/98. Fisheries which contribute less than 2.5% of the landing are excluded (Figure extracted from Rowling et al. 2010).

Life history

- Life history knowledge for spotted mackerel is based entirely from research on east coast fish, which appear to be a single stock separate from the rest of Australia.
- They grow fast and mature early. Juveniles recruit to estuarine and nearshore areas.
- Adults move south into NSW during the austral summer and north for spawning from August to October in the Townsville/Mackay regions.

Life cycle, age and growth

A comprehensive understanding of spotted mackerel ecology and life history has been documented for the Australian east coast (Begg and Hopper, 1997; Begg et al., 1997; Begg, 1998; Begg et al., 1998; Begg and Sellin, 1998) (Figure 23.3). Spotted mackerel are dioecious (ie. separate sexes). Males attain sexual maturity between 401-450 mm FL and females between 451 to 500 mm FL and spawning occurs in northern Queensland waters from August to October (Begg, 1998). There is evidence that spawning is restricted to the waters between Townsville and Mackay (Jenkins et al. 1985). Aggregations of spotted mackerel seasonally occur mid-year north of Townsville, but these are not considered to be aggregations associated with any spawning (Cameron and Begg, pers. comm.). A tagging study has provided some evidence for a seasonal migration of spotted mackerel in that recaptures occurred to the north of the release sites (Rockhampton and Hervey Bay) in August and September but to the south of these locations during the Austral summer (Begg et al., 1997). Movements into NSW are therefore seasonal and restricted to the Austral summer and autumn months. Movements north of Cairns and in the Northern Territory and Western Australian waters are unknown. Known movements support a genetic study which identified that spotted mackerel form a single stock on the east coast of Australia and that this stock was genetically different from that in the Northern Territory (Cameron & Begg 2002). No information is available on Western Australian stocks or where the boundary between the Queensland east coast stock and the Northern Territory stock occurs.

Growth of spotted mackerel has been studied by Begg and Sellin (1998) for Queensland and NSW. In that study Von Bertalanffy growth parameters differ between the sexes but regional differences were minor with respective parameters in the range of: L_∞ = 727 to 729 mm FL, K = 0.272 to 0.339 and t_o = -4.00 to –2.53 for males and L_∞ = 823 to 866 mm FL, K = 0.41 to 0.52 t_o = -1.96 to -1.36. Longevity of spotted mackerel is at least 8 years and they are known to attain 104 cm and 10 kg in weight (Allen, 2009).

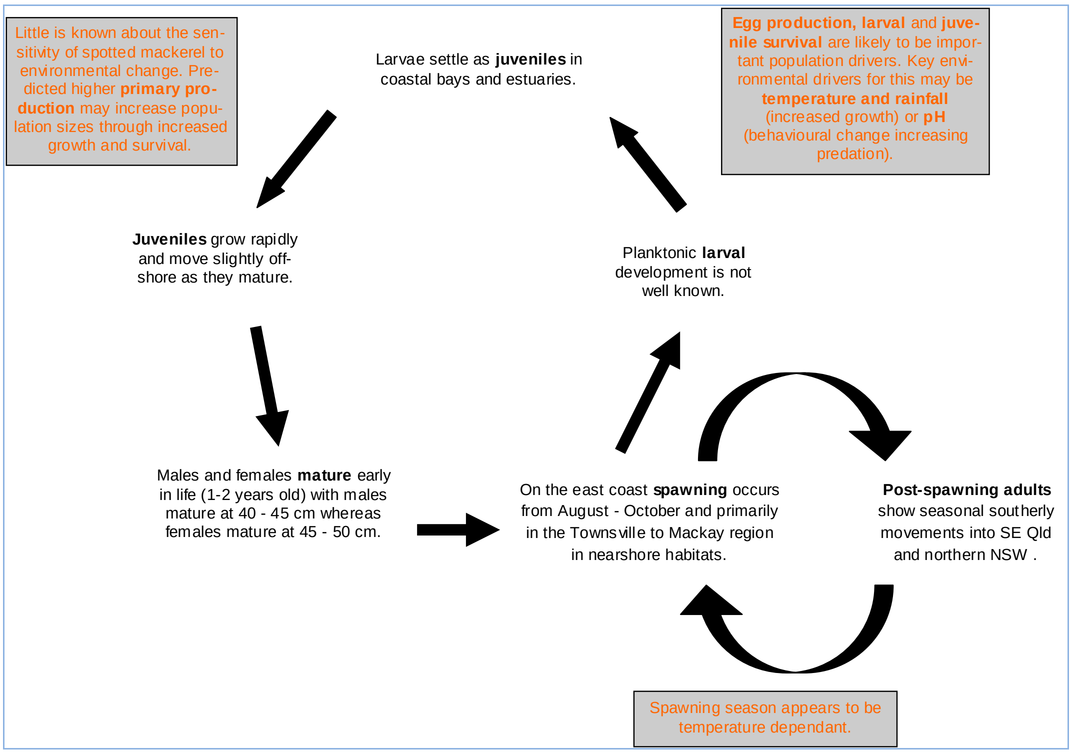

Figure 23.3. Generalised life cycle of the spotted mackerel, *S.munroi*, and the stages of potential environmental driver impacts. Life cycle is based on published research for the east coast stock (Begg and Hopper, 1997; Begg et al., 1997; Begg, 1998; Begg et al., 1998; Begg and Sellin, 1998).

<u>Distribution, habitat and environmental preferences</u>

The spotted mackerel is distributed in the northern half of Australia, from the Abrolhos Islands in Western Australia to central New South Wales, and southern Papua New Guinea (Figure 23.4). The species is found in coastal seas throughout the region. Research encompassing otolith microchemistry, genetic diversity, tagging and reproductive biology as well as seasonal variation in commercial harvesting strongly support the hypothesis that spotted mackerel form a single east coast stock with an annual large scale movement along the Queensland east coast to northern New South Wales. This includes Queensland and New South Wales feeding grounds in summer and a return migration in winter to northern spawning grounds (Begg and Hopper 1997, Begg et al 1997; Begg et al 1998; Begg 1998; Cameron & Begg 2002).

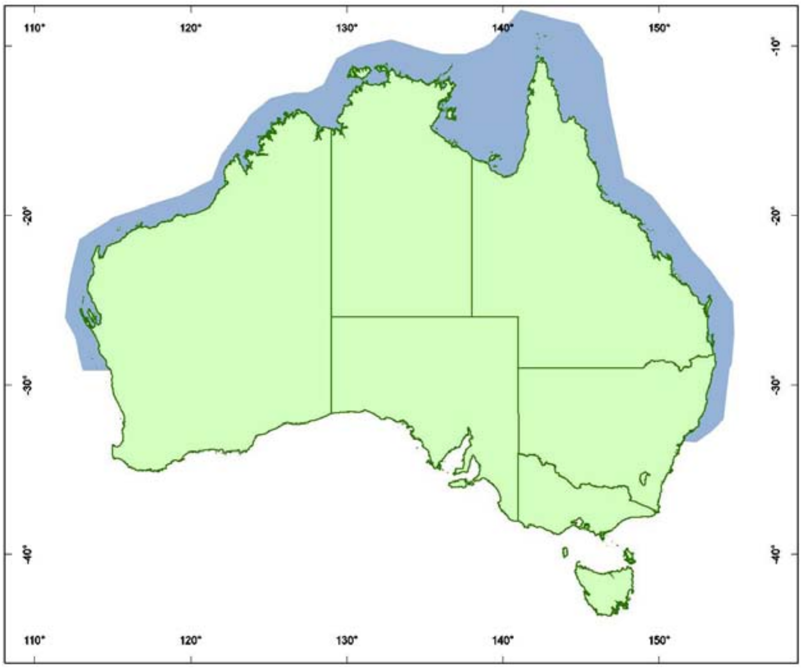

Figure 23.4. Australian distribution of spotted mackerel.

Predators and prey

Spotted mackerel feed primarily on fish, particularly Clupeids and Engraulids. The diet is also supplemented with invertebrates such as prawns and squid (Begg & Hopper, 1997).

Recruitment

There is no information on egg and larval development of spotted mackerel. They are known to have a pelagic larval phase and it is believed that larvae and juveniles move into coastal embayments and estuaries. This suggests that survival of annual cohorts are likely to be influenced not only by local environmental conditions, such as water temperature, salinity, pH, rainfall and river flow, but also by land-based influences on estuarine and nearshore conditions. Fishery independent measures of recruitment are unavailable across regions however, inter-annual variation in landings of spotted mackerel suggest some recruitment variation.

Current impacts of climate change

There are no reported impacts of climate change on spotted mackerel.

Sensitivity to change

- The known east coast spawning area is spatially and temporally restricted, i.e. north Qld from August to October, and likely to be linked to SST.
- Potential southerly extension of the species range and annual migratory pattern with increasing SST.
- Annual population recruitment may be influenced by local riverflow/rainfall since juveniles reside in estuaries and associated habitats.

As drivers for spawning are unknown, there is the potential for climate change to impact on spotted mackerel spawning patterns and distribution. Thermal tolerances are not understood however the species migrations appears to be correlated with water temperatures. The presence of reproductively active fish in waters of north Queensland is associated with a period of lower temperatures and annual southward migrations are correlated with warming waters during the Austral summer and autumn. The East Australia Current has been shown to have increased in strength and has extended further southward over the past 60 years (Ridgeway and Hill, 2009) and this may have influenced the annual southerly migrations of spotted mackerel into New South Wales during this time but this has not been documented anywhere. If, as is predicted, this trend continues, spotted mackerel may become a far more important species in New South Wales, especially since larger spotted mackerel are more typical in New South Wales, with the possibility of increasingly southwards migrations and/or an increasing presence through a range shift.

The early life history stages of most organisms are generally more sensitive to environmental conditions. Although not documented for spotted mackerel, based on evidence for other similar *Scomberomorus* species (see McPherson, 1978, 1981; Williams & O'Brien, 1998; Halliday et al, 2001), they may settle as juveniles in inshore and estuarine nursery areas. This makes early survival and growth potentially influenced by local rainfall and river flows as has been documented for other species with inshore early life history stages (eg. Halliday et al, 2008, 2011).

Resilience to change

- Spotted mackerel have a broad distribution across northern Australia, are highly mobile and highly productive.
- Annual spawning (on the east coast) is restricted in time and place.

Spotted mackerel have a broad distribution range covering the entire northern Australian coastline. Although at least two stocks are apparent across this range, the spatial scale of stock division is vast. For example, the east coast population of spotted mackerel, at least to Cairns in the north, has been shown to represent a single stock (Begg et al., 1997; Begg et al., 1998; Begg and Sellin, 1998). This broad distribution, and the fact they are a highly mobile pelagic species, suggests they are resilient to changes in the environment. Further, spotted mackerel have been shown to have variable growth rates, as well as size and age at maturity and sex change depending on location and possibly population densities indicating they are an adaptable species to varying environmental and population conditions. They have a broad diet with two of their major prey families (Clupeids and Engraulids) some of the most prolific baitfish species throughout northern Australia.

Other

- Recreational harvest levels are poorly understood.
- A close association of early life history stages with inshore estuarine habitats suggests rainfall/riverflow and land-based influences may affect population recruitment, however this is poorly understood.

Ecosystem level interactions

Spotted mackerel rely on schooling baitfish as prey species and the effects of climate change on baitfish species remains very poorly understood.

Additional (multiple) stressors

Spotted mackerel are a popular target species on the Australian east coast, particularly for recreational fishers, which will inevitably increase with increasing human populations. The commercial fishery was historically heavily fished, however management changes that introduced a total allowable commercial catch (TACC) and restricted commercial fishing gear to hook and line has reduced annual catch from a peak of 410 t in 2000-01 to the average annual catch over the past four years of 65 t (DEEDI, 2011b). The level of recreational catch is poorly understood.

Given the likelihood of juvenile preference for nearshore waters the survival of annual cohorts may be more prone to being affected by land-based influences on estuarine and nearshore conditions, such as changes in water quality.

Critical data gaps and level of uncertainty

Better estimates of recreational harvest levels for both Queensland and New South Wales need to be determined given their importance to this sector and the high level of uncertainty in current estimates. Future assessments should use data from each jurisdiction (Qld, NSW) since the east coast is assumed to represent a single stock.

The sensitivity of spotted mackerel early life history and adult stages to increases in temperature and rainfall should be investigated since the spawning areas appear to be linked to certain times and places (north Qld waters during August-October), and the fishery sector allocation implications of a southerly shift in their range. The effect of rainfall/river flows on early life history survival and subsequent recruitment to the fishery should be investigated via recruitment indices and commercial catch data.

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