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Freshwater Flow Requirements of Estuarine Fisheries: Data Review and Research Needs

LWA Tropical Rivers Program

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PROJECT OBJECTIVES

a) Develop or adapt existing (where possible) conceptual models of the links between water flow and estuarine-dependent fisheries for catchment types in the Gulf of Carpentaria.
b) Identify and review the value of current datasets relevant to these conceptual models.
c) Identify gaps in the knowledge and research needs that would contribute to determining the freshwater requirements of estuarine-dependent fisheries in the Gulf of Carpentaria.

APPROACH AND METHODS

BACKGROUND

The estuaries of Australia's tropical rivers support commercial fisheries for finfish and shellfish valued at over $220 million per annum. There are also significant tourism-related and local recreational and indigenous fisheries for icon species such as barramundi and mud crabs. Development of water resources in Australia's Tropical Rivers region is being planned, with development options being considered for the Flinders, Mitchell, McArthur, Roper, Daly and Victoria catchments. Greater knowledge of the water requirements of tropical aquatic ecosystems is crucial, so that downstream effects of water resource development can be managed and/or minimised.

Most research into the environmental flow requirements of aquatic ecosystems has focused on freshwater areas in southern Australia. Concepts developed from such research will require considerable modification to be applicable to estuaries of the Gulf of Carpentaria. There is a need to develop conceptual models of the role of fresh water in tropical estuaries that can estimate likely impacts of flow modification on fisheries and the industries that these resources support (i.e., commercial and recreational fishing and fishing-related tourism). This will require targeted research into the causal mechanisms of the flow-fisheries production relationship. Currently, there is insufficient information on the freshwater requirements of estuaries to permit standard environmental flow methods to be applied. Water Resource Plans for the Pioneer and Burdekin catchments (tropical, Queensland east coast), recognised the importance of freshwater for fisheries production in estuarine and adjacent-coastal waters, but were unable to consider the needs of the estuary because of lack of data and conceptual models. The first step in addressing these deficiencies is to review available data and to prioritise the critical knowledge required to allow the informed sustainable development of tropical water resources.

CONCEPTUAL MODELS OF THE LINKS BETWEEN WATER FLOW AND ESTUARINE-DEPENDENT FISHERIES FOR CATCHMENT TYPES IN THE GULF OF CARPENTARIA

Conceptual models of the role of freshwater flow for estuarine-dependent fisheries were developed by the FRDC project 2001/022 (based in the Fitzroy River, a dry tropical estuary on the Queensland east coast) using an integrated framework (Robins *et al.* 2005). These conceptual models for key commercially and recreationally important fisheries species were assessed for their transferability to various catchment/estuary types in the Gulf of Carpentaria, and where necessary modified to suit conditions in the Gulf of Carpentaria. Input to the conceptual models was sought from experts familiar with Gulf of Carpentaria estuarine-dependent fisheries, including researchers from Queensland Department of Primary Industry and Fisheries, NTDPI&F, CSIRO, and local commercial, recreational and indigenous fishers.

IDENTIFY AND REVIEW THE VALUE OF CURRENT DATASETS RELEVANT TO THESE CONCEPTUAL MODELS

State and Commonwealth agencies were surveyed to compile an inventory of data relevant to estuarine-dependent fisheries in the Gulf of Carpentaria (GoC). Metadata for the available data has been compiled into a web-searchable database for information not already available. A portal to the respective meta-databases is provided on the Coastal Zone Co-operative Research Centre's website. Information collated is in the form of the ANZLIC standard and includes data custodianship, accessibility (e.g., cost, restrictions, access requests), and data fields (e.g., localities, time-frames, collection methods, measurements).

Very few of the data sets have been collected with the specific view of looking at the effects of freshwater on populations and is therefore of little immediate value to the current project. Those datasets with existing hard parts of fish (ie. scales and otoliths) are of most value in attempting to determine the role of freshwater on fish populations as it allows a longer time series of data to be achieved at a much lower cost.

IDENTIFY GAPS IN THE KNOWLEDGE AND RESEARCH NEEDS THAT WOULD CONTRIBUTE TO DETERMINING THE FRESHWATER REQUIREMENTS OF ESTUARINE-DEPENDENT FISHERIES IN THE GULF OF CARPENTARIA.

Significant knowledge gaps were identified and translated into research needs for determining the freshwater flow requirements of estuarine-dependent fisheries, based on the available data and conceptual models. Feedback on the relevance of these research needs was sought from stakeholders in the GoC.

RESULTS

1. CONCEPTUAL MODELS OF THE LINKS BETWEEN WATER FLOW AND ESTUARINE-DEPENDENT FISHERIES FOR CATCHMENT TYPES IN THE GULF OF CARPENTARIA

Conceptual models of the impacts that freshwater flows have been developed for seven species or species complexes that are caught in both the commercial and recreational fisheries and reviewed by researchers with experience in the Gulf of Carpentaria (Appendix 1). These conceptual models have been used to develop a range of research that could potentially elucidate the linkages between the importance of freshwater flows and fisheries production.

The common themes in all the conceptual models are:

- Connectivity and access to seasonal habitats
- Distribution of larval through chemical cues
- Stimulation of movement either towards or away from freshwater influences
- Enhanced biological productivity in estuaries

A wide range of different views on the usefulness of this type of research have been expressed by various researchers throughout the process of conceptual model development. These have been incorporated into the conceptual models presented in Appendix 1.

2. Identify and review the value of current datasets relevant to these conceptual models

We have compiled meta-data for 77 studies or data sets that are relevant to estuarine and coastal waters fisheries production of the Gulf of Carpentaria. Most of these datasets were not collected to determine the role of freshwater flows on estuarine fisheries production.

The Northern Prawn Fishery has had significant work undertaken to determine the lifecycles, effects of fishing and possible drivers of the prawn populations in the Gulf of Carpentaria. There has been comparatively little work on the finfish stocks. Only 15 metadata sets relate to estuarine finfish and mud crab stocks. Only one of these studies, on mudcrab recruitment and freshwater flows in the Roper and McArthur Rivers of the Northern Territory, was designed to identify the possible linkages between mud crab fisheries production and the influence of freshwater flow.

Commercial catch data is returned as a compulsory part of a fishing licence. Although there is a reasonable data set of fish catch from the commercial sector in both Queensland and Northern Territory, catch records are not a reliable measure of the overall fisheries production because of the vagaries of fisheries management (changes in input and output controls for social as well as biological reasons) and the reliance on data with very little or no validation. The resolution at which this data is collected makes it difficult to isolate different river systems particularly when the mouths of these systems are within 30 nM of each other. Catch data collected from commercial fisheries in both Queensland and the Northern Territory could be used to identify biogeographical regions within the Gulf of Carpentaria.

Of the finfish data sets identified, only 3 have collections of hard parts that could possibly be used in an attempt to hindcast the effect of flows on the fisheries production as measured by year class strength. These are some barramundi and king threadfin hard part collections from limited locations in the Northern Territory and collections made by the Queensland

Fisheries Service Long term monitoring program in the Flinders and Staaten Rivers in the Queensland section of the Gulf of Carpentaria. These existing collections of hard parts (otoliths and scales) may allow hindcasting to be used to determine if there have been major climatic influences on the age structure of the Gulf of Carpentaria fin fish populations using a variety of analysis techniques including ageing, otolith microchemistry and marginal increment analysis.

Although fisheries production is generally considered to be the catch of the particular species in question there are a range of problems when dealing with catch or CPUE alone. These often relate to the changes in fisheries management arrangements that are adapted over time. For longer lived fin fish species a better indicator of the role of freshwater flows is considered to be the year class strength of each year class entering the fishery. By using this type of model as the production estimate there is a greater chance of determining which flow events are creating conditions that are favourable to the survival of young of the year fish that enter the catch after a considerable lag time (years).

Otoliths from fish in tropical waters are notoriously difficult to age (probably because of the maintenance of high water temperatures throughout the whole in year) leading to the use of scales to age fish from tropical climates. The use of microchemistry may present an opportunity to validate the ages of these fish when other estimates of the age are less reliable.

The lack of river flow gauging stations throughout the Gulf of Carpentaria limits the available data of this measure. Rainfall records may provide a more accurate and wide spread coverage within the river catchments and associated estuaries.

3. IDENTIFY GAPS IN THE KNOWLEDGE AND RESEARCH NEEDS THAT WOULD CONTRIBUTE TO DETERMINING THE FRESHWATER REQUIREMENTS OF ESTUARINE-DEPENDENT FISHERIES IN THE GULF OF CARPENTARIA.

The current knowledge of fin fish populations in the Gulf of Carpentaria is limited to:

- information on the catches of fish from the commercial fishery
- information on the recreational fishery around Karumba
- some information on the biology and feeding patterns of barramundi
- very limited information on biological and ecological requirements of all other species caught in the commercial and recreational fisheries
- all information is limited in the geographical scope
- no social or economic valuations of the estuarine fishery.

The freshwater requirements of estuarine dependent fisheries of the Gulf of Carpentaria (other than for banana prawns) have not to date been investigated through a targeted research program. This is especially so for the fin fish of the region where even the basic biological requirements of many of the species is not understood and extends to the social and economic values of these fish species to the local and wider communities.

As an initial assessment of the likely linkages between estuarine fisheries production and freshwater flow in the Gulf of Carpentaria catchments should:

- Standardise ageing between northern Australian researchers of various fish species
- Apply the conceptual model developed by Robins *et al.* (2005) in investigating the role of freshwater flows to existing hard part data sets and flow/rainfall records
- Target collection of fish hard parts from estuarine fisheries of the rivers most likely to be affected by water infrastructure.
- Require direction from water managers on the most likely catchments to be affected.

Correlative analysis of existing data sets for catch and flow would be the starting point for determining if further investigations are warranted. Using the conceptual methodologies of Robins *et al.* (2005) a number of fishery production models can be investigated. These include effects on catchability, recruitment (as year class strength) and productivity. Through the use of hard parts and existing catch records it may be possible to identify different estuarine characteristics linked to fisheries productivity.

The appropriate technique for ageing of fish using scales (as in NT) and otoliths (as Qld) for tropical estuarine fish species should be developed and standardised. Initial assessment should be made using ageing of both scales and otoliths to standardise the ageing and develop reliability of the ageing procedure.

ADOPTION OF OUTPUTS AND SUMMARY OF COMMUNICATION AND ADOPTION ACTIVITIES TO DATE

Web-accessible meta-database of inventory of current data on fisheries in the Gulf of Carpentaria can be found at **WWW.COASTALZONE.ORG.AU** .

ASSESSMENT OF COMMERCIAL POTENTIAL

Nil

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SOURCES OF ADDITIONAL INFORMATION

Robins, J. B., Halliday, I. A., Staunton Smith, J., Mayer, D. G. and Sellin, M. J. (2005) Freshwater-flow requirements of estuarine fisheries in tropical Australia: a review of the state of knowledge and application of a suggested approach. *Marine and Freshwater Research* **56**, 343-360.

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Appendix 1: Conceptual Models and research needs into the links between water flow and estuarine fisheries for the Gulf of Carpentaria catchments.

OVERVIEW

The estuaries and near-shore waters of the Gulf of Carpentaria support commercial, recreational and indigenous fisheries for a number of prawn, finfish, shark and crab species. The main species of importance to fisheries are banana prawns (*Fenneropenaeus merguiensis*) tiger prawns *(P. esculentus, P. semisulcatus),* endeavour prawns *(Metapenaeus ensis, M. endeavouri*), barramundi (*Lates calcarifer*), king threadfin (*Polydactylus macrochir*), blue threadfin (*Eleutheronema tetradactylum*), grunter *(Pomadasys kaakan, P. argenteus),* sharks (*Carcharhinus tilstoni, C. sorrah, C. leucas, C. limbatus*) and mud crabs (*Scylla serrata*) (Table 1). These species are harvested by a variety of methods, including otter-trawls, set gill-nets, and traps (i.e., pots), with target species being method-specific.

Table 1. Production and value of commercial fisheries in tropical estuarine and near-shore waters within the Gulf of Carpentaria (Australia) for species that are 'connected' with rivers.

Common name	**Species**	**Qld**[1]	**NT**[2]
White banana prawn	*Fenneropenaeus merguiensis*	Avg 4,000t, $50M, Range 2,000 t to 14,000 t (Commonwealth managed)	
Brown tiger prawn Grooved tiger prawn	*Penaeus esculentus* *P. semisulcatus*	2,116t, $65 M (Commonwealth managed)	
Red endeavour prawn Blue endeavour prawn	*Metapenaeus ensis* *M. endeavouri*	868t, $12 M (Commonwealth managed)	
Barramundi	*Lates calcarifer*	723t, $5.2M + 61t recreational	660t, $3.7M +460t recreational + 90indigenous harvest
King threadfin	*Polydactylus macrochir*	442t, $1.8M	263t, $0.57M
Blue threadfin	*Eleutheronema tetradactylum*	82.3t, $0.32M	40t CNF, $0.14M
Golden snapper (fingermark)	*Lutjanus johnii*		8.7t $0.05M
Black jewfish	*Protonibea diacanthus*	2.4t, $0.01M	170t, $0.4M +12t recreational
Scale Croaker or Jewelfish	*Nibea squamosa*		
Triple tail		2.5t, $0.01M	
Grunter	*Pomadasys kaakan* *P. argenteus*	33.7t, $0.17M + recreational	
Shark: Australian blacktip whaler Sorrah whale, and Bull Shark	 *Carcharhinus tilstoni* *C. sorrah* *C. leucas*	345t, $2.0M	670t, $4.2M; +10t; +40t CNF, $0.14M + indigenous harvest
Grey mackerel	*Scomberomorous semifasciatus*	346t, $2.1M	766t, $3.4M
Mullet	*Liza vaigiensis*, *L. argentea*	1.2t, $0.003M	40t CNF, $0.05M + indigenous harvest
Golden catfish	*Arius thalassinus*	3.5t, $0.01M	+ indigenous harvest
Queenfish	*Scomberoides lysan*, *S. commersonianus*	25t, $0.08M	2.6t +40t CNF, $0.14M
Black Pomfret	*Parastromateus niger*		
Mud crab	*Scylla serrata*	175t, $1.8M	393t, $4.3M +65t recreational harvest +69t indigenous harvest

[1]. Source: Williams (2002), Roelofs (2004) and CHRIS (2004) ; [2] Source: EA Sustainability Report (00-01 year) for prawn species, Coleman (2002) and Zeroni (2004) for fish and crabs; (Major commercial fishing areas for the NT barramundi net fishery are North Arnhem, Blue Mud Bay, Murgenella, Roper and Daley Rivers, and Van Diemen's Gulf.); (Barramundi in the Mary River of the Northern Territory showed a consistent cyclic pattern of abundance, with a high number of recruits every second year.)

The commercial sectors of these fisheries have a combined value of about $220 million AUD per year. These estuarine-associated species are dependent upon estuarine habitats for different parts of their lifecycles particularly during their juvenile stages. The abundance of estuarine-associated species in the Gulf of Carpentaria is influenced to varying degrees by freshwater flowing into the estuary, most of which occurs during the summer monsoonal season. Freshwater flows to the estuary increase during late spring and summer, and flow decreases during winter and early spring. Changes to the timing, duration and magnitude of freshwater flowing to estuaries may change as a consequence of the development water resources, and these changes are likely to impact upon estuarine species (Drinkwater and Frank 1994; Gillanders and Kingsford 2002).

Estuarine-dependent fishery species may be affected by freshwater flow through:
(i) trophic linkages via changes to primary or secondary production that result from the addition (or loss) of nutrients; (ii) changes in their distribution as a consequence of altered (expanded, reduced or connected) habitats; and (iii) changes in population dynamics such as recruitment, growth, survival, and abundance (Copeland 1966; Aleem 1972; Peters 1982; Drinkwater 1986; Drinkwater and Frank 1994; Loneragan and Bunn 1999; Gillanders and Kingsford 2002; Staunton-Smith *et al.* 2004). Proposed mechanisms of the role of freshwater flow can be summarised as effects on: (i) catchability; (ii) recruitment (i.e., survival during early stages of life, which translates to the 'strength' or size of a cohort); and (iii) productivity resulting in increased growth rates (Robins *et al.* 2005). Examination of the proposed mechanisms allow the *a priori* identification of freshwater flow variables to be used in identifying the necessary information to determine potential impacts of water resource development on estuarine-dependent fishery species (Tyler 1992).

We focused on the main fishery species to develop conceptual models of the role of freshwater flow throughout a species lifecycle. This has assisted in documenting potential positive and negative impacts as well as identifying knowledge gaps and hypotheses that could be tested through further research. A short summary of the life history of each species and the potential role of freshwater flow is provided for the main fishery species (i.e., banana prawns, barramundi, mud crabs, king threadfin). However, lack of knowledge for many of the fishery species in the Gulf of Carpentaria limits the level of detail and certainty with which we could develop conceptual models and assess the role of freshwater flow.

PRAWNS

There are 50 different species of penaeid prawn inhabiting Australian waters (Grey *et al.* 1983), of which five species are commercially important in the Gulf of Carpentaria (Table 1). Penaeid prawns have a similar life history, but show different degrees of migration. There is strong spatial partitioning between the species (Staples *et al.* 1985), which is a function of salinity (i.e., tolerance of freshwater) and habitat type (Staples *et al.* 1985). As such, the role of freshwater flow in population biology should be considered separately for each penaeid species. Most correlations between freshwater flow (or rainfall) and prawn catch have been reported for estuarine-dependent species or those species with greater tolerance or exploitation of brackish-water habitats (Gunter and Hildebrand 1954; Ruello 1973; Glaister 1978; Staples and Vance 1986; Gammelsrod 1992; Galindo-Bect *et al.* 2000). Of the commercially important prawn species in the Gulf of Carpentaria, banana prawns have the greatest association with estuarine habitats and freshwater flows. Of the other species, tiger prawns are associated with seagrass and algal beds, and areas adjacent to these habitats (Staples *et al.* 1985). Endeavour prawns utilise a greater diversity of habitats, including seagrass, algal beds, mud-mangrove banks, with *M. ensis* also using open channel areas (Staples *et al.* 1985).

BANANA PRAWNS (FENNEROPENAEUS MERGUIENSIS)

Banana prawns are an estuarine and coastal species associated as adults with waters up to 20 km from the coast (up to 45 m, Grey *et al.* 1983), but juveniles extensively use estuarine habitats, with juveniles being found up to 30 km inland, close to the upper limit of tidal influence in the Embly River (Staples *et al.* 1985). Banana prawns have a typical type-2 penaeid life cycle (Dall *et al.* 1990a). Adolescent banana prawns migrate downstream from estuarine habitats to marine waters, where they mature and spawn benthic eggs, which become pelagic larvae. Nauplia, protozoeal and mysis stages of banana prawns have the highest survival in 30 to 35 ppt salinity (Nisa and Ahmed 2000). Larvae and post-larvae migrate from offshore waters into estuaries using tidal currents, and settle as post-larval phase into estuarine nursery habitats, particularly those associated with muddy, mangrove-lined rivers and creeks. Juvenile banana prawns are benthic, remaining in the estuary for several months, before migrating to coastal marine waters. The downstream migration of juvenile and sub-adult banana prawns occurs from summer to autumn and coincides with seasonal rainfall in the Gulf of Carpentaria (Staples and Vance 1986). Banana prawns spawn in spring[1], resulting in juvenile prawns migrating into estuarine nursery habitats between November and May. Banana prawns are thought to have a one-year life cycle, with spring-spawned individuals contributing to individuals taken by the commercial trawl fleet between February and May.

Whilst in the estuary, juvenile banana prawns are carnivorous detritivores, consuming a wide range of organisms, such as polychaetes, copepods, amphipods, isopods, mysids, carids, sergestids, foraminifera, molluscs, gastropods, nematodes, insects, diatoms, algae, bacteria, and epiphytes (Wassenberg and Hill 1993) and organic detritus (Chong and Sasekumar 1981). Banana prawns feed while inside mangrove forests as well as in the shallows of creeks and rivers (S. Pillians, pers. comm.). 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

[1] Banana prawns spawn throughout the year with a peak in spawning activity in spring and autumn. However, it is speculated that it is the spring-spawned individuals that contribute most to the commercial autumn fishery for banana prawns.

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; Primavera 1996; Loneragan *et al.* 1997).

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). He reported a similar finding for $\delta^{15}N$, with banana prawns (<9mm 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 seagrass (*E. acoroides*) and mangrove (*C. tagal*). Loneragan *et al.* (1997) concluded that juvenile banana prawns were likely to obtain <10% of their nutrition from mangrove detritus.

The abundance of banana prawn larvae is also likely to be affected by the timing and magnitude of blooms of *Trichodesmium* spp. in coastal waters of the Gulf of Carpentaria. *Trichodesmium* spp. provides little nutritional value to banana prawn larvae and blooms negatively affect the growth and survival rate of larval banana prawns (Preston *et al.* 1998).

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 rage 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 (1980) 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 estimates growth rates. Staples (1980) 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.

Haywood and Staples (1993) reported that salinity had no detectable effect on growth rates. However, experimentally, juvenile banana prawns were found to have optimal food consumption and production at a salinity of 20, with higher salinities considerably decreasing 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), while Staples and Heales (1991) report that the optimum temperature and salinity for the growth in length of juvenile banana prawns (i.e., shortest intermolt period and larges CL increment) as 31°C and 30 salinity (resulting in a weekly growth rate of ~1 mm/week).

However, accounting for survival, increases in wet and dry weight, the optimum temperature and salinity for the greatest increase in biomass and production were 28°C and 25 ppt. Staples and Heales (1991) concluded that deviations from the optimum of temperature have a greater effect on productivity than of salinity. Staples and Heales (1991) predicted that in an estuary, post-larval 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.

Annual landings of banana prawns from otter trawl fisheries have been significantly correlated with summer rainfall. Offshore commercial catches of adult banana prawns are often higher in years when there is high coastal rainfall (Vance *et al.* 1985). This is probably related to physical movement of juveniles out of the estuaries (i.e., catchability, Staples and Vance 1987), but may be helped by the increase in nutrients to the coastal areas associated with freshwater runoff. Timing of the freshwater flow event in relation to the developmental stage of banana prawns will determine the contribution of an estuary to the offshore banana prawn population (Staples and Vance 1987). Freshwater flows may also have a negative effect on banana prawns.

The immigration of post-larval banana prawns into estuaries of the southern Gulf of Carpentaria is hindered when estuarine waters are lowered in salinity to freshwater conditions (Staples and Vance 1987). As such, the relationship between freshwater flow and 'yield' of banana prawns is parabolic: being positive when the effect of flow on the emigration of juveniles into offshore waters dominates the subsequence abundance of banana prawns (i.e., effect on post-larvae is relatively small) and negative when the effect of flow on the immigration and survival of post-larvae into riverine waters dominates the subsequent abundance of banana prawns (i.e., effect on sub-adults is relatively small) (Evans *et al.* 1997).

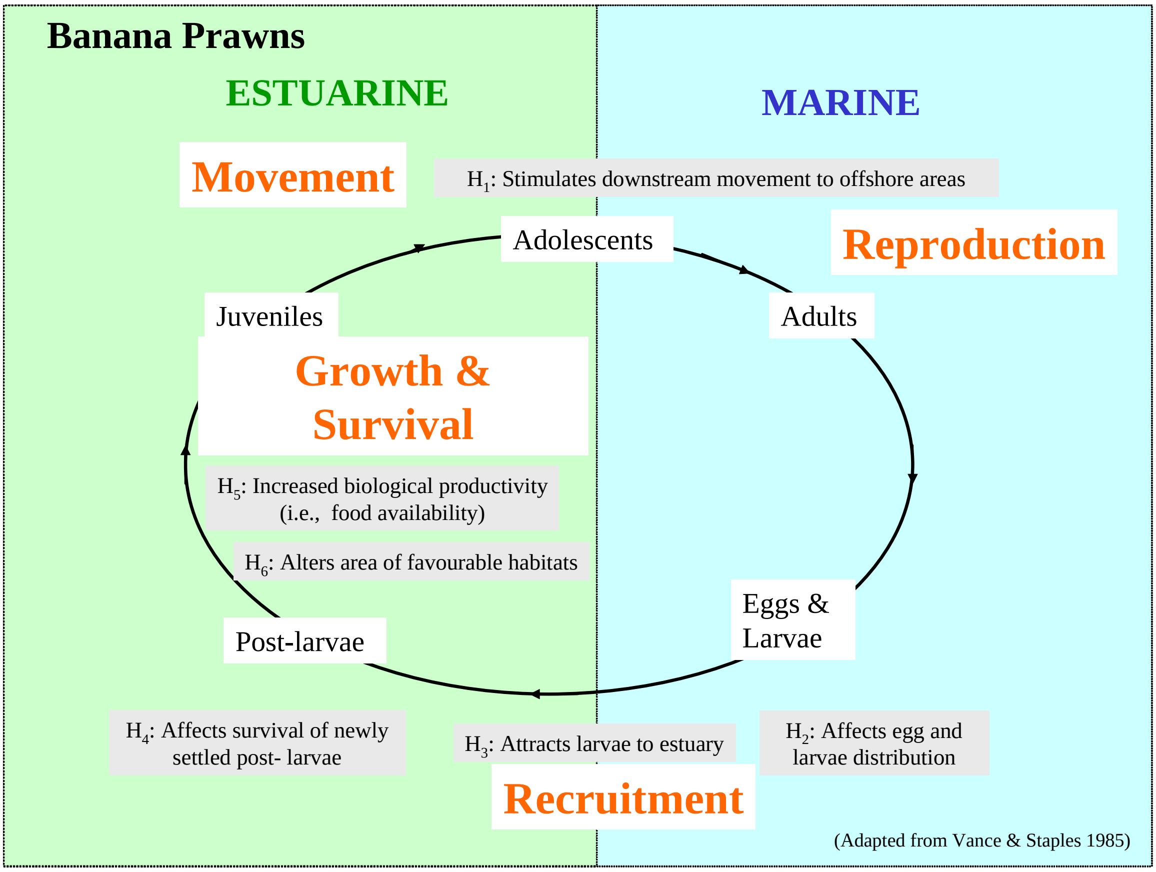
Ways in which freshwater flows can effect the banana prawn life cycle or population

Freshwater flows are likely to affect the life history processes of penaeid prawns in numerous ways. Freshwater flows are thought to have a direct and relatively immediate (i.e., within weeks) effect on some prawn species, stimulating juveniles and adults to move downstream, emigrating from the estuary into coastal waters (Gunter and Hildebrand 1954; Ruello 1973; Glaister 1978; Staples and Vance 1986). The timing of freshwater flow events as well as the size of the juvenile prawn population influences the contribution of an estuary to the offshore population (Staples and Vance 1987).

Freshwater flows are thought to contribute to the expansion of estuarine nursery habitat, although, in some instances, freshwater flows have been negatively correlated with prawn catches, possibly because high levels of runoff may make nursery habitats unsuitable for banana prawns (Vance *et al.* 1985, Evans *et al.* 1997) or because high freshwater flow may be a barrier to larval immigration into estuaries (Staples and Vance 1987). These can be summarised as follows:

1. Stimulates downstream movement of juvenile and sub-adult banana prawns to offshore areas, potentially increasing their catchability by the ottertrawl fishery. The stimulus is possibly salinity changes, although flushing may occur at high flow rates.
2. Affects the transport of larvae through currents. Large freshwater flows may prevent larval immigration to estuarine habitats either by washing eggs and larvae away from the estuary or dilution of chemical cues.
3. Creates chemical signals for larvae to enter the estuary.
4. Affects the survival of newly settled post-larvae in estuarine habitats, with freshwater (i.e., salinity of 0 ppt) being unsuitable habitat for post-larvae.
5. Enhances biological productivity of the estuary, thereby increasing the availability of food in the estuary for post-larvae, juveniles and adolescents which results in improved growth, survival and 'condition' of the banana prawn population, potentially leading to larger biomass and better reproduction.
6. Affects the area of favourable habitat for juveniles and adolescents, potentially through larger areas of decreased salinity, the creation of a salinity gradient (i.e., 5 to 30 ppt) or turbid conditions reducing predation, which increases the survival of juveniles and adolescents.

Figure 1. Conceptual model of the possible influences of freshwater flows on the life-cycle of the banana prawn (*Fenneropenaeus merguiensis*) in the Gulf of Carpentaria.



BARRAMUNDI (LATES CALCARIFER)

Barramundi are one of the main finfish species caught by commercial, recreational and indigenous fishers in the Gulf of Carpentaria (Table 1). This species is strongly associated with estuaries, utilising freshwater, estuarine and coastal areas adjacent to rivers during different life stages.

Barramundi have a complex life history, being catadromous (i.e., migrating from freshwater to saltwater to spawn) and protandrous (changing sex from male to female). Catadromy in barramundi is not obligatory, as a proportion of barramundi in estuaries of the Northern Territory do not enter freshwater (Pender and Griffin 1996; Griffin and Walters 1998). However, where access and habitats permits, barramundi will typically move into freshwater habitats as juveniles, returning to estuaries and coastal foreshores when mature. Generally, barramundi are not catadromous where rivers are ephemeral or where the construction of barriers associated with water infrastructure prevents the movement of fish upstream (Russell 1990).

Mature female barramundi reside mostly 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 some spatial separation of male and female fish, with smaller and younger male fish residing in the upper estuary or in freshwater reaches and females residing predominately in lower estuarine and coastal areas. However, male fish also inhabit lower and coastal areas. Mature males resident in freshwater habitats must move downstream to spawn in the estuary. 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 (R. Garrett pers. comm. 2000). This effect could be achieved by small freshwater flows that do not necessarily release landlocked individuals.

However, barramundi in the Daly River (Northern Territory) moved downstream in August and September, possibly as a consequence of a rise in water temperature and/or increase in day length (Griffin 1987). In addition, large barramundi (i.e., 80 - 90 cm TL) in waterholes in the Princess Charlotte Bay area were repeatedly caught in the same waterhole over a number of years, suggesting that not all large barramundi move downstream (J. Russell, per. comm. 2005).

In Australia, barramundi spawn during spring and summer. The timing and duration varies between regions, rivers and years. In the southern Gulf of Carpentaria, spawning occurs from November to March, with a peak in December (Davis 1985), while in the northern Gulf of Carpentaria (Queensland side), spawning occurs from October (Williams 2002). Spawning in the Northern Territory occurs between September and February (Davis 1985), but most spawning activity occurs before there is any reduction of coastal salinity, i.e., before the main freshwater flows which occur after mid-December (Davis 1985; R. Griffin pers. comm. 2005).

The commencement and completion of a major part of the breeding cycle before the onset of the wet season is possibly a strategy for avoiding low-salinity water (Russell and Garrett 1985). Davis (1985, p 188) commented on the variation in the timing and duration of barramundi spawning and concluded that “there is considerable variation in the timing and duration of breeding between regions, rivers and from year to year, but essentially it is synchronized so that juveniles can take advantage of the aquatic habitat that results from rains in the monsoon season”. Davis (1985, p189) goes onto say that “vast aquatic habitats formed during the summer monsoons provide juvenile barramundi with an almost predator-free, prey-rich environment promoting rapid growth and improved survival”. Griffin and Kelly (2001, p7) also suggest “rainfall is an important influence, presumably through its effect on the availability and habitability of swamp habitat, particularly in the early part of the spawning season”.

Localised spawning occurs in Australia (*cf* Papua New Guinea) because the relatively small discharge of freshwater from northern Australian rivers (Russell and Garrett 1985). Garrett (1987, p 39) suggests that “the position of spawning grounds probably differ slightly from year to year, depending on coastal salinities" …and that "these in turn vary with the degree of river discharge".

Barramundi in the Gulf of Carpentaria (Embley and Hay Rivers), are multiple spawners, with speculation that a prolonged spawning season might be the result of landlocked fish arriving at spawning grounds "late" (Davis 1987). Dunstan (1959) suggested that "spawning of river barramundi occurs just prior to or during the wet season, usually October to January (spawning season 1)" and that "the barramundi land-locked in coastal lagoons and swamps are released when the wet season floodwaters connect these areas with the estuaries or open sea, they usually spawn from January to March (spawning season 2)". Dunstan (1959) suggested that "in years when the wet season is not pronounced, and floodwaters are insufficient to release land-locked adult barramundi, the number of spawning fish at sea is greatly reduced".

However, this is unlikely to have major implications reproductive dynamics, because most (i) spawning occurs before the onset floods, (ii) virtually all the fish in the land-locked situations are males, making their contribution to egg production late in the season negligible (R. Griffin, pers. comm. 2005), suggested that it was unlikely that late spawning probably does not result in significant recruitment during 'normal' wet seasons because the late-spawned recruits are unlikely to survive the high predation pressure from early-spawned recruits already occupying nursery areas (Garrett 1987). Prolonged spawning resulting in multiple recruitment could be important in overcoming climatic variability (i.e., late or interrupted monsoons, Garrett 1987).

In general, spawning activity peaks during new and full moon periods (Grey 1987), i.e., the week following new and full moon in northern Gulf of Carpentaria estuaries (Garrett 1987). Spawning on the incoming tide may help eggs to move into estuaries or coastal swamps.

Gametogenesis in barramundi is initiated by the seasonal increase in water temperate and photoperiod (Russell 1990). Movement to spawning areas is triggered by the seasonal increase in water temperature (Grey 1987; Griffin 1987). High salinity appears to be the main requirement of spawning grounds (Davis 1987), i.e., 32 to 38 ppt (R. Garrett, pers. comm. 2000). Fertilized barramundi eggs are pelagic, with optimal hatching occurring at salinities between 20 and 30 ppt (Maneewong 1987). Barramundi larvae spend about three weeks in inshore waters.

Barramundi post-larvae move to nursery habitats and utilise freshwater habitats if available (Russell and Garrett 1985). Davis (1987) caught small barramundi larvae 77 km upstream in the South Alligator River in the Northern Territory. Moore (1980) suggested that barramundi larvae are cued/attracted upstream by chemicals released from swamps. Peak "spring" tides and seasonal flooding assist barramundi post-larvae to enter supra-littoral habitats (Davis 1984; Russell and Garrett 1985; Davis 1988), coastal lagoons (Grey 1987) and other seasonal habitats that form during the monsoon season (Williams 2002). 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). 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 (1987) confirmed this relationship, reporting a significant correlation (r=0.81) between juvenile abundance (i.e., young-of-the-year) and early wet season rainfall. Griffin (1985) only considers rainfall, although it is equally likely that floods that inundate flood plains may have a similar effect in extending the spatial and temporal extent of these high quality nursery habitats. Significant correlations between otolith based assessment of year-class-strength and freshwater flow were reported for the Fitzroy River on the east coast of Queensland (Staunton-Smith *et al.* 2004).

Many juvenile barramundi move to permanent freshwater habitats when the seasonal coastal habitats dry-out (Russell and Garrett 1985). Such movement may be stimulated by the lowering of water-levels and depletion of food sources (Russell and Garrett 1985). In the Gulf of Carpentaria, floodwaters recede around March. As such, juvenile barramundi are moving upstream to freshwater habitats at about three to five months of age.

Movement upstream to freshwater habitats can also occur when barramundi are between one and two years old (Williams 2002). Dunstan (1959) suggested that "1+ fish are found in deep holes of the upper reaches, with 1+ fish being plentiful below the falls on the Burdekin River that are about 120 miles from the mouth, 1+ fish are common in the Dawson River and other tributaries of the Fitzroy River". Fishway studies on the Queensland east coast have recorded juvenile barramundi (120 to 500 mm total length (TL)) moving upstream primarily between spring and early summer i.e., October to December (Stuart 1997), when the fish are nine to 12 months old. The greatest numbers of moving barramundi were recorded during low flows when salinities below barrage were high (i.e., October, November and December).

However, barramundi were recorded moving through the Fitzroy River fishway throughout the year (i.e., June, September, January, February, March, May). All barramundi ascending the Fitzroy River fishway were < 600 mm FL and immature (Stuart and Mallen Cooper 1999) and move upstream in equal numbers in the day and night. Stuart and Mallen Copper (1999) noted that most barramundi <310 mm FL were collected during two days immediately after the barrage gates were closed and the only sources of freshwater flow to the estuary was from the fishway.

Dunstan (1959) suggested that the "abundance of barramundi in Queensland East Coast rivers appears to be closely associated with the flow of freshwater". Annual wet-season rainfall is thought to influence adult spawning success and juvenile recruitment (Williams 2002). Strong and weak year classes were correlated with the amount of rainfall during the spawning season (particularly the early wet season) in the Yellow Water Billabong (Kakadu, Northern Territory, Griffin (1994).

Breeding success is enhanced in high rainfall years and such events are often followed by a strong year-class (Staunton-Smith *et al.* 2004) evident in the fishery some years later as evidenced by higher catches (Williams 2002; Robins *et al.* 2005). Rainfall levels in the southern Gulf of Carpentaria are thought to influence catches four to seven years later (Williams 2002), with a direct correlation between monthly freshwater discharge and monthly catch (Williams 2002).

In Queensland, commercial catches of barramundi are highest prior to and following wet season (Williams 2002), i.e., October/November and February to May. Land-locked fish released by floods will move to estuarine and coastal areas where commercial fishing occurs and will contribute to the commercial catch. This can result in higher commercial CPUE in years of big floods (R. Griffin, pers. comm. 2005; Halliday unpublished data).

Barramundi stocks in the Gulf of Carpentaria are genetically different to those of the Queensland east coast (Shaklee and Salini 1985). Davis (1985, p189) suggests that because of localised spawning and genetic evidence of stock heterogeneity (as published by Shaklee and Salini 1985) 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 sperate stocks".

Size-at-maturity also differs between areas. Davis (1982) reported that size-at-maturity for males was 600 and 550 mm for fish in the Northern Territory and South-eastern Gulf of Carpentaria respectively and for females was 900 and 850 mm. Size at maturity is probably related to age, with slower growth rates occurring in the Gulf of Carpentaria (Davis 1982). Griffin (1988) also speculates 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 in the north-eastern Gulf of Carpentaria (i.e., north of 13°S, Embely River northwards) are sexually precocious (although stunted in size), maturing up to 2 years earlier than barramundi in other rivers in the Gulf of Capentaria (Davis 1984).

Barramundi are opportunistic predators and are likely to exploit increased abundance or accessibility to prey species (such as banana prawns) that are linked to freshwater flows (i.e., a trophic cascade effect). Analysis of tag-recapture data from the Fitzroy River system on the Queensland east coast demonstrated strong positive effects of freshwater flow on growth rates of barramundi (Sawynok 1988; Robins *et al.* submitted). After accounting for length-at-release, time-at-liberty and seasonality of growth (Xiao 1999, 2000), growth rates were significantly and positively related to freshwater flowing to the estuary Robins *et al.* (submitted).

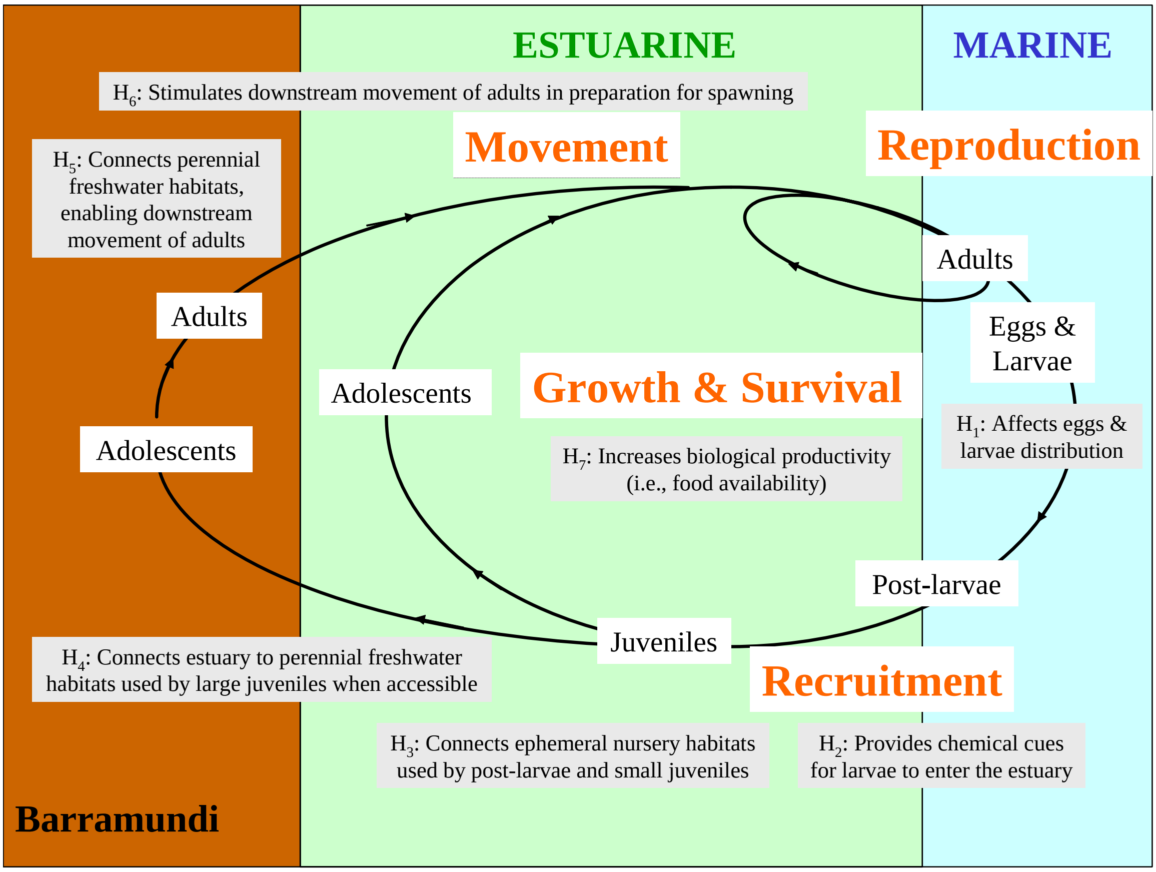
Populations of barramundi are likely to be highly responsive to freshwater flows given their preference to utilise freshwater habitats where accessible or available and the residency of most individuals within a region, thereby reflecting local freshwater flow conditions over time. The influence of freshwater flows on barramundi populations in the Gulf of Carpentaria can be summarised as follows:

1. Affecting the distribution of eggs and larvae; large flows may wash eggs and larvae away from the estuarine water (i.e., a negative effect);
2. Creating chemical signals that cue larvae to enter the estuary[2] (although high tides may also facilitate chemical cues);
3. Provides a connection between the estuary and ephemeral supra-littoral nursery habitats (e.g., flooded floodplains and coastal swamps); post-larval and small juveniles use these connections to enter temporary nursery habits, which allow good growth and survival (i.e., enhances the available nursery areas);
4. Provides a connection between the estuary and perennial freshwater habitats; large juveniles use the connections to move into freshwater habitats, which allow good growth and survival[2];
5. Provides a connection between perennial freshwater habitats and the estuary, enabling mature individuals to move downstream and participate in seasonal spawning[3];
6. Stimulates mature barramundi to move downstream in preparation for seasonal spawning, although the stimulation is unknown. Potentially it could be changes in salinity for estuary-based individual, or flow rates for freshwater-based individuals;
7. Enhances biological productivity of the estuary, thereby increasing the availability of food for juveniles, adolescents and adults resident in the estuary, which potentially results in improved growth, survival and 'condition' of the estuarine population (e.g., fat barramundi syndrome, leading to faster age-at-maturity or greater reproductive output for a season).

[2] The flooding of supra-littoral habitats by high tides may also (a) provide a connection between the estuary and nursery habitats, (b) prolong the life of ephemeral nursery habitats and (c) create chemical cues that attract larvae into the estuary (John Russell, pers. comm.. 2005).

[3] Timing of the flow in relation to the spawning season is probably critical. A late flow will assist wider dispersal of recruits upstream (Roland Griffin, pers. comm. 2005).

Figure 2. Conceptual model of the possible influences of freshwater flows on the life-cycle of the barramundi (*Lates calcarifer*) in the Gulf of Carpentaria.



MUD CRAB (SCYLLA SERRATA)

The mud crab, also known as the mangrove crab, is a portunid crab characteristically associated with mangrove areas. Adults and juveniles use spatially separate feeding areas (Hill *et al.* 1982), and as such competition between adults and younger crabs is probably not a significant factor in juvenile and sub-adult survival. Juvenile crabs (20 to 99 mm carapace width (CW)), live in the mangrove zone, remaining there during low tide (Hill *et al.* 1982). Sub-adult crabs (100 to 149 mm CW) migrate into the intertidal zone to feed at high tide and retreat to sub-tidal waters at low tide. Adults (> 150 mm) mainly feed sub-tidally, with few using intertidal areas at high tide (Hill *et al.* 1982). Burrows are used as general refuges by sub-adult and adult mud crabs, especially after moulting and when mating (Fielder and Heasman 1978). Mud crabs live for maximum of three years (Heasman 1980), growing to between 80 and 100 mm CW in their first year; 130 to 160 mm CW in their second year, and to around 240 mm CW in their third year.

The life cycle of the mud crab involves several stages and uses both marine offshore areas and estuaries (Arriola 1940). Mated ovigerous female mud crabs migrate to offshore waters (e.g., 10 to 30 km offshore and 20 to 40 m depth). Peak 'spawning' (i.e., migration of females and the release of eggs) is thought to occur just before spring in tropical areas (i.e., September to November), and slightly later in southern areas (October to December, Heasman *et al.* 1985; Knuckey 1990). Migration of females offshore for 'spawning' in the Gulf of Carpentaria occurs in September or October, well before the onset of the monsoon. Therefore, the spawning migration and egg release (i.e., spawning) probably are not triggered by low salinities in estuaries (Hill 1994).

Mud crab eggs and early larval stages (i.e., zoeal and megalopal stages) require high salinity water, with considerable mortality occurring at salinities below 20 ppt (Hill 1974; Quinn and Kojis 1987). The marine planktonic stages lasts about one month (Knuckey 1999), with eggs incubating for ten to 17 days (Brown 1993), zoeal stages (I to IV) occur over 12 to 15 days. The semi-pelagic/bottom-dwelling megalopa migrate into estuaries (Fielder and Heasman 1978), and after five to 12 days, metamorphose into juvenile crabs (Williams 2002). Final stage megalopa and small juvenile crabs were observed in May on the seaward side of sand bars at the Roper River, Northern Territory (Mounsey 1990). The arrival of final stage megalopa and juvenile crabs into estuaries coincides with periods of high nutrient input associated with monsoonal rainfall (Quinn and Kojis 1987). This may allow young of the year to take advantage of trophic blooms associated with floods. Growth varies with latitude, as does minimum size at maturity. Mud crabs in Australia reach maturity in 18 months in the tropics (Fielder and Heasman 1978). Minimum size at maturity is larger at higher latitudes (i.e., sub-tropical areas, Brown 1993). In the NT, mud crabs have a high tendency to moult during December, January and February (Mounsey 1990).

Fisheries for mud crabs are associated mostly with estuaries. Mud crab populations in southern Queensland are composed of three year-classes (Hill *et al.* 1985). Main landings occur between December and June, and are related to water temperature but not salinity (Williams and Hill 1982). Activity and feeding are reduced at temperatures below 20°C (Hill 1980). Within year variation of catches of mud crabs is influenced by temperature (i.e., low in June and July) as well as the prevalence of moulting in October and to a lesser extent in December and January (Williams and Hill 1982). Catchability also varies with size and sex of mud crabs. The Queensland fishery is a male only harvest, compared to the Northern Territory, where females are also taken.

Early life history stages of mud crabs (i.e., eggs and larval stages) require high salinities (i.e., >20 ppt, Hill 1974). Most other evidence of the sensitivity of mud crabs to changes in salinity is anecdotal (as discussed below). However, Davenport and Wong (1987) conducted limited experiments on the salinity tolerances of adult mud crabs, which showed varying levels of mortality after varying periods of exposure to different salinities. They also conducted salinity preference experiments, and reported that mud crabs "show no ability to discriminate between salinities" and do not respond behaviourally to salinity. However, during salinity preference experiments, mud crabs were only allowed 30 minutes to 'chose' a salinity, which may not be a sufficient period for the mud crabs to react.

(Helmke *et al.* 1998, p16) reported that commercial crabbers generally believed that environmental factors caused declining catches in the Gulf of Carpentaria in 1998. The commercial crabbers believed that a drop in the number of crabs caught along the northern Gulf coast in 1998 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 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, p17) 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'.

Heavy floods resulting in salinity dropping to 2 ppt 'eliminated' mud crabs from the Kleinemond estuary and severely reduced the number of crabs in the Kowie estuary in South Africa (Hill 1975), with dead crabs being found on the beach at the mouth of the estuary following the flood. The downstream movement (and concentration) of mud crabs to the mouths of rivers following floods is also reported (based on anecdotal evidence) for Australian estuaries (Stephenson and Campbell 1960, p 114).

Recruitment success is suggested to be seasonal and inversely related to rainfall in Madagascar (Le Reste *et al.* 1976). Advection of larvae away from the nursery habitats is the suggested cause of the relationship. It is possible that the modification of the pattern of tidal currents by flooding influences migration of larval stages into estuaries, a process that is ultimately dependent on favourable currents (Forbes and Hay (1988). However, a major cyclone and associated flooding had little measurable effect on the resident population of adults or recruitment of megalopa larvae in St Lucia estuary in Natal, South Africa. Forbes and Hay (1988) suggest that it may be a salinity-temperature combination that caused crab mortality in the Kleinemond estuary but not in the St Lucia system.

Dalzell and Wright (1990) found no significant correlation between rainfall and total number of landings of mud crabs from 20 locations in northern Papua New Guinea. However, Loneragan and Bunn (1999) reported significant positive correlations between mudcrab catch and summer freshwater flow in the Logan River estuary (a sub-tropical estuary in Queensland). They speculated that freshwater flow might influence: (i) the catchability of legal size mud crabs (mostly sub-adults and adults), by stimulating their downstream movement away from low salinity water, and (ii) recruitment by reducing the competition for burrows and increasing the survival of juveniles. Increased juvenile survival would suggest that enhanced catches of mud crab could occur in the following years (i.e., a lagged effect), but lagged correlations were not examined by Loneragan and Bunn (1999). Robins *et al.* (2005) found significant positive correlations between autumn flow lagged by two years and mud crab catches in the Fitzroy River estuary (a dry tropical estuary on the Queensland east coast), which would support recruitment effects suggested by Loneragan and Bunn (1999). However, Hill (*et al.* 1985) reported that juveniles use spatially different habitats to those of adults, which does not support the burrow competition theory of Loneragan and Bunn (1999). Hill (1975) also suggests that mud crabs may be stimulated to move downstream by river flow associated with higher rainfall.

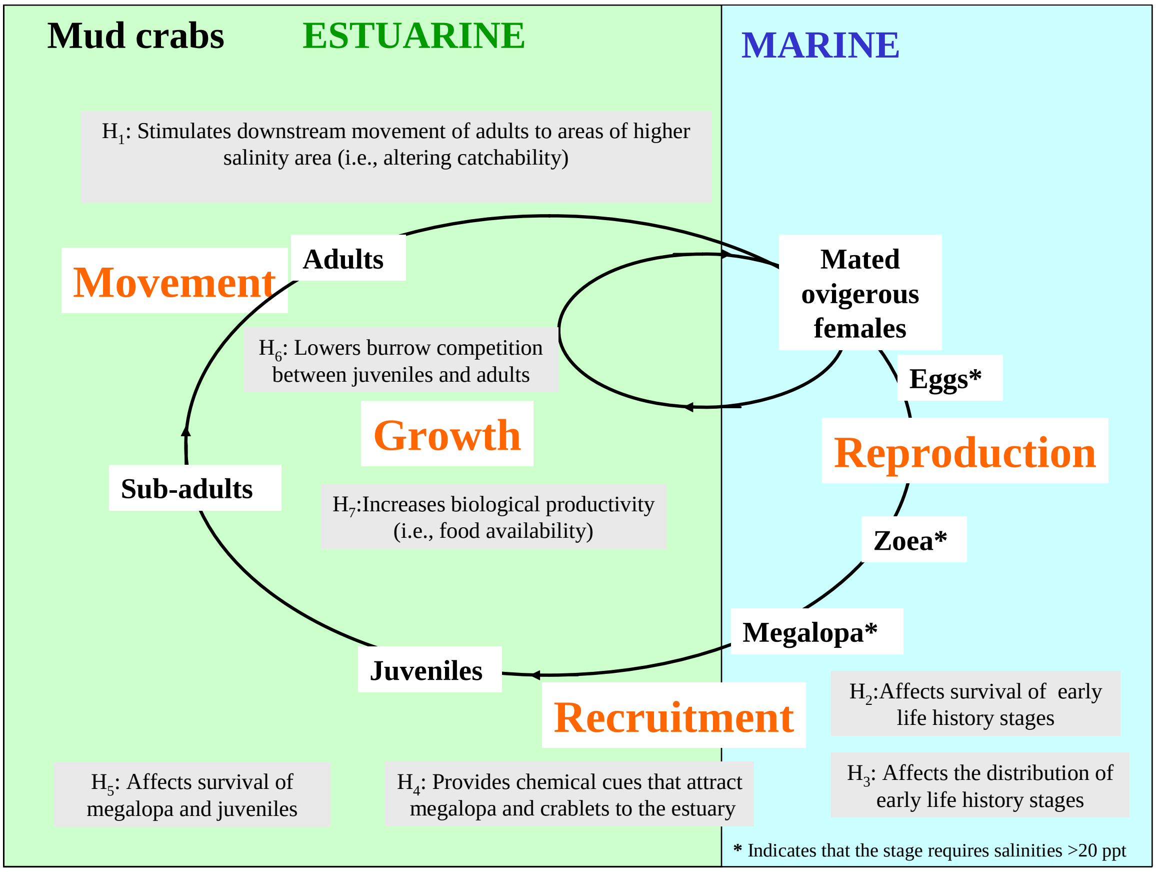
Mud crabs are second level trophic feeders, opportunistically preying on slow moving or immobile prey organisms (Fielder and Heasman 1978) such as crabs, barnacles, and bivalves (Brown 1993). Juvenile mud crabs (15 mm CW) feed on plant material, while small mud crabs (<30 mm CW) feed on plant material as well as invertebrates such as molluscs and crustaceans (Hill 1976). Isotope studies support suggestions of an ontogenetic change in the diet of mud crabs. 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).

Based on the available information in the literature, it is possible that freshwater flow influences the catchability and/or the recruitment of mud crabs. However, there is conflicting evidence in the literature as to the mechanisms of this influence.

The influence of freshwater flows on mud crab populations in the Gulf of Carpentaria could potentially occur through the following mechanisms:

1. Stimulates the movement of adult crabs downstream to higher salinity areas as a consequence of a dislike for low salinity waters possibly increasing catch rates
2. Affects survival of early life history stages. Eggs, zoea and megalopa require salinity > 20 ppt and may be negatively affected by lowered salinities associated with flooding of estuaries;
3. Affects the distribution of early life history stages. Eggs, zoea and megalopa may be washed away from the estuarine habitats by flood flows or prevented from entering estuarine habitats due to lowered salinity (i.e., a negative effect).
4. Creates chemical signals for megalopa or crablets to enter estuary
5. Affects survival of megalopa and juveniles in estuarine habitats, with freshwater (i.e., salinity of 0) being unsuitable habitat.
6. Lowers burrow competition between juveniles and adults, because adults move to higher salinity areas.
7. Enhances biological productivity of the estuary, thereby increasing the availability of food for juveniles, adolescents and adults, which potentially results in improved growth, survival and 'condition'.

Figure 3. Conceptual model of the possible influences of freshwater flows on the life-cycle of the mud crab (*Scylla serrata*) in the Gulf of Carpentaria.



KING THREADFIN (POLYDACTYLUS MACROCHIR)

King threadfin (previously *Polydactylus sheridani*) are another important fishery species to utilise estuaries in northern Australia. They have a complex life history, being protandrous hermaphrodites (i.e., males first then females). They utilise estuarine and associated coastal foreshore waters. Adults can be found upstream during winter, presumably as salinity increases (I. Hallilday pers. comm. 2005),

Adults spawn in inshore coastal waters away from river mouths (Williams 2002), and are likely to have an extended spawning season (Garrett 1996). Spawning peaks during later winter or early spring (Garrett 1996; Welch *et al.* 2002), occurring in September and October in "northerly stocks" and November and December in more "southerly stocks" (Garrett 1996). In the Northern Territory, king threadfins are reported to spawn from October to March, with a peak in December (Kailola *et al.* 1993). In the Fitzroy River in central Queensland, anecdotal reports suggest that king threadfin spawn on the first full moon tides in September (Stevenson 1998, p5), with a site within the estuary (Cattle Point, probably with a high salinity at this time of year) being "a salmon hot spot" for fishing.

Preliminary genetic tests indicate that distinct populations of king threadfin occur in Queensland (i.e., east coast versus Gulf of Carpentaria), but that there is little evidence to suggest of genetic differences between stocks in the Gulf of Carpentaria (i.e., Queensland and Northern Territory) (Garrett 1996).

Spawning is thought to occur in high salinity water (>32 ppt R. Garrett pers. comm.), and it is likely that the pelagic eggs require high salinity water for high survival rates. The early life history of this species is relatively poorly quantified, although nursery areas are probably inshore, shallow and of low salinity (Kailola *et al.* 1993; Williams 2002). Juvenile fish (~10 cm FL) appear in estuaries of the Queensland east coast (i.e., between Townsville to Cairns) in January (I. Halliday pers. comm. 2005). No king threadfin were recorded in temporary supralittoral pools in the Gulf of Carpentaria (Russell and Garrett 1983; R.Griffin pers. comm. 2005; P. DeLestang pers. comm. 2005), suggesting that king threadfin restrict their use of estuarine habitats to permanent water areas of the main channels and tributaries of creeks and rivers.

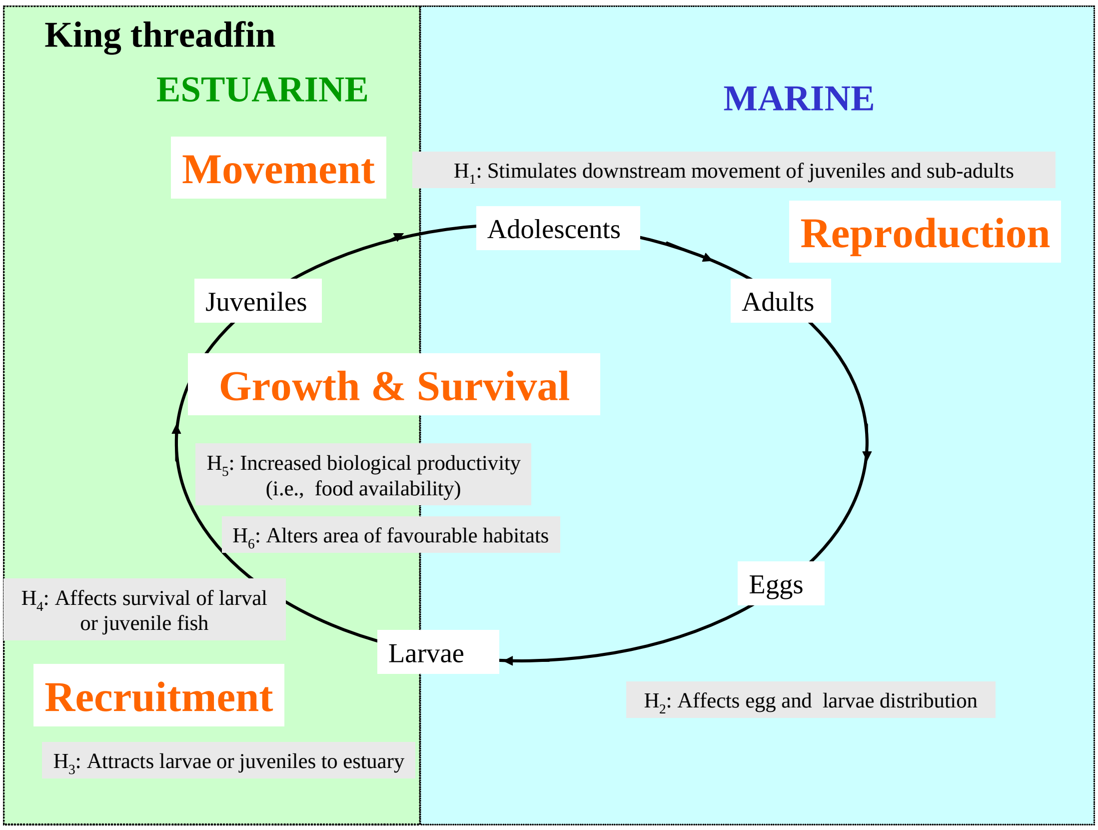
King threadfin reach maturity at between 2 to 5 years and a size at 60 to 80 cm FL (Roelofs 2004). Most individuals change from males to females between 6 and 10 years old and a size of 75 and 100 cm FL. Minimum legal size is 40 cm TL for Queensland east coast and 60 cm TL for the Queensland side of the Gulf of Carpentaria (Welch *et al.* 2002). There is no legal size limit for king threadfin in the Northern Territory (P. DeLestang pers. comm. 2005). In Queensland, peak inshore catches occur in late summer and autumn, coinciding with the movement of commercial fishers from riverine to foreshore areas (Williams 2002), reflecting a change in targeting by commercial fishers from barramundi to king threadfin. In the Northern Territory, peak catches occur in February and March (P. DeLestang pers. comm. 2005). King threadfin are carnivorous, eating a variety of the seasonally available small fish species and crustaceans, including penaeid pawns (Salini *et al.* 1998). Commercial net fishers in the Northern Territory anecdotally report king threadfin consuming banana prawns (R. Griffin pers. comm. 2005).

The level of wet season rainfall may influence adult spawning success and juvenile survival (Williams 2002), but this has not been investigated and quantified. King threadfin can move large distances along the coastline (e.g, 550 km Kailola *et al.* 1993), potentially confounding relationships between freshwater flow and species abundance and distribution. No significant correlations between the catch (or CPUE) of king threadfin have been found for the Northern Territory (R. Griffin, pers. comm. 2005) (or for east coast of central Queensland Robins unpublished data).

Based on the limited information in the literature, it is possible that freshwater flow influences the catchability and/or the recruitment of king threadfin. There is also likely to be a trophic productivity effect as king threadfin exploit increased abundances of prey associated with freshwater flow events. The influence of freshwater flows on king threadfin populations could potentially occur through the following speculative mechanisms:

1. Stimulates downstream movement of juvenile and sub-adult king threadfin, potentially increasing their catchability in set-net fisheries through increased movement or increased densities in fished areas. The stimulus is possibly salinity changes.
2. Affects the transport of larvae through currents. Large freshwater flows may prevent larval immigration to estuarine nursery habitats either by washing eggs and larvae away from the estuary.
3. Creates chemical signals for larvae or juveniles to enter the estuary.
4. Affects the survival of larval or juvenile fish in estuarine habitats, with freshwater (i.e., salinity of 0) being unsuitable habitat.
5. Enhances biological productivity of the estuary, thereby increasing the availability of food in the estuary for larvae, juveniles and adolescents which results in improved growth and survival, potentially leading to greater year-class strength or biomass available to the fishery.
6. Affects the area of favourable habitat for juveniles and adolescents, potentially through larger areas of decreased salinity, the creation of a salinity gradient (i.e., 5 to 30) or turbid conditions reducing predation, which increases the survival of juveniles and adolescents.

Figure 4. Conceptual model of the possible influences of freshwater flows on the life-cycle of the king threadfin (*Polydactylus macrochir*) in the Gulf of Carpentaria.



GREY MACKEREL (SCOMBEROMORUS SEMIFASCIATUS)

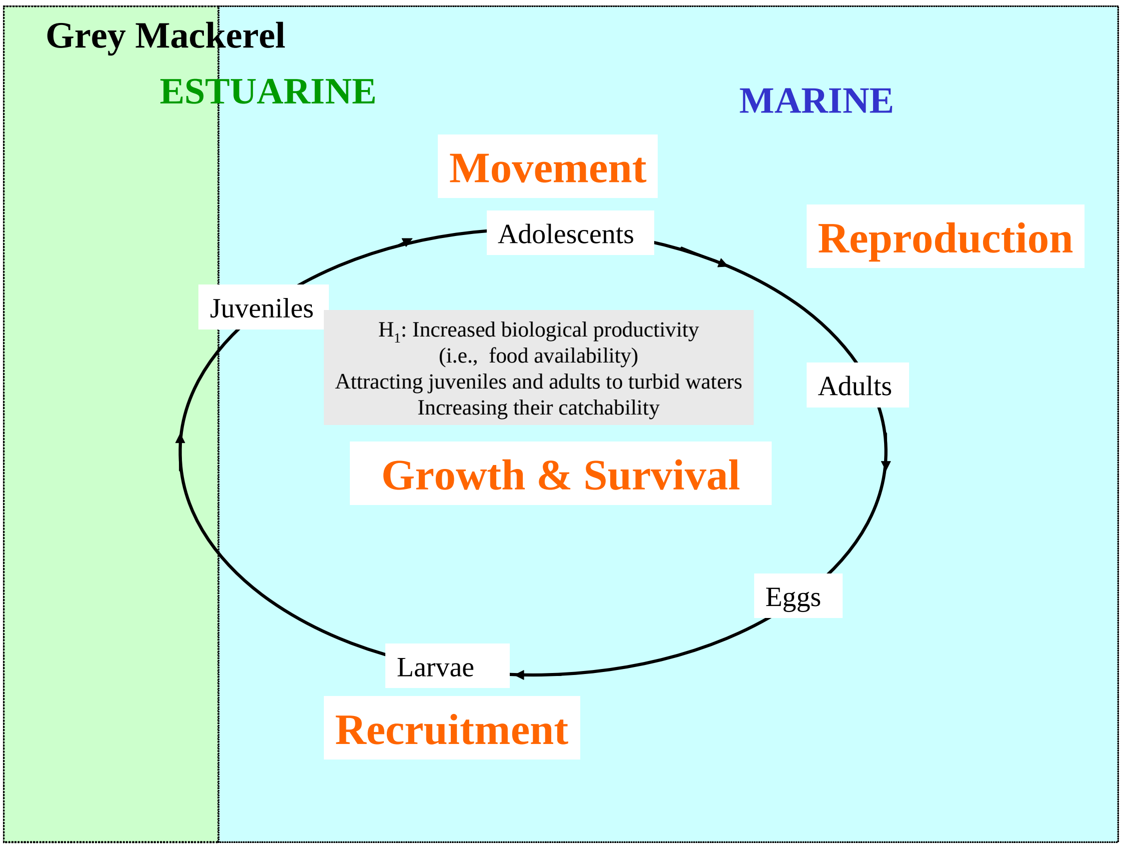
Grey or broad-barred mackerel (*S. semifasciatus*) are a pelagic species, inhabiting coastal waters. This mackerel species tends to be harvested in "inshore waters of higher turbidity" than waters frequented by other mackerel species (Williams 2002). Genetically different stocks occur in the Arafura Sea/Gulf of Carpentaria from those on the Queensland east coast (Cameron and Begg 2002).

Grey mackerel spawn between October and January in the Gulf of Carpentaria (Cameron and Begg 2002). Adults spawn in inshore or coastal waters, with larvae occurring in coastal bays between October and February (Cameron and Begg 2002). Grey mackerel larvae and juveniles are "dependent" on estuarine and coastal nursery habitats (Williams 2002).

Fishers who catch grey mackerel tend to specialise in this species (Williams 2002). In the Gulf of Carpentaria, grey mackerel are part of a suite of species harvested by the inshore set gill net fishery that also harvests barramundi. They are also taken by fishers who target shark slightly further from shore than the barramundi fishery (Williams 2002). Grey mackerel take one to two years to reach maturity. They have a minimum legal size of 50cm total length in Queensland.

Grey mackerel feed largely on baitfish. Anecdotal reports suggest that catchability of grey mackerel is influenced by freshwater flows (Williams 2002). It is speculated that increased estuarine productivity associated with floods (e.g., more baitfish) attracts grey mackerels to turbid inshore waters, increasing their catchability.

Figure 5. Conceptual model of the possible influences of freshwater flows on the life-cycle of the grey mackerel (*Scomberomorus semifasciatus*) in the Gulf of Carpentaria.



MULLET (LIZA VAIGIENSIS AND L. ARGENTEA)

Mullet is the common name applied to a group of species that have similar features, but most commonly refers to the sea (grey or stripped) mullet (*Mugil cephalus*). However in the Gulf of Carpentaria, diamond scale mullet (*Liza vaigiensis*) and flat-tailed mullet *(Liza argentea*) are main species taken by commercial fisheries (Williams 2002).

Each species of mullet has variations to the following generalised mullet life cycle based mostly on research into *M. cephalus*. Mullet utilise fresh, estuarine and coastal waters (Kailola *et al.* 1993) and have a have a similar life cycle to that of barramundi. Spawning occurs in marine waters; juveniles and adults (of most mullet species) use freshwater habitats where accessible, but can develop in estuarine and coastal habitats where access to freshwater habitats is restricted (i.e., opportunistically catadromous, Thomson 1963).

Spawning is preceded by the downstream movement of mature individuals from freshwater and upper reaches of estuaries in late summer, often coinciding with seasonal rain and freshwater flow. Schools of mullet aggregate in the lower reaches of estuaries, until movement outside estuary to coastal waters is stimulated by offshore winds (i.e., westerly winds) in autumn or winter (Thomson 1963). Spawning schools of mullet predominately travel northwards along the east Australian coast (Kailola *et al.* 1993, Williams 2002), and may potentially be caught a substantial distance away from the river system in which they initially developed. It is also thought that post-spawning, adult mullet return to estuarine systems, but that individuals enter more northerly rivers after spawning than where they originated from (Kailola *et al.* 1993). Movement of schools of mullet in the Gulf of Carpentaria are not quantified.

In addition to movements associated with spawning, mullet on the east coast of Australia commonly have a ‘hard-gut’ migration of immature fish along coastal beaches. These schools are though to originate from local rivers and may later return to estuarine or freshwater reaches. It is speculated that they may be stimulated to move as a consequence of flooding in rivers, often being referred to as ‘wash-out’ mullet in New South Wales and Queensland (Thomson 1963).

Mullet have a protected spawning season (i.e., March to July) with most spawning occurring in winter (Williams 2002). Spawning in marine waters (Thomson 1963), adjacent to the surf zone (Kailola *et al.* 1993) or in inshore shallows or estuaries in the north Queensland (Grant and Spain 1975). Eggs and larvae require high salinity water and drift from marine spawning grounds with prevailing currents for about two to three months, until they reach 20 to 30 mm (FL). Post-larval mullet move into estuaries from September onwards (Thomson 1963). Lowered salinities are suggested to be an attractant to mullet fry (Thomson 1963). Small juvenile mullet will disperse into freshwater habitats (where accessible) before the end of November. Small mullet (8 to 102 mm *Liza* sp.; 32 to 65 mm *Valamugil* sp.) were recorded in temporary supralittoral pools in the Gulf of Carpentaria (Russell and Garrett 1983), suggesting that mullet species will opportunistically use available nursery habitats.

Estuaries are used by juvenile mullet, which often school during the ebb tide, to disperse over sand and mud flats to feed during high tide (Thomson 1963). Mullet mature after about three years (Kailola *et al.* 1993), with individuals between three and six years participating in the spawning migrations (Virgona *et al.* 1998).

Cardona (2000), using experimental and wild studies, demonstrated that the growth of *Mugil cephalus* was highly dependent on salinity values and that this changed ontogenetically. Cardona suggests that "mullet with a total length between 40 and 300 mm are highly dependent on areas with low salinity and hence any human activity reducing the availability of such an environment will negatively affect the fisheries of this species". However, Cardona cautioned that this may not apply to Indo-Pacific populations.

Mullet are opportunistic omnivores, feeing on detritus, diatoms, algae and micro-inverts filtered from muddy and sandy substrates in estuaries, as well as algae in freshwater habitats (Thomson 1963).

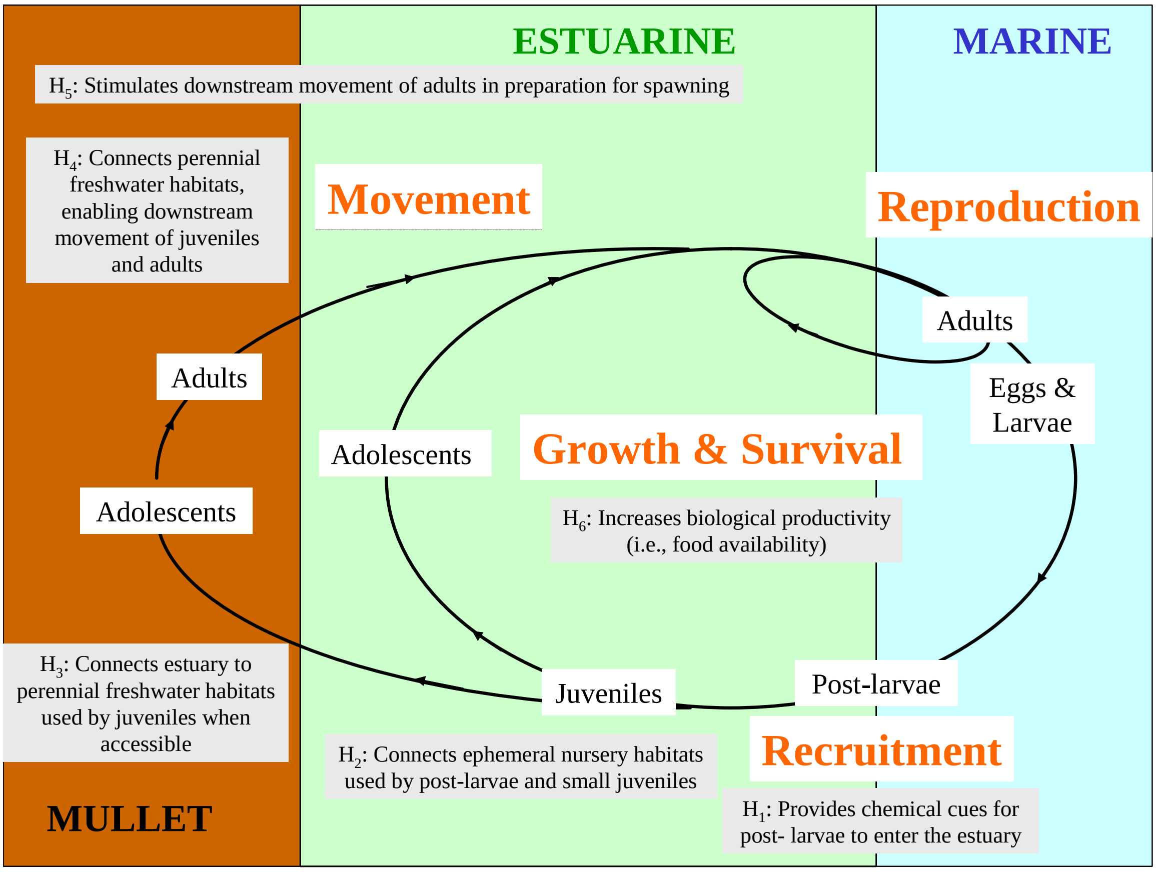
Populations of mullet are likely to be responsive to freshwater flows given their life preference to utilise freshwater habitats where accessible or available, and the anecdotal belief that flows are associated with the movement of fish downstream. However, relationships between freshwater flow and fisheries catch may be confounded by the migration patterns of mullet, which undertake substantial longshore migrations. The alteration of river system through dams reduces the availability and/or accessibility of brackish and freshwater habitats for juveniles. This could potentially be a factor limiting the productivity of the mullet population and have consequential impacts on the size of the resulting mullet fishery (Williams 2002). The influence of freshwater flows on mullet populations could potentially occur through the following mechanisms:

1. Creates chemical signals that cue larvae to enter the estuary;
2. Provides a connection between the estuary and ephemeral supra-littoral nursery habitats (e.g., floodplains and coastal swamps) that post-larval and small juveniles use opportunistically; these habitats may allow good growth and survival of young-of-the-year (i.e., enhances the available nursery areas);
3. Provides a connection between the estuary and perennial freshwater habitats; large juveniles use the connections to move into freshwater habitats, which allow good growth and survival;
4. Stimulates mature mullet to move downstream in preparation for seasonal spawning, although the stimulation is unknown. Potentially it could be changes in salinity for estuary-based individual, for flow rates for freshwater-based individuals. Also may

induce immature mullet to move downstream and undertake the 'hard-gut' migration as a consequence of 'washout' effects.

5. Provides a connection between perennial freshwater habitats (including the overflow of impoundments) and the estuary, enabling mature individuals to move downstream and participate in seasonal spawning;
6. Enhances biological productivity of the estuary, thereby increasing the availability of food for juveniles, adolescents and adults resident in the estuary, which potentially results in improved growth, survival and 'condition' of the estuarine population, leading to faster age-at-maturity or greater reproductive output for a season.

Figure 6. Conceptual model of the possible influences of freshwater flows on the life-cycle of the mullet (*Liza vaigiensis* and L. *argentea*) in the Gulf of Carpentaria.



ESTUARINE AND COASTAL SHARKS: BULL SHARK (CARCHARHINUS LEUCAS), AUSTRALIAN BLACKTIP WHALER (C. TILSTONI) AND SORRAH WHALER (C. SORRAH)

Shark fisheries are often comprised of a number of species. In tropical waters (i.e., the Gulf of Carpentaria) the principal shark species caught are the bull shark (*C. leucas*) in estuarine waters and of the Australian blacktip whaler shark (*C. tilstoni*) and the sorrah whaler (*C. sorrah*) in coastal offshore waters (S. Peverell pers. comm. 2005; Coleman 2002; Williams 2002). Sharks are harvested for their flesh as well as for their fins.

Bull sharks are inhabit coastal waters, estuaries and rivers (including lakes), and are strongly associated with areas of freshwater inflow. They are frequently found in far upstream in freshwater as juveniles and adults. Female bull sharks bear live young (i.e., are viviparous) in estuaries and near river mouths, after a gestation period of 10 months. Juvenile bull sharks move upstream,

The black tip whaler and sorrah whaler inhabit marine and estuarine habitats (Williams 2002), but are not strongly reliant on estuarine and foreshore areas for juvenile habitat (Williams 2002). The black tip whaler is viviparous, with mating occurring in February and March, ovulation occurring in March and April, with birth of pups (i.e., live young) occurring in January (i.e., 10 months gestation) (NT Shark Fishery ESD Report 2003). Sexual maturity is reached in 3 to 4 years for females. Size at maturity is 110 cm for males and 115 cm for females. The black tip whaler feeds on pelagic teleosts, cephalopods and crustaceans. The sorrah whaler has similar life history to the black tip whaler, although reaches sexual maturity within 2 to 3 years for females and at a size of 90 and 95 cm for males and females respectively.

The effects of freshwater flowing to estuaries needs to be considered separately for species strongly associated with estuarine and river reaches (i.e., the bull shark) from those not strong associated with estuaries (i.e., the black tip and sorrah whaler).

Possible effects of freshwater flow on black tip and sorrah whalers may include those associated with trophic productivity of estuarine and coastal waters and subsequent food availability.

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Appendix 2: Summary table of the ANZLIC metadata sourced for freshwater flows and estuarine fisheries production in the Gulf of Carpentaria.

MRef	DESCRIPTION	START DATE	END DATE	PROGRESS	DATA FORMAT	CUSTODIAN
1	Southern Surveyor Voyage SS 01/93 Biological Data Overview	13-01-1993	10-02-1993	Complete	Database files - Oracle Vouchered Specimens	CSIRO Division of Marine Research
2	Soela Voyage SO 2/81 Biological Data Overview	30-05-1981	14-06-1981	Complete	Field Data Sheets Vouchered Specimens	CSIRO Division of Marine Research
3	Southern Surveyor Voyage SS 03/90 Biological Data Overview	21-11-1990	14-12-1990	Complete	Database files - Oracle Vouchered Specimens	CSIRO Division of Marine Research
4	Southern Surveyor Voyage SS 05/91 Biological Data Overview	18-11-1991	02-12-1991	Complete	Database files - Oracle Vouchered Specimens	CSIRO Division of Marine Research
5	Gulf of Carpentaria Fish Data 1990-1993	01-01-1990	31-12-1993	Complete	Digital format Vouchered Specimens	CSIRO Division of Marine Research
6	CSIRO Marine Research "BIODATA" Database - Research Vessel Data ex AFZIS Database, 1978-1989	05-02-1978	29-04-1989	Complete	Database Files - Oracle	DPI&F Southern Fisheries Centre
7	Species Distribution and Catch Allocation in the Northern Prawn Fishery (NPF) 2002 - 2005	01-01-2002	01-01-2005	In Progress	Digital -	DPI&F Southern Fisheries Centre
8	RAPTIS Fish Trawl Survey, Gulf of Carpentaria 1990	01-06-1990	30-06-1990	Complete	Digital - other	CSIRO Division of Marine Research
9	Closures Review in the Northern Prawn Fishery (NPF)	01-01-2004	01-12-2004	In Progress	Digital - Database Files - Oracle	CSIRO Division of Marine Research
10	Northern Prawn Fishery - Anecdotal information (target species, by-catch, environment and practical fishing issues)	01-06-2003		Planned	Digital - Database Files - Oracle	CSIRO Division of Marine Research
11	CSIRO Commercial Factory Prawn Catch Sampling in the Gulf of Carpentaria - 1979 - 1991	01-01-1979	01-01-1991	Complete	Digital - Database Files - Oracle	CSIRO Division of Marine Research
12	Munro Prawn Surveys - SE Gulf of Carpentaria 1963-1965	01-01-1963	01-01-1965	Complete	Field Data Sheets Printed Text	DPI&F Southern Fisheries Centre
13	Munro Prawn Surveys - Fish Records - SE Gulf of Carpentaria 1963-1965	29-07-1963	22-02-1965	Complete	Database Files - Oracle	CSIRO Division of Marine Research
14	Gulf of Carpentaria Prawn Data - MX (Maxim) Dataset 1983-1985	01-08-1983	31-03-1985	Complete	Database Files - Oracle	CSIRO Division of Marine Research
15	CSIRO/Industry Northern Prawn Fishery (NPF) Banana Prawn Sampling 1983 - 1986	01-01-1983	01-01-1986	Complete	Database Files - Oracle	CSIRO Division of Marine Research
16	Food Webs of Prawns in Tropical Systems Dataset 1991-1995	01-01-1994	31-12-1995	Complete	Digital - other	CSIRO Division of Marine Research
17	Gulf of Carpentaria Adult Prawn Data 1995	01-06-1995	30-06-1995	Complete	Database Files - Oracle	CSIRO Division of Marine Research
18	Stock Recruitment Relationships Prawn Trawl Try Gear Catches 1996 - 1997	01-01-1996	01-01-1997	Complete	Database Files - Oracle	DPI&F Southern Fisheries Centre
19	Northern Prawn Fisheries (NPF) Monitoring Project 2002 - 2004	01-01-2002	01-01-2004	In Progress	Database Files - Oracle	CSIRO Division of Marine Research
20	Albatross Bay Phytoplankton Data 1986-1992	01-03-1986	01-04-1992	Complete	Database Files - Oracle	CSIRO Division of Marine Research

21	Albatross Bay Prawn Larval Data 1986-1992	01-03-1986	01-04-1992	Complete	other	CSIRO Division of Marine Research
22	Albatross Bay Adult Prawn Data 1986-1992	01-03-1986	01-04-1992	Complete	Database Files - Oracle	CSIRO Division of Marine Research
23	Albatross Bay Fish Data 1986-1988	11-08-1986	15-11-1988	Complete	Database Files - Oracle	CSIRO Division of Marine Research
24	Albatross Bay Nearshore Fish Study 1991-1992	01-01-1991	31-12-1992	Complete	Database Files - Oracle	CSIRO Division of Marine Research
25	Albatross Bay Offshore Fish Study 1991-1992	01-01-1991	31-12-1992	Complete	Database Files - Oracle	CSIRO Division of Marine Research
26	Juvenile Tiger Prawn Diet Data, Embley River 1993-1994	01-10-1993	31-03-1994	Complete	other	CSIRO Division of Marine Research
27	Juvenile Prawn Tethering Experiments, Embley River 1994-1995	01-10-1994	30-04-1995	Complete	other	CSIRO Division of Marine Research
28	Embley River Fish Study 1986-1992	01-01-1986	31-12-1992	Complete	Database Files - Oracle	CSIRO Division of Marine Research
29	Embley River Invertebrate and Fish Settlement Data 1993-1994	01-01-1993	31-12-1994	Complete	other	CSIRO Division of Marine Research
30	Weipa Juvenile Prawn Data 1981-1982	01-08-1981	01-12-1982	Complete	Database Files - Oracle	CSIRO Division of Marine Research
31	Weipa Juvenile Prawn Data 1986-1992	01-09-1986	01-05-1992	Complete	Database Files - Oracle	CSIRO Division of Marine Research
32	Coastal Nursery - Juvenile Prawn Data, Weipa 1992-1995	01-11-1992	01-02-1995	Complete	Database Files - Oracle	CSIRO Division of Marine Research
34	Karumba/Norman River Banana Prawn Data 1975-1979	01-06-1975	31-12-1979	Complete	Database Files - Oracle	CSIRO Division of Marine Research
35	Karumba/Norman River Fish Study 1991-1992	01-01-1991	31-12-1992	Complete	other	CSIRO Division of Marine Research
36	MacArthur River Mines Prawn Data 1994-1996	01-01-1994	31-12-1996	Complete	other	CSIRO Division of Marine Research
37	MacArthur River Mines Seagrass Data 1994-1996	01-01-1994	31-12-1996	Complete	other	CSIRO Division of Marine Research
38	Groote Eylandt Juvenile Prawn Data 1983-1989	01-01-1983	31-12-1989	Complete	other	CSIRO Division of Marine Research
39	Groote Eylandt Nearshore Fish Study 1989-1990	01-01-1989	31-12-1990	Complete	other	CSIRO Division of Marine Research
40	DPI Tiger and Endeavour Prawn Closure Study, Western Gulf Of Carpentaria 1982-1983	01-10-1982	01-03-1983	Complete	Database Files - Oracle	CSIRO Division of Marine Research
41	Queensland Fish Habitat Areas	01-01-1996	21-12-2003	Complete	ArcInfo coverage	Queensland Fisheries Service
42	Queensland Commercial Fishery catch and effort 6 minute resolution	01-01-2001	01-12-2003	Planned	ArcInfo Coverage	Queensland Fisheries Service
43	Queensland Commercial Fishery catch and effort (Qld) 30 minute resolution	01-01-1988	01-12-2003	Planned	ArcInfo Coverage	Queensland Fisheries Service
44	Department Of Primary Industries Regions	01-06-1992		Complete	ARC/INFO 7.04, Vector Coverage, UTM zone 56	Department of Primary Industries, Fisheries & Forestry
45	Fisheries Closed Waters	01-09-2001	19-01-2004	In Progress	ArcGIS Geodatabase	Queensland Fisheries Service

46	Intertidal Wetlands Inventory	01-06-1994		In Progress	Advanced Revelation Database	EPA/ QPWS
47	Australian Estuaries Database - CAMRIS	01-01-1995	30-07-1996	Complete	Arc/Info point coverage	Australian Government Department of the Environment & Heritage
48	Queensland Seagrass Meadows 1984-1988	01-11-1984	30-11-1988	Complete	ArcInfo Coverage	Queensland Fisheries Service
49	Australia - Assessment of River Condition (Reach and Basin) - 2001	01-01-2001	23-08-2001	Complete	ArcView shapefile & dbf	Australian Government Department of the Environment & Heritage
50	Australia - SOE 2001 - Australian Rivers Assessment System (AusRivAS) Band (Observed : Expected) scores	01-01-1994	01-04-2001	Complete	ArcView shapefiles	Australian Government Department of the Environment & Heritage
51	OzEstuaries online GIS			In Progress	ER Mapper ECW, ArcView shapefile, Tagged Image File Format	Geoscience Australia
52	Queensland Coastal Wetland Vegetation	01-01-1992	01-10-2003	Complete	ArcInfo Coverage	Queensland Fisheries Service
53	Queensland coastal waterways geomorphic habitat mapping, Version 2 (1:100 000 scale digital data)			Complete	ArcView shape file	Geoscience Australia
54	Mangrove productivity 1993-1994	01-03-1993	01-01-1994	Complete	Database Files - Oracle	CSIRO Division of Marine Research
55	Vertebrate and Invertebrate Fauna of Australia			In Progress	Texpress database	Australian Museum
56	Charter Boat Operations (Northern)		30-09-2003	Complete	GIS - ARC/MAP, Images - EPS, GIF, JPEG	National Oceans Office (NOO)
57	Food web linkages and biology of pelagic fishes in northern Australia 2002-2004	01-08-2002	01-05-2004	Complete	Database Files - MS Access	CSIRO Division of Marine Research
58	Multiple Use - Native Title and Conservation Status (Northern)		1/03/2004	Complete	GIS - ARC/MAP, Images - GIF, TIFF	National Oceans Office (NOO)
59	Major water resources infrastructure (part of the Aust. Water Recourses Assessment 2000)	01-06-2001	29-07-2001	In Progress	ESRI Shape file	Agriculture Fisheries & Forestry - Australia (AFFA)
60	Surface Water Gauging Stations (Part Of The Australian Water Resources Assessment 2000 Database)	01-06-2001	29-07-2001	Not known	ArcInfo 8 Point Coverage, ESRI Shapefile	Agriculture Fisheries & Forestry - Australia (AFFA)
61	Stocking survey program in the Norman Catchment	01-01-1989	01-01-2005	In Progress	other	Queensland Fisheries Service
63	Scoping report- Gulf rivers, dams and weirs : initial appraisal of fisheries aspects	01-01-2004	01-12-2004	Complete	Other	DPI&F Freshwater Research
64	Survey report : Glenore Weir, Normanton 15 August 2000	01-01-1999	08-10-2004	Complete	DPI&F database	Queensland Fisheries Service
66	Estuarine survey in the Albert River.	15-07-1998	18-07-1998	Complete	See custodian	Queensland Fisheries Service
67	Estuarine surveys in the Norman River	01-01-1997	01-01-1998	Complete	Microsoft Access database	Queensland Fisheries Service
68	Survey results of the 1998 Normanton and Burketown, freshwater fishing competitions: project report to Queensland Fisheries Management Authority	01-01-1998	01-12-1998	Complete	Microsoft Access database	Queensland Fisheries Service
69	Barramundi surveys in the Barron and Mitchell catchments.	01-01-1997	01-01-1999	Complete	CSIRO database	Queensland DPI&F Northern Fisheries Centre
70	Surveys into Barramundi Lates calcarifer juvenile nursery habitats in the eastern Gulf of Carpentaria catchments.	01-01-1980	31/12/2004	Complete	See custodian	Queensland DPI&F Northern Fisheries Centre
71	Barramundi recruitment of the Mary River NT	01-01-1987	31/12/2004	In Progress	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines

72	Fish communities using wetlands	01-01-1998	31/12/2002	Not known	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines
74	Hydrological data for Northern Territory Rives			Not known	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines
75	King threadfin data			Not known	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines
76	Spanish mackeral data		Current	In Progress	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines
80	Commercial logbook data	01-01-1983	Current	In Progress	Data base files MS access	Department of Primary Industries, Fisheries & Mines
81	Mud crab fisheries situation report.	01-01-1998	31/12/2003	In Progress	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines
82	Fish inhabiting mangroves in Darwin Harbour	01-01-2001	31/12/2003	Complete	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines
83	Mud crab linking rainfall in Roper and McAuthur Rivers		Current	In Progress	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines
85	Recreational fishing competition of barramundi in Daly River.	01-01-1993	31/12/2004	In Progress	Spreadsheet files Excel	Department of Primary Industries, Fisheries & Mines