

The Nekton of Moreton Bay

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Abstract

Nekton are a colourful and conspicuous component of the fauna of Moreton Bay, and form the basis of important recreational and commercial fisheries. This paper is about nekton (fish, prawns and cephalopods) distributional patterns and ecological processes, and human impacts on them.

At a broad scale, the nektonic fauna of the western sector of the Bay, where there is high turbidity and variable salinity, differs from that of the eastern sector which is more oceanic and has clearer water. The relation of nekton distribution to soft sediment habitats such as seagrass, mangroves and saltmarsh creeks is known from numerous surveys. Hard substratum habitats, such as rocky and coral reefs, and pelagic waters, have been sampled far less frequently, and only very general data about species occurrence have been recorded. By determining patterns in nekton distribution, inferences have been made, especially relating to important economic species, about ecological processes such as spawning, settlement, recruitment, dispersal, migration, predation, competition, growth, mortality and energy transfer. Manipulative experimentation to clarify such processes has been undertaken only very rarely in Moreton Bay. Severe methodological constraints limit the strength of conclusions that can be made about nekton patterns and processes. More care is needed in the selection and description of sampling processes.

Recorded effects of human impacts on nekton of Moreton Bay include: changes in fish abundance due to fishing, changes in assemblage composition due to habitat modifications such as the development of canal estates, and tainting of fish by pollutants. Likely impacts on nekton of other activities such as dredging, changes in catchment land-use and collecting for the aquarium trade are undocumented.

Introduction

Undoubtedly the nekton comprise the most colourful, commonly sought after marine resource in Moreton Bay. They provide a vital economic resource for the commercial and recreational fishing industries (Quinn, 1993c), an aesthetic resource for the tourism and diving industries, and fascinating subject matter for scientists and students. They provide food for charismatic megafauna (e.g. dolphins), possibly regulate community structure in the plankton and benthos, and are intimately linked with many other ecological processes within the Bay.

Intimate knowledge of natural cycles of migration is held by Bay-side aboriginal communities, for whom marine products are of considerable social and economic value (Walters, 1986). Early chroniclers of the region's history provided accounts of the abundance of nekton resources of the Bay and its rivers, and even then made reference to changes in the structure of populations and communities of nekton as a result of fishing (Welsby, 1905).

Recent examination of catch records indicate that a decline in catch per unit effort (CPUE) and fish size has occurred over the past fifty years (Thwaites & Williams, 1994). There is little doubt that loss of habitat is a contributing factor in the modification of nekton community structure. Young (1978) and others have indicated the importance of littoral areas, particularly mangroves and seagrasses to the health of estuarine nekton. Urbanisation, construction of canal estates and their aesthetically enhanced foreshores, the extension of Brisbane Airport, and now the massive redevelopment of the Port of Brisbane have all added to the assault on the nekton through eutrophication, pollution and fishing to change the character of the nekton communities of Moreton Bay.

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What are nekton?

In discussing the nekton of Moreton Bay and catchment, we are first faced with the problem of achieving a workable definition of nekton to avoid areas of overlap or gaps between this and other reviews. Nekton (from the Greek *nekton*, neuter of *nektes*, meaning swimming) have been variously defined as:

1. "Pelagic animals, such as adult squids, fish and mammals, that are active swimmers to the extent that they can determine their position in the ocean by swimming" (Summerhayes & Thorpe, 1996);
2. "...compris[ing] the more powerful swimming animals, vertebrates and cephalopods, which are capable of travelling from one place to another independently of the flow of water" (Tait, 1968);
3. "... hav[ing] sufficient powers of locomotion to make their way against currents" (Marshall, 1979); and
4. "Animals, such as fishes, which can maintain their position and move against local currents..." (Parsons *et al.*, 1984).

Many animals either fall into or out of these definitions as a function of daily cycles in activity, ontogeny (e.g. changes in body size or the development of swimming appendages with growth), reproductive cycles (e.g. spawning migrations), or under the influence of particular stimuli (e.g. fright). Many, such as fish, prawns and crabs have a planktonic larval dispersal stage, whilst others may dwell in burrows for much of their life and can be considered part of the benthos (e.g. alpheid shrimps; blind gobies, *Trypauchen*). Most adult prawns (Penaeidae) burrow in the sediment during the day (i.e. are benthic) but also are capable of swimming against moderate currents and of very fast swimming during escape responses (i.e. may be considered nekton). Some fish are amphibious (e.g. mudskippers), and some terrestrial vertebrates enter estuarine and coastal waters, are capable of swimming underwater against currents and so could be considered nektonic (e.g. varanid lizards, crocodiles, water fowl, seabirds).

In this paper nekton are defined as: aquatic animals which usually dwell beneath the water's surface, and which for all or a part of their life, are capable of either maintaining or modifying their position in the water column with respect to the substrate, against a horizontal current of at least 0.1 m/s. The assignment of that particular current velocity is purely arbitrary and knowledge of the locomotory abilities of various taxa in the Moreton Bay marine communities is almost nil. Assignment of various taxa to the 'nekton' is based merely on the general knowledge of the authors on the relative locomotory capacities of different groups.

Accepting the above, the following groups are included in this account: juvenile and adult fish, juvenile and adult prawns, and cephalopods. Organisms which fall within the definition but are excluded from consideration because information on them occurs elsewhere are: swimming crabs, reptiles, birds and mammals. Organisms that fall outside of the definition but might be considered nekton by some, because of their taxonomic affinities include: larval fish, prawns and crabs, and fish or crustaceans that spend their lives in burrows.

Pattern, process and human impacts

Fisheries in the Bay have been well described (Williams, 1980; Stephenson & Williams, 1981; Pollock & Williams, 1983a; b; Warburton & Blaber, 1992), therefore this paper centres on the ecology of nekton. The three main foci of this review are: (1) a review of the extent of biological data available on Moreton Bay nekton; (2) an examination of survey work for indications of consistent patterns and processes within the nekton communities of Moreton Bay; and, (3) an

assessment of our current understanding of human impacts on the nekton. A knowledge of ecological processes which drive the observed community patterns and mediate the relationships between nekton and other groups (e.g. plankton and benthos) is particularly important. The present status of knowledge of the taxonomy and biogeography of the nekton is described in Davie & Hooper (this volume).

Patterns in Nekton Communities in Moreton Bay

Most detailed knowledge of the biology of Moreton Bay nekton has been found while addressing management questions flowing from the high economic worth of prawns and fish. Commercially and recreationally important species have received most research effort, with relatively little effort expended on species of little economic, but possibly major ecological importance (e.g. planktivores). There has also been a bias toward the investigation of the biology and autecology of the adult phase of nekton with relatively little knowledge sought about larvae and juveniles. Summaries of the biology of economically important species are given in Table 1 and by Quinn (1993c).

The nekton communities of Moreton Bay can be broadly divided into three: those on sedimentary habitats, such as sand or mud intertidal and subtidal areas; those over hard substrates, such as coral and rocky reefs and shores; and, those in the water column with no known specific substrate requirement. To each habitat group various subjective divisions can be applied, and structurally similar habitats at different locations within the Bay and catchment may be subject to different hydrodynamic and water quality conditions, resulting in site-specific characteristics within the nekton population.

Spatial patterns

Nekton communities in Moreton Bay may be divided into several different spatial entities. A survey by Young & Wadley (1979) of epibenthic fauna (containing many nektonic taxa) from shallow areas of Moreton Bay detected two main faunal assemblages: one to the east of line between Toorbul Point and Dunwich which they termed "more marine", and the other to the west which they described as "less marine". Burgess (1980) investigated demersal assemblages in the Bay and determined three species groupings characteristic of the western, central and eastern Bay. Stephenson & Dredge (1976) found the greatest numbers of fishes at stations in the upper estuary. In contrast, Quinn (1980) found greatest abundances in the lower estuary. These differences may be a result of the different years in which the studies were conducted and the different gear used in each. Weng (1990) investigated five areas, all less than 4 m depth, recording a total of 86 species, with 29 of the most abundant species classified as estuarine. He found that sites near a river mouth (Caboolture River) and a sewage outfall (Luggage Point) had the highest numerical abundance and lowest species richness, and were faunistically very similar. This finding is not surprising, as the sewage outfall is also at the mouth of a river. Weng also found distinctive assemblages at a sand drift site (south Bribie Island), seagrass site (Toorbul) and mangrove site (Deception Bay). Warburton & Blaber (1992) studied shallow water (5-8 m) assemblages by beam trawling seven sites in western Moreton Bay and found that vegetated sites supported greater abundance in four of the five most abundant species. The pattern of high abundance at vegetated sites found by Warburton & Blaber (1992) is in agreement with other studies of the Bay (Young & Wadley, 1979; Blaber & Blaber, 1980; Courtney *et al.*, 1995; and see Hill & Wassenberg, 1993).

Table 1. Nekton for which there is some biological or ecological knowledge. Economic status is given as CF = commercial fishery; MCF = major commercial fishery; MRF = major recreational fishery; RF = recreational fishery; Trophic level is given as DET = detritivore, HE = herbivore, MIC = microcarnivore, MAC = macrocarnivore; Adult habitat is given as B = Bay, C = coastal waters; E = estuaries, and R = rivers; Spawning habitat is given as C = coastal waters, E = estuary mouth, P = pelagic, SB = sand bars, SG = seagrass beds.
Note: There is insufficient knowledge of larval biology and status of the fishery for most species.

Species	Common name	Economic status	Trophic level	Adult habitat	Spawning habitat	Nursery habitat
<i>Mugil cephalus</i>	striped mullet	MCF	HE, DET	R, E, C	C	EM
<i>Acanthopagrus australis</i>	yellowfin bream	MCF, MRF	MAC	R, E, C	SB	SG
<i>Sillago ciliata</i>	summer whiting	MCF, MRF	MIC	E, C	SB	EM, CM
<i>S. maculata</i>	winter whiting	CF, RF	MIC	E	E?	EM
<i>S. analis</i>	golden-lined whiting	CF, MRF	MIC	E	E?	
<i>S. bassensis</i>	diver whiting	CF, MRF	MIC	C	SB?	
<i>Platycephalus fuscus</i>	mud flathead	CF, MRF	MAC	E	SB?	
<i>P. arenarius</i>	sand flathead	CF, RF	MAC	C	SB?	
<i>Hyporhamphus, Hemiramphus</i> and <i>Arrhamphus</i>	garfish	CF, RF	HE	R, E, C	SG	
<i>Pomatomus saltatrix</i>	tailor	CF, MRF	MAC	C	C	
<i>Pagrus auratus</i>	snapper					
<i>Metapenaeus bennettiae</i>	greasyback prawn	RF, MRF	DET	E	E	SG
<i>M. macleayi</i>	school prawn	RF, MCF	DET	E	E/C	SG
<i>Penaeus plebejus</i>	eastern King prawn	RF, MCF	DET	B	C	SG
<i>P. esculentus</i>	tiger prawn	RF, MCF	HE	C	C	SG
Cephalopods	squid	RF, CF	MAC	B, C	C-P	?

Structure and bottom topography are also important. Dredge & Young (1977), in a study of Middle Banks (north eastern Moreton Bay), found only low numbers and diversity of fishes from the highly mobile sand banks. They did note however, that prawns were in higher abundance in gutters and that fishes were more common around topographic features such as rocky ledges. This finding highlights our lack of knowledge of fine-scale patterns in demersal assemblages, a problem that has been overcome in other systems (e.g. Jervis Bay) by the application of video transect techniques. However, predictions of community structure cannot be made merely on the presence or absence of structure. For example, Young & Wadley (1979) noted that their data supported Young's (1978) finding that the distribution of four species of juvenile prawn was mainly driven by distribution of temperature and salinity in the Bay. Furthermore, the spatial distribution of the epibenthic fauna (including nekton) is complex. Young & Wadley (1979) wrote:

"In view of the many inter-correlated features of the littoral and infralittoral environment, it was difficult to partition the contrasting features responsible for the observed geographical differences... ..it was apparent that the degree of marine conditions had an overriding influence upon the composition of the fauna". They went on, "within each marine-influenced area significant differences were apparent between fauna of shallowest and deepest stations, and the fauna from the same seagrass community was usually only similar if the stations were sited in areas of similar salinity and temperature conditions...(and)... In areas of less marine influence (the fauna) was usually undifferentiable between stations of different depths or the presence or absence of seagrasses".

From this they deduced that density-independent factors (degree of marine influence on temperature and salinity) may control population densities by regulating density-dependent effects (e.g. the utilization of seagrasses).

Temporal patterns

A frequently reported feature of Morton Bay nekton assemblages is that species richness and abundance are at a maximum in summer and a minimum in winter (Quinn, 1980; Young & Wadley, 1979; Blaber & Blaber, 1980; Burgess, 1980; Morton *et al.*, 1988). Annual patterns within the Bay appear to involve a large influx of fish in the spring and summer, with numbers and diversity at a maximum in most habitats studied (Young & Wadley, 1979; Blaber & Blaber, 1980; Tibbetts, 1991; Warburton & Blaber, 1992). Most species breed during the warmer months, with only a few showing increase, and presumed breeding activity, in the cooler months. Quinn's (1980) analysis of fishes in Serpentine Creek found that species richness and abundance peaked in April and May. He found significant correlations between abundance and both temperature and salinity. Jones (1986) found *Sepia esculenta* (cuttlefish) (September - January most abundant) and *Loligo etheridgi* (squid) (January - June most abundant) to dominate the cephalod component of the community sampled by trawls. Of the penaeids in his samples, he found abundance peaks for *Penaeus esculentus* (tiger prawn) in June, *P. plebejus* (eastern king prawn) from November to January and *Metapenaeus endeavouri* (endeavour prawn) from March to April. Stephenson *et al.* (1982b) reported that few of the 60 species analysed had spring maxima, most had summer maxima. They found annual cycles were more pronounced at the more marine sites. Stephenson (1980) and Stephenson *et al.* (1982b) suggested that based on earlier studies of patterns of abundance in the benthos (Skilleter, this volume), this pattern of abundance in the nekton agreed with the hypothesis that the benthos is largely controlled by the nekto-benthos (*viz.* epibenthos) and weather. However, there is the converse

view that patterns of production in the benthos control the diversity and abundance of nekton. For example, Jones (1986) considered that seasonal patterns of depauperation in Moreton Bay may be a function of nutrient supply during flood events. Jones compared Moreton Bay with the situation in the Gulf of Mexico (similar latitude) and found that there was no winter depauperation, rather different species dominate in different seasons. A third alternative explaining the seasonal decrease in the nekton has been suggested by Warburton & Blaber (1992), who found strong seasonality of *Pelates quadrilineatus* (trumpeter perch) and *Leiognathus mortonensis* (ponyfish) but that maximal abundances occurred at different seasons than in other studies (e.g. Young & Wadley, 1979; Blaber & Blaber, 1980; Young, 1981). They went on to note that Blaber & Wassenberg (1989) had found that piscivorous birds showed little seasonal variation in consumption of *P. quadrilineatus*. From these data Warburton & Blaber (1992) proposed that the differences they found for both *P. quadrilineatus* and *L. mortonensis* reflect variation in recruitment timing and the location and selectivity of sampling. Indeed, Jones (1986) had suggested that "the dynamic nature of the nektobenthic community is demonstrated by the significant interactions between time and space". Young & Wadley (1979) found that only in two of nine locations did temporal change in species composition exceed inter-station differences. A consequence of their finding is that areas of superficially similar habitat (e.g. *Avicennia marina* mangrove forest) may support different communities and act as nurseries to a different extent. Thus to call all mangrove systems important is not enough, either for fisheries biologists or ecologists. Hydrographic conditions may influence larval fish supply or food availability. Furthermore, annual variation in nutrient supply as proposed by Jones (1986), may contradict the model proposed by Brewer *et al.*, (1995) that food is not limiting in tropical systems, and that in the absence of adequate food supply, organisms either die or move to more productive habitats.

Moreton Bay as a nursery for nekton

It is widely accepted that the shallow, sheltered, turbid waters of Moreton Bay provide an important nursery habitat for juvenile nekton (Blaber & Blaber, 1980; Laegdsgaard & Johnson, 1995). Weng (1990) reported that shallow sites in the western Bay, whilst important as nursery sites for estuarine species, were of relatively little importance for the juveniles of marine species. Laegdsgaard & Johnson (1995) studied two mangrove-lined shores in western Moreton Bay using seine nets and small set nets with small mesh size to estimate the relative importance of seagrass, mangrove and mud habitats as nursery areas for juvenile fishes. They found the seagrass community to be distinct from both mud and mangrove habitats, and that seagrass was of relatively little value as a nursery habitat for economically valuable species. Whilst the fish communities of adjacent mangrove and mud habitats were similar, the mangrove forest typically supported smaller or younger fishes in greater abundance. Laegdsgaard & Johnson (1995) hypothesised that mudflats represent transition zones between juvenile and adult habitats. During their study they found seven of ten economically important species in greatest numbers within mangrove forests. Summarising their findings, they wrote: "Clearly mangrove sites in Moreton Bay play a more important role and have greater potential as nursery habitats (for juvenile fish) than do adjacent habitats".

Conversely, prawns seem to prefer seagrass as a nursery habitat. Young (1978) found that *P. plejebus*, *P. esculentus*, *M. bennettiae* (greasyback prawn) and *M. macleayi* (school prawn) use all available littoral areas of Moreton Bay, and are particularly found in seagrassed littoral areas in preference to infralittoral areas. Young (1978) summarised his data by stating that juvenile *P. plejebus* and *M. bennettiae* settle everywhere in shallow areas of Moreton Bay but

those in seagrass areas survive better. However, Dall (1958) found that *M. mastersi* (= *bennettiae*) postlarvae in the Brisbane River prefer warm sheltered areas with algal cover, indicating that macroalgae may also be important.

While we accept that in general, mangrove forests are important for juvenile fishes and that seagrasses are important for juvenile crustaceans, and given our reservations about the notion of equal value of similar habitats as nursery areas, studies are urgently required into the variation in quality of nursery habitats around Moreton Bay. Furthermore, there is little understanding of synergies that might result from the presence or absence of certain combinations of nursery habitats. For example, while it is recognised that mangroves are an important source of food and shelter for juvenile fishes, unless juveniles spend the time during which mangroves are emmersed (more than half of every day) in tide pools (Crowley & Tibbetts, 1995), they must migrate relatively large distances between infralittoral (low tide) habitats and their feeding (mangrove) habitat. In doing so they expose themselves to predation. Certain combinations of transitional nursery habitats (i.e. those habitats they encounter on their tidal migration) may increase feeding opportunities and reduce predation rate. Thus, determining the relative contribution of superficially similar nursery habitats to fisheries production (for example) may be far more complex than originally thought. To say merely that mangroves are important nurseries is no longer sufficient.

Soft bottom communities

Most investigations of nekton assemblages in Moreton Bay have been carried out on the demersal (epibenthic) fauna of sedimentary shores and subtidal habitats. The faunas of these habitats grade into one another and there is evidence that nekton assemblages are strongly influenced by temperature and salinity regimes. Nevertheless, certain species seem to consistently dominate particular habitats and, with the exception of surf beach and surf bar communities, they are generally well known.

Relatively few studies have examined the fish communities of salt marsh areas. Morton *et al.*, (1988) found that the fish fauna of saltmarsh pools in southwestern Moreton Bay is dominated by *Gambusia affinis* (mosquito fish), *Pseudomugil signifer* (blue eye) and gobiids (gobies). At high tide such areas are visited by commercially important species such as mullet and bream (Morton *et al.*, 1987)

Mugilids (mullet) and ariids+plotosids (catfish) seem to be a ubiquitous component of estuarine fish assemblages (Thomson, 1957; Pollard & Hannan, 1994). Most other species found in the riverine reaches of estuaries appear to be transients. In a study of fish community structure along an estuarine gradient in the Albert River, south western Moreton Bay, Thompson (1957) recorded 20 species. Four of these were freshwater with the remainder being estuarine. Mugilids and *Craterocephalus stercusmuscarum* (fly-speckled hardyhead) were the only permanent residents. The most complete report on the distribution of fishes in the estuarine portion of the Brisbane River is given by Mackay & Johnson (1990). They also provide details of species recorded near the river mouth and freshwater reaches.

Weng (1990) reported that the community at a shallow riverine site (Caboolture River) was dominated by *Gerres ovatus* (= *subfasciatus*) (silver biddy), *Eurythmus lepturus* (long-tailed catfish), *Harengula* (= *Herklotsichthys castelnaui*) (southern herring) and *Sillago maculata* (trumpeter whiting). Species which only occurred at this site included *E. lepturus*, *Siphamia rosiegaster* (pink-breasted siphon fish), *S. multifasciata* (siphon fish) and *Johnius australis* (little jewfish). In areas outside of rivers, but still under estuarine conditions in the western Bay, demersal fish assemblages are dominated in terms of abundance by *Centropogon*

marmoratus (fortesque), *Priacanthus macracanthus* (red bigeye), *Paramonocanthus otisensis* (dusky leatherjacket), *L. mortonensis* (pony fish), *Monocanthus chinensis* (fan belly leatherjacket), *P. quadrilineatus* and *Apogon fasciatus* (striped cardinal fish) (Stephenson *et al.*, 1982b; Warburton & Blaber, 1992). *A. fasciatus*, whilst of no economic importance, may be of ecological importance as it was 2.9-9.6 times more abundant than any other species. *Sillago bassensis* (school whiting), *Sillago robusta* (stout whiting) and *Hyperlophus vittatus* (sandy sprat) only occur at the most marine site (Weng, 1990).

Hard bottom communities

To say that the nekton faunas of hard bottom substrates and pelagic communities are less well known would be a gross understatement. There are no published reports on the community structure of either hard bottom or pelagic nekton for Moreton Bay. When compared with soft bottom habitats, rocky substrates are subject to a level of human activity which exceeds what we would expect for areas of such minor geographic area and fisheries significance. Recreational fishers recognise reefs as important to the macrocarnivorous fishes they target. Recreational divers seek diverse and visually spectacular communities that abound on rocky and coral reefs. Moreover, commercial aquarium fish collectors focus most of their efforts on such assemblages.

The structure of assemblages of nekton associated with coral reefs is affected by water quality, location with respect to larval supply, and habitat complexity. Coral reefs within Moreton Bay support species of each of the dominant coral reef fish families: Acanthuridae (surgeon fish), Scaridae (parrot fish), Pomacentridae (damsel fish), Pomacanthidae (angel fish) and Chaetodontidae (butterfly fish). The diversity of particular assemblages appears to be driven by interaction amongst the above factors. For example, the reef to the north west of Peel Island is dominated by massive corals (see Johnson & Neil, this volume), while Myora reef is dominated by branching corals. The former, being fairly devoid of complex shelter, is home to a much lower diversity of fishes than occurs at Myora (Tibbetts, pers. obs.). Flinders Reef, just outside Moreton Bay, supports a diverse assemblage of coral reef species intermixed with a few temperate fish taxa (e.g. *Girella tricuspidata*, luderick) (Tibbetts, pers. obs.).

We could find no formal publications on the nekton of rocky subtidal reefs or intertidal areas of rocky shores, with the exception of Tibbetts *et al.* (this volume) which gives data on the distribution of fish species and dietary preferences for pool habitats on rocky shores at Dunwich, Manly, Redcliffe, Caloundra and Point Lookout. The rocky intertidal fish community is dominated by blenniids (blennies) and gobiids (gobies) on sheltered shores, and by blenniids and tripterygiids (triplefins) on exposed shores. Blennies dominate the biomass on these shores and, being grazing omnivores, may play a role in modifying benthic community structure, particularly that of algae.

Processes in Nekton Communities

The processes (or dynamics) underlying the patterns described above are not particularly well understood. In the following paragraphs, evidence for the various processes likely to be important in determining the distribution and abundance of nekton species will be discussed.

Note, however, that:

- (1) evidence comes in the main from studies of economically important species rather than ecologically important species; and,
- (2) processes are often inferred from descriptions of patterns (survey results), but the strongest evidence comes from manipulative experiments, which have been undertaken very rarely in Moreton Bay.

Spawning

Fisheries scientists like to identify the spawning grounds of economically important species so that both the spawning adult fish stock and the habitat itself can be protected. The two methods of determining spawning grounds are:

- (1) to determine the location of adults when they are ripe with eggs, and
- (2) to locate larvae (often planktonic) and use water flow data (e.g. seasonal and tidal flow patterns) to establish from where the larvae originated.

Three patterns of spawning have thus been described for nekton species from Moreton Bay. Some commercial and recreational fish species spawn on sandbars at the entrances to the Bay. It is well established that *Acanthopagrus australis* (yellowfin bream), for example, spawn on sandbars (Pollock, 1984; 1985), and it is thought that *Sillago ciliata* (sand whiting) spawn on sandbars at Southport, Jumpinpin, north of Moreton Island and the northern entrance to Pumicestone Passage (Morton, 1985; Quinn, 1993c). Other species, such as *Platycephalus fuscus* (dusky flathead) (Quinn, 1993c) and *Metapenaeus bennettiae* (greasyback prawns) (Dall, 1958) spawn within or alongside estuaries, and either spend their life resident in the estuary or elsewhere in the Bay. Still other species live in estuaries of the Bay for part of their life but spawn outside the Bay. *Pomatomus saltatrix* (tailor), for example, join a spawning run north along the Queensland coast, with the major spawning area being Fraser Island (Bade, 1977; Morton *et al.*, 1993). Zeller *et al.* (1996) proposed that the strong southward current (East Australian Current) drives highly buoyant eggs and surface-dwelling larvae southward from spawning grounds near Indian Head on Fraser Island. *Mugil cephalus* (mullet) also leave the estuaries, in which they spend much of their life, to make a spawning run along sand beaches in and around the Bay (Thomson, 1954), and it is at this time that the bulk of the commercial catch is made. Not all adults make the spawning run, as some remain in estuaries (Kesteven, 1953). *Penaeus plebejus* (king prawn) and *P. esculentus* (brown tiger prawn) move to oceanic waters to spawn, although some *P. esculentus* adults are thought to remain in the Bay and spawn (Young & Carpenter, 1977). Nektonic species that spawn outside the Bay have larvae that disperse, probably with the assistance of wind-driven and tidal currents, back to the Bay. The juveniles then take up residence in the shallow, sheltered habitats of the Bay.

Settlement and recruitment

With regard to nekton, settlement is defined to be when dispersive larval stages, often planktonic, take up a benthic existence (i.e. become more closely associated with the seabed and its habitats). Recruitment is recorded when individuals appear in a population under study. The term recruitment is somewhat subjective in that a fisheries scientist or manager might consider recruitment to be either the age or size at which nekton are first susceptible to fishing gear, whereas an ecologist might count recruits in the same species as post-settlement individuals in a "nursery" habitat. Measuring this latter form of recruitment is considered to be very important by some scientists because it seems that, in some cases at least, the level of recruitment explains very well the abundance of adults. The degree of importance of recruitment in structuring nekton communities is one of the most hotly debated topics in marine ecology. The link between recruitment levels and abundance of adults has not yet been made in Moreton Bay.

The timing of settlement is known for many nektonic species in Moreton Bay, even for species that have no direct economic importance. Several habitat specific studies (e.g. Watabe, 1993; Laegdsgaard & Johnson, 1995; in mangroves; Young & Carpenter, 1977; Blaber & Blaber, 1980; in riverine, seagrass and sand habitats; Morton *et al.*, 1987, in saltmarsh) have shown that the majority of fish and crustacean species appear in shallow waters as early juveniles in

the summer months, with notable exceptions being *M. cephalus*, *A. australis* and *P. plebejus*, which arrive in winter. Juvenile *P. saltatrix* recruit only in March in Moreton Bay, and in a distinct pulse (Blaber & Blaber, 1980). They then appear to inhabit chiefly shallow waters over tidal flats adjacent to mangrove forests in western Moreton Bay (Blaber & Blaber, 1980; Morton, 1990).

The data on the abundances of juveniles measured over several years have not been collected and there is, therefore, no chance of linking recruitment rates with adult abundance as has been done elsewhere. Also lacking are efforts to determine whether recruitment levels of any species are influenced by the quantity or quality of water from the catchment. *Penaeus merguensis* (banana prawn) show a greatly increased recruitment in the Northern Prawn Fishery in the Gulf of Carpentaria in years of high rainfall (Pownall, 1994), but whether *P. merguensis* or other estuarine species, such as *Metapenaeus bennettiae*, are similarly affected in Moreton Bay is not known.

The most well established model explaining the distribution and abundance of nekton in estuarine habitats is based on studies of seagrass meadows in Botany Bay, NSW (reviewed in Bell & Pollard, 1989). According to the model, habitat selection is important during or immediately following settlement. The term 'habitat selection' has a specific meaning here, being the detection and selection of above-ground structure. The larvae of many species, when ready to settle, select vegetated over unvegetated habitat. This would explain the greater abundance of nekton in vegetated areas. Alternative explanations, such as movement to find prey items (which are more plentiful in seagrass meadows than adjacent unvegetated patches (Howard *et al.*, 1989), have not been discounted. The importance of food availability in directly structuring nekton communities has recently been highlighted by experiments in other Australian estuaries (Connolly, 1994; Jenkins *et al.*, 1996).

The model also contends that early juveniles will move *within* a meadow to select denser vegetation, but will tend not to cross bare patches to reach other meadows. In one of the few manipulative field experiments conducted in Moreton Bay, Hopkins (1996) examined the preferences of newly settled juveniles by placing artificial seagrass units of differing densities in shallow unvegetated and seagrass habitats. It was found that some species were more abundant in the denser habitat. More interesting was the result that for most species, abundances were no greater in habitat (Artificial Seagrass Units) left in place for three days than in habitat left in place for only one day.

Other workers have surveyed different habitats in a bid to determine the preferences of newly arrived juveniles. Recruitment of tiger and greasyback prawns is heaviest into seagrass meadows, whereas king prawns tend to be more common in unvegetated areas (Young & Carpenter, 1977; Searle, 1991). However, the importance of seagrass *per se* is not known as the distribution of young prawns is also related to salinity and depth gradients, which tend to be correlated with seagrass presence and type (Young & Carpenter, 1977). The distribution of juveniles of a wider range of nekton, including prawns, actually seems to be determined primarily by the degree of marine influence (salinity and temperature), rather than vegetation (Young & Wadley, 1979). Laegdsgaard (1996) sampled mangrove, mudflat and seagrass at two locations in the Bay, and concluded that newly settling fish are more common in the mangroves, and that they then move to mudflats and eventually seagrass as they grow older.

Dispersal and migration

Dispersal is the movement of egg, larval, or early juvenile stages. Movement of older juveniles and adults is called migration. Measuring dispersal directly is very difficult, but can be inferred where there is reliable information about spawning areas and the time and place of arrival of juveniles (e.g. Pollock, 1982a; 1983). The spawning runs by adults of several economically

important fish species have been described above. Several other species of fish (Blaber & Blaber, 1980) and prawns (Young & Carpenter, 1977) move from shallow, sheltered estuarine habitats to deeper water as they grow larger. Warburton & Blaber (1992) also found some evidence of ontogenetic migration (i.e. a change in distribution associated with increase in size), as adults of *Pelates quadrilineatus*, *Leiognathus* spp., *Paramonocanthus otisensis* and *Monocanthus chinensis* occur in deeper water (Blaber & Blaber, 1980), whilst *Lovamia fasciata* (= *Apogon fasciatus*) is largely confined to relatively shallow water (5-9m, Rainer, 1984). The implications of dispersal for transfer of energy (as fish biomass) from estuaries to deeper waters are obvious but have not yet been studied. Thomson (1957) describes the penetration of estuarine species of fish such as *M. cephalus*, *Hyporhamphus regularis* (= *H. r. ardelio*) (river garfish) and even *Galeolamna ahenea* (= *Carcharinus leucas*) (bull sharks) into the freshwater reaches of the Logan and Albert rivers. Morton *et al.* (1987) showed by fin-clipping that individual bream (*A. australis*) and toadfish (*Torquigener* spp.) returned several times over a seven day period to the same small tidal creek supplying a saltmarsh flat. Other species, including mullet, did not reappear.

The measurement of movement by tagging is effective on larger fish species taken by recreational or commercial fishers since there is a reasonable chance of getting tags returned. Moreover, the attachment of tags does not significantly increase mortality. Morton *et al.* (1993) tagged 2 173 juvenile *P. saltatrix*. They found that of the 237 fish recaptured (11%) over 30 months, most had moved short distances from the release point, suggesting that estuaries such as Moreton Bay act as nursery areas for tailor prior to their movement to open surf beaches as adult fish. Pollock (1981) in a study of *G. tricuspidata*, found no fish less than 3 years old and hypothesised that adult fish move to Moreton Bay from the south. *Penaeus plebejus* settle in seagrass and are found in higher numbers in seagrass than in sand or mud and undergo a slow migration to deeper water (Young, 1975). It has been proposed that these prawns migrate on darks (i.e. last to 1st quarter phases) (Racek, 1957).

As yet, there is no standard method for following the movement of fish and prawns that are either too small or fragile to tag and/or are not likely to be recaptured once marked because they are rarely collected. Little work has been done in Moreton Bay on species such as this, yet if we are inclined to restore the nekton fauna of degraded habitats (e.g. seagrass beds), it is important to know the likelihood of recolonisation of such areas. A range of new methods including genetic (Richardson *et al.*, 1986) and otolith microchemistry (Connolly, this volume), techniques for measuring movement and even dispersal of larvae are being developed with the potential to be used in Moreton Bay.

Predation and competition

Although the majority of the species of fish in Moreton Bay is carnivorous, only a few eat other fish, most take invertebrate prey (Blaber & Blaber, 1980). It has been shown that juvenile *Sillago maculata* (trumpeter whiting) include juvenile *M. bennettiae* in their diet (Mangubhai *et al.*, this volume). Whilst the presence of fish or prawns in diets of other animals provides evidence of direct predation, there has been no attempt to quantify the importance of predation on populations of these prey species in Moreton Bay. Predation rates on juvenile sillaginids have been tested in a tethering experiment, which demonstrated that predation was more severe in habitat without vegetative structure (Laegdsgaard, 1996).

Suggestions of interspecific competition for resources within the nekton of the Bay are based only on weak circumstantial evidence. Weng (1986), for example, showed that in Moreton Bay, the larger whiting species (sand whiting *Sillago ciliata* and golden-lined whiting *S. analis*)

occurred in the same places as *Acanthopagrus australis* (yellowfin bream), but that the smaller trumpeter whiting (*S. maculata*) did not. Given that all of these species have a similar diet, Weng (1986) suggested that the smaller species could not compete with bream. It has been well demonstrated that manipulative experiments are the soundest method of providing convincing evidence of competition for a resource (Underwood, 1986), but such experiments have not been attempted within Moreton Bay.

Growth, diet and mortality

Growth rates are known for some economically important species: *Penaeus esculentus* (tiger prawn) (O'Brien, 1994), *A. australis* (Pollock, 1982b), *Girella tricuspidata* (Pollock, 1981), and *S. ciliata* (Weng, 1988). Natural mortality rates (i.e. excluding fishing mortality) have been estimated for *P. esculentus* (O'Brien, 1994) and in the laboratory for *S. ciliata* (Weng, 1988). The diets of many species have been observed through examination of stomach contents (e.g. Moriarty, 1976; Blaber & Blaber, 1980).

The diets of animals often change as they grow, in response to changes in their size relative to prey size. The planktonic larvae stages of fish feed on plankton, the early juvenile stages of many estuarine species are likely to feed exclusively on very small, bottom dwelling organisms, collectively known as meiobenthos (Coull *et al.*, 1995), whilst late juveniles and adults feed on a more specialised diet. For example, Sumpton & Greenwood (1990), in a study of the feeding ecology of fish in the Logan-Albert estuary system, found that *Johniops* (= *Johnius*) *vogleri* (little jewfish) and *Polynemus multiradiatus* (putty-nosed perch) are initially plankton feeders, and that they both undergo a dietary shift as they grow, eating first copepods, then mysids and later *Acetes* (an abundant sergestid shrimp).

In upper estuarine and saltmarsh assemblages, terrestrial foods are often of greatest importance (Morton *et al.*, 1988; Sumpton & Greenwood, 1990). Fish assemblages in lower estuarine and open Bay waters are dominated by carnivores which feed on benthic-pelagic prey such as polychaetes, amphipods, decapods, mysids and copepods (Walkden-Brown, 1968; Sumpton & Greenwood, 1990; Warburton & Blaber, 1992). Feeding in such communities occurs mainly by day (Warburton & Blaber, 1992), however there is some evidence of temporal segregation in feeding periodicity (Walkden-Brown, 1968). Whilst authors often ascribe particular prey preferences to their subjects, there is evidence of trophic plasticity. For example, Warburton & Blaber (1992) found evidence of diet switching in *P. quadrilineatus* and suggested that this may be indicative of an adaptive response to changes in local prey availability. Trophic plasticity has been confirmed in estuarine fishes as a result of changes in prey availability following flood events. In a study of the feeding ecology of fish in the Logan-Albert estuary system, Sumpton & Greenwood (1990) found that both *Arius graeffei* (fork-tailed catfish) and *J. vogleri* shifted from a diet dominated by mysids to one dominated by copepods. They suggested also that flood-induced mortality in benthic species resulted in the loss of polychaetes from the diets of benthic carnivores. However, it is likely that major prey switching occurs only in response to an extreme event. Brewer *et al.* (1995) found that in most fishes, related species and species from similar habitats, ate similar prey. They hypothesised that competition may be low in tropical waters and thus predators can be selective. Whilst competition may be low in tropical systems, the winter decrease in species richness and abundance, which is a characteristic of Moreton Bay's subtropical nekton assemblages, may be a function of seasonal changes in benthic productivity and diversity. For example, Walkden-Brown (1968) found that the abundance and diversity of prey in fish diets decreased in the winter months. It remains to be

resolved whether density-dependent effects (e.g. predator vs prey abundance) cause the decrease in species richness and abundance of the benthos and nekton in winter months, or whether density-independent factors (e.g. salinity and temperature) are the cause.

Few studies of Moreton Bay have attempted to quantify parameters that may be applied to ecological models of energy flow involving the nekton. Moriarty (1976), using measurements of muramic acid, determined that bacteria comprised 15-30% of organic carbon in the stomach of *M. cephalus* feeding on seagrass flats and that diatoms contributed 20-30%. Observations by Hollaway & Tibbetts (in prep.) indicate that mullet graze on intertidal diatom and meiobenthic assemblages in the Brisbane River and leave characteristic feeding scars which may enable their grazing impact to be quantified. Moriarty (1976) estimated that mullet ingest 50 g dry/sediment/day corresponding to a 1.5 g C/day for sediment in a stomach containing 3% C.

Wassenberg & Hill (1987a) investigated the natural diet of the tiger prawns *Penaeus esculentus* and *P. semisulcatus* in Moreton Bay and found that adults ate a range of benthos including, bivalves, gastropods and crustaceans, and that meiobenthos were only important in the diet of animals taken from seagrass beds. Moriarty (1977) found that diet depended on location. He also determined that *P. plebejus*, *M. bennettiae* and *P. esculentus* fed on crustaceans, molluscs and polychaetes and that detritus was important in the diet of *M. bennettiae*. Moriarty (1976) found that for the detritivore *M. bennettiae*, bacteria comprised 20-35% of the proventriculus contents, which suggests that they select organic matter rich in bacteria. Wassenberg (1990) found that juvenile *P. esculentus* ate vegetable as well as animal matter, particularly seagrass seeds when in season.

Certain members of the nekton may cause an acceleration of nutrient cycling within the Bay. For example garfish, (Hemiramphidae) which feed on floating seagrass (Tibbetts, 1991), cause the sedimentation of seagrasses that would otherwise be lost to the seagrass habitats either through export to the ocean or flotsam accretion on shores. The fine trituration of seagrasses that pass through the alimentary system of such fishes render them more susceptible to rapid breakdown by saprophytes.

Morton (1990) challenged the paradigm that mangrove communities are dominated by planktivores (Blaber, 1980; Robertson & Duke, 1987) and that nutrient export is mainly through detritus export pathways. Morton suggested a model in which leaf litter is consumed by sesarimid crabs (which are in turn consumed by lower carnivores), as a more accurate model of mangrove production export than others which suggest litter export drives mangrove contribution to estuarine systems (c.f. salt marsh in temperate areas). He noted, however, that he had only sampled a single area with limited temporal replication. Whilst Morton's block net (take all) approach has yet to be repeated and his model confirmed for other mangrove habitats in Moreton Bay, his findings illustrate the extent of our uncertainty about basic ecological processes in important ecological systems in Moreton Bay. Furthermore, they demonstrate that present ecological models may more closely reflect the selectivity of our sampling gear rather than the ecology of a particular community.

Methodological Constraints on our Understanding of Pattern and Process in the Nekton

Our review of studies on the nekton of Moreton Bay has revealed the use of a wide range of methodologies (Table 2). It is clear from broad brush comparisons between some of these studies (e.g. Morton *et al.*, 1987 vs Morton *et al.*, 1988 and Stephenson & Dredge, 1976

vs Quinn, 1980), that the community structure determined for a particular habitat is greatly influenced by the type of gear used to sample that "community". Morton (1990) suggested that most previous studies of mangrove communities had used techniques (such as beam trawling and seining close to mangroves), that are unlikely to take fishes of direct commercial value, especially large, mobile individuals. In effect, large, mobile species that may be important to community processes may be eliminated from consideration by the use of inappropriate gear. Stephenson & Dredge (1976) and Blaber & Blaber (1980) used techniques that are likely to provide a more accurate indication of the true abundance and composition of the fish community of mangroves (Morton, 1990). Moreover, few studies attempt to estimate gear efficiency or differences in susceptibility among community members. Morton (1990) measured the catch efficiency of his block net by releasing marked fish into the sampled area. He found that demersal species such as *S. analis* are more likely to escape from the block net (only 66% recaptured), than pelagic species such as *Tylosurus macleayanus* (longtom), *Gerres ovatus* (= *subfasciatus*) (silverbidy), *Mugil georgii* (fantail mullet), *Arrhamphus sclerolepis* (snub-nosed gar) and *Harengula* (= *Herklotichthys abbreviata*) (southern herring) which were all recaptured with a greater than 90% success rate. Weng (1983) noted that juvenile whiting are able to bury themselves in sand and would thus avoid capture by haul nets. Morton's (1990) data, together with Weng's observation, indicate that the contribution by some demersal species to nekton assemblages may have been greatly underestimated and that efforts should be made to calibrate the efficiency of nets against the catchability of the nekton. Allen *et al.* (1992) collected haul net (seine) samples to make comparisons between the fauna captured in the first and subsequent samples and also between seine samples and samples taken with rotenone (an ichthyocide) following seining. They recommended that in any temporal study using seine nets, collection efficiency should be measured once a season. Coles' (1979) findings lend support to the recommendations made by the previous (American) study. He found that movement by prawns in and out of the sediment influenced their susceptibility to capture and that burying behaviour changed with both season and time of day. Jones (1986), investigating the spatial and temporal patterns in nekto-benthic invertebrates (i.e. crabs, prawns and cephalopods), warned that while the differences between the abundance and species richness of nocturnal and diurnal samples are often explained by reference to supposed net avoidance during the day, divers in his study did not observe net avoidance and that even fast swimming squid were caught. He concluded that: "...nocturnal sampling is essential both for adequate description of the community and the estimation of abundance of individual species. This is because the daytime community is usually a depauperate version of the night community" (Jones, 1986; p.145). Moreover, our understanding of community processes may be influenced by sampling methodology. For example, Morton (1990) found that in terms of the herbivores, *G. tricuspidata* (luderick) dominated community biomass sampled by block net and planktivores/microcarnivores dominated biomass of seine net samples. Whilst these techniques were employed in adjacent (but dissimilar) habitats, the finding illustrates the point that sampling technique strongly influences ecological interpretation of the functioning of Moreton Bay's nekton communities.

A problem related to that of escape from the sampling device by speed, stealth or guile, is that of nekton escaping from the device because they are too small to be caught. To overcome this problem Young & Wadley (1979) excluded animals less than 6 mm or greater than 10 cm from analysis to reduce the bias of net avoidance or escape on the data. Unfortunately, few others have followed their example.

Table 2. A summary of the different sampling gear used to investigate fish assemblages in Moreton Bay indicating the strength of the influence of gear type and dimension on our understanding of community structure. Under gear dimensions, SM refers to the stretched mesh measurement of net mesh.

Habitat	Site	Gear	Gear Dimensions	Notes	Author(s)
Saltmarsh	Coomera	Block net	12 mm SM	19 species, 11 of economic value, dominated by tetraodontids, bream and mugilids	Morton <i>et al.</i> , 1988
Saltmarsh	Coomera	Dip nets	0.5x 0.4 m x 2 mm	8 species, 4 of economic value, dominated by <i>Gambusia affinis</i> , <i>Pseudomugil signifer</i> and gobiids	Morton <i>et al.</i> , 1987
Saltmarsh/ Mangrove	Eden Island	Pop nets	25 m ² x 1 mm	19 species dominated by the planktivore <i>Ambassis marianus</i>	Moussalli & Connolly, this volume
Mangrove	Lota	Block net	240 m x 18 mm SM	42 species, dominated by <i>Mugil georgii</i> in numbers (30%) and <i>G. tricuspidata</i> in biomass (72%)	Morton, 1990
Adjacent to Mangroves	Lota	Seine net	70 m x 18 mm SM	30 species, dominated by planktivores/microcarnivores	Morton, 1990
Adjacent to Mangroves	Lota	Gill net	30 x 4 m 150 mm SM	12 species, dominated by <i>Mugil cephalus</i> and <i>G. tricuspidata</i>	Morton, 1990
Mangrove	Fisherman Island & Deception Bay	Trap (Block) net	8 x 2 m x 1 mm mesh	Total of 53 species (all three habitats), only 4 species exclusive to seagrass, 27 species exclusive to mangrove/mud habitats	Laegdsgaard & Johnson, 1995

Another problem arises from the difficulty of repeating a previously applied methodology, either through the use of relative measures (e.g. Laegdsgaard & Johnson (1995) hauled their seine nets for 20 *paces*) or lack of information (e.g. Weng (1990) makes no mention of the *width* of his beam trawl). A sufficient description of the sampling method is one that would allow a subsequent investigation to repeat exactly the work which is described. Without some adherence to these basic principles of scientific reporting, we will miss opportunities for making long term comparisons.

Techniques vary in the quality of their quantitative data. For example, density estimates derived for pop nets (i.e. buoyant, anchored wall nets, released by a trigger or timer, that surround nekton that have moved into the netted area) are likely to be accurate (disregarding possibly serious disturbance effects) because they sample a set area. Seine nets provide reasonable density estimates, but are susceptible to variations in the pattern of deployment and net ballooning (being lifted from the seabed) in moderate currents. Gill net catches must be indexed to the sizes of mesh used and the time the nets are allowed to fish, and block nets by their catchment area (i.e. the area of habitat covered by water which drains through the net) (see Morton, 1990). Furthermore, whilst fish abundance is usually described in terms of density (numbers per m²), they may actually occupy all levels of the water column, and in some habitats (e.g. pelagic) concentration (numbers per m³) may be a more appropriate measure.

Replication is another important factor in gaining useful quantitative data for temporal and spatial nekton studies. Studies conducted prior to the advent of personal computers suffered from an inability to treat large data matrices. Accordingly, there was little use in taking (or using) adequate levels of replication. For example, Young & Wadley (1979) sampled each of nine stations in triplicate at night. Constrained by the length of time it took to sort and identify the epibenthos (P. Young, pers. comm.), with the exception of November, they selected one replicate at random from each triplet for identification and counting. They found that they could have described the same spatial pattern from a single month of intensive (*viz.* replicated) sampling as they determined from their extensive 12 month survey that lacked replication. However, given the heterogenous nature of the Bay, the number of samples required for accurate estimates of particular community parameters may be large. Stephenson *et al.* (1982a), in an investigation of demersal trawl catches to evaluate the effects of different sampling regimes, reported little success and suggested that this was due to random variation in the data. In a follow up study, Stephenson *et al.* (1982b) found great variation in catches between two years sampled and, considering this to be due to climatic differences between the two years, they wrote: "A very prolonged study would have been necessary before the effects of weather could have been quantified, and a basis found for assessing potential changes due to man". It is obvious that there are major obstacles to gathering meaningful estimates of community structure and flux. However, certain techniques make adequate replication problematic. For example, Morton (1990) found significantly fewer species and individuals in block net samples taken in the same area 24 h later. The extent of depauperation of fauna in terms of both numerical abundance and species richness led him to exclude those 'replicates' from his analysis.

Human Impacts on Nekton Communities

Commercial and recreational fishing

Detailed discussion of the management of Moreton Bay fisheries is beyond the scope of this paper. The reader is directed to recent reviews of fisheries productivity (Quinn, 1993b) and the role of the Queensland Department of Primary Industries in the management of fish stocks

and fishing (Quinn, 1993a), as well as a detailed report on the status of Moreton Bay fisheries by Quinn (1993c). In general, he regarded the nekton stocks of Moreton Bay as stable. However, recent work by Thwaites (1996) indicates cause for concern. Both catch per unit effort (equated with a decrease in population size) and mean capture size were found to have decreased for the four species of estuarine and coastal fish examined: *Pomatomus saltatrix* (tailor), *Platycephalus fuscus* (dusky flathead), *Acanthopagrus australis* (bream) and *Sillago ciliata* (sand whiting). To what extent these decreases related to increases in recreational fishing pressure is not known. Thwaites (1996) suggests that the change is due to combination of increase in fishing effort, improvements in fishing technology and habitat modification.

Wassenberg & Hill (1990) estimated that approximately 3000 t of bycatch from trawlers enters Moreton Bay annually. Only 3% of this floats. Of fish that sink, about half are consumed by birds and dolphins. Sand crabs are dominant scavengers of fish that reach the bottom due to their speed and capacity to break up material. Fish are important scavengers of discards during the day. Blaber & Wassenberg (1989) examined the feeding ecology of birds feeding on trawler discard and suggested that *Phalacrocorax varius* (pied cormorant), *P. melanoleucos* (little pied cormorant) and *Sterna bergii* (crested tern) are primarily dependent on trawler bycatch and that the population of 350 *P. varius* consumed approximately 13.7% of the total bycatch. Wassenberg & Hill (1987b), in a study of *Portunus pelagicus* (sand crab), found that about a third of its diet comprises trawl bycatch. They noted that *P. pelagicus* was the most common scavenger of baits set to simulate trawl discards. Liggins *et al.* (1996) conducted observer-based surveys of bycatch from prawn trawling in Botany Bay and Port Jackson, New South Wales. They found that bycatch included large numbers of small, recreationally important fin fish and estimated that a mean annual bycatch of 1.52 ± 0.2 million fish was taken from Botany Bay and $219\,000 \pm 23\,000$ from Port Jackson. They recommended urgent consideration of strategies to reduce bycatch.

Dredge (1974) found from a creel survey that Serpentine Creek was subjected to between 170 and 270 fisher hrs/ha/year and that on a world scale this represented very high angling pressure. Indeed, West & Gordon (1994) stated: "Although data on recreational fishing throughout Australia are limited, anglers now appear to be the dominant harvesters of seasonal estuarine fish species." This finding has been confirmed for Moreton Bay (Quinn, 1993c).

Habitat modification

All losses of mangrove and seagrass habitat must be considered to have a direct and deleterious effect on the nekton stocks in Moreton Bay (Young, 1978). In Young's (1978) words: "destruction of littoral areas in Moreton Bay will be accompanied by a corresponding decrease in the commercial prawn fishery. This decrease will be magnified where seagrasses are included in the destruction". Several studies have recently highlighted the importance of these areas within the Bay as nursery areas for juveniles (Blaber & Blaber, 1980; Warburton & Blaber, 1992) and feeding grounds for adult fish (e.g. Brewer & Warburton, 1992). Morton (1989) in an investigation of the influence of habitat modification on estuarine fish communities, found that modified estuaries generally had fewer macrobenthic carnivores (fish that tend to have greater economic value) and more planktivores and microcarnivores than did a nearby unmodified estuary. Pollard & Hannan (1994) investigated the effects of flood mitigation structures, such as flood gates and modified channels, on fish habitat in the Clarence River (northern NSW). They found that flood gates resulted in the loss of upstream mangroves and impeded fish from previously accessible nurseries and feeding habitats.

Other forms of habitat modification likely to influence nekton assemblages, yet about which we know little, include: bait digging, dredging, trawling, land reclamation, sedimentation and anchor damage. Little work has been done in Moreton Bay on the direct and indirect effects of dredging. This is particularly surprising considering the extent of dredge spoil dumping that occurs in the Bay and the continued dredging of the Brisbane River for gravel, sand and to maintain navigation channels. The suspension of sediments and release of contaminants locked in sediments are two principal effects of such activity, but as yet, the scale of their impact on nekton and upon the organisms upon which they feed is not known.

The main forms of habitat creation in Moreton Bay are the creation of artificial reefs, jetties and moorings and the development of canal estates (see Morton, 1992; Williamson *et al.*, 1994). Little information is available on the impacts on nekton of the former, however, it is likely that nekton community structure will be locally modified and this may have consequences for the communities upon which they feed.

Mining activities such as those that were until recently undertaken in the extraction of limestone from reef areas within Moreton Bay (ceased in 1997), and sand and gravel from the beds of rivers (ceased in 1998), including the Brisbane River, are likely to have had a serious effect on nekton communities, however, these effects are yet to be quantified and are unlikely to ever be known.

Pollution

Connell (1974) studied a kerosene-like taint present in the flesh of mullet. He found that the probable cause was a mixture of chemicals that resembled kerosene and that these were present also in the sediment in the gut contents and in sediments in the Brisbane River. Connell *et al.* (1975) found the same mixture to be responsible for a taint in *Mylio* (= *Acanthopagrus*) *australis* (breem). Shaw & Connell (1982) looked at factors influencing PCB accumulation in food chains in the Brisbane River. They found particularly high levels in pelican (8.2 mg/kg), gull (2.6 mg/kg) and catfish (2.1 mg/kg).

Sammut *et al.* (1996) studied the Richmond River in northern New South Wales and found that acidification is an estuarine flood plain process that occurs in Holocene sulfidic sediments laid down in vegetated, low energy tidal environments (e.g. mangroves). Sulfates from seawater are changed to sulfides by microbial reduction (frequently in the form of iron pyrite). Sulfuric acid is generated by these sediments when they are oxidised by exposure to the air. One flood event caused a 90 km stretch of the Richmond River to become acidified. Sulfuric acid is produced in these sediments at a rate of 300 kg/ha/yr. Sammut *et al.* (1996) have suggested a range of potential long term effects of estuarine acidification including: disturbance to fish reproduction and recruitment, loss of food resources, acid barriers to migration, reduction in species diversity and long term habitat degradation. Sub-lethal effects on fish include red spot disease, which has been observed in the Brisbane River (I. Tibbetts, pers. obs.). Studies are currently underway on the effects of acidification in the Pimpama River which drains into southern Moreton Bay (A. Porter, pers. comm.).

The influence of waste water (e.g. nutrient input from Luggage Point) upon the nekton of Moreton Bay and catchment is likely to be a function of the differential ability of different species and life history stages to withstand reduced water quality, the impact on the abundance of their food and the disturbance to aquatic vegetation that provides various nursery habitats.

Fossicking

The impacts of fossicking (i.e. the unstructured recreational disturbance or removal of organisms or habitat), have not been assessed for the region. Fossicking is an exclusively intertidal phenomenon and is generally restricted to accessible areas of shore, achieving its maximum intensity in the summer months and during holiday periods. It is likely that this activity has some influence through disturbance or removal of organisms but whether such disturbances are any greater than those caused by natural events (e.g. storms) is unknown.

Cage-based aquaculture

Cage culture of marine fishes is gaining popularity throughout the world. In Australia, current practice includes the culture of salmon and tuna in large enclosures located in sheltered embayments. Currently there are no such systems in Moreton Bay. Studies in other areas have indicated that such systems can induce localised eutrophication resulting from uneaten food and faeces which sediment below the cages and greatly increases sediment nutrient levels. Other effects include the accidental enmeshing of large nekton in predator exclusion mesh which is hung around the cages. Organisms such as dolphins and sharks have either been injured or killed in such events. A third effect stems from the influence of the cage structure as a fish attracting device. Fish gain shelter from the structure as well as food in the form of attached epibionts, food not eaten by the cultured organisms and feces. This presumably leads to a marked change in the fish assemblage in the area of the cage culture system, and this may influence the composition of benthic communities.

Terrestrial-based aquaculture

Throughout the Indo-Pacific, the provision of space for aquaculture operations through land reclamation and the subsequent discharge of eutrophic water have been highlighted as the two principal causes of destruction of large areas of saltmarsh, mangrove, and seagrass habitat. In Moreton Bay such activity continues, albeit on a small scale, however, land use and the quality of any discharge from aquaculture systems are under strict conditions of monitoring and control. Since the influence of aquaculture systems on the nekton is mainly via either habitat loss or changes in water quality, see our comments on these issues above.

Restocking

While to our knowledge, no restocking of wild populations of estuarine or marine species has been attempted in Moreton Bay, the Maroochy River estuary to the north of Caloundra continues to be restocked from supplies of juvenile estuarine species reared at Bribie Island Aquaculture Research Centre (BIARC). Approximately 14 000 juvenile *Sillago ciliata* (sand whiting) and 76 400 *Platycephalus fuscus* (dusky flathead) fingerlings between 30 and 60 mm TL have been released with the intention of supplementing wild stocks depleted by a massive fish kill in the river in the early 1990s (P. Palmer, pers. comm.). To gauge the impact of the release on the wild population of juveniles and the effectiveness of the restocking program, attempts were made to mark the fish with oxy-tetracycline prior to their release. However, only 10-20% of whiting and flathead retained a recognisable mark. Whilst a scale pattern recognition system is able to discriminate between wild and hatchery reared whiting with an 80-90% accuracy, this technique has failed with flathead scales and the use of genetic markers is being investigated. The supplementation of wild fisheries with hatchery-reared juveniles is a regular feature of freshwater fisheries, and much work needs to be done on the effectiveness of such programs on marine and estuarine species and on any ecological impacts of such releases. Efforts to

replace depleted stocks arise from the economic importance of fish such as whiting, flathead and bream. Their role as principal targets for recreational anglers generates activity in local retail and accommodation industries.

Aquarium fish collection

The continued collection of fish by private or commercial aquarists is a major cause for concern. Collections are made, usually by suspended nets operated by divers, from subtidal rocky and coral reefs, as these areas are inhabited by the smaller, more colourful fishes that are targeted by such operations. In the absence of knowledge about settlement, recruitment, survivorship, age and the resilience of communities to the selective removal of particular community members, it is uncertain whether the efforts of aquarium fish collectors have the capacity to alter long term community structure or render certain members of such communities locally extinct. Given the small area and degree of hydrographic and geographic isolation of rocky and coral reef communities in Moreton Bay, it is likely that serious anthropogenic perturbations will first be detected in such areas. On the positive side, the knowledge and experience of aquarium fish collectors will undoubtedly contribute to research and monitoring programs. Their knowledge of the care of marine aquarium fish may benefit efforts to culture high value (economic or ecological) species to obviate the necessity for their collection from the wild.

Communities and Species at Risk

Apart from the aforementioned threat to the communities of rocky and coral reefs, and the possibility (which increases to likelihood and then certainty as the time period under consideration is extended) of a major pollution event affecting nekton residents in intertidal areas of Moreton Bay, there are no specific threatened species or communities of which we are aware. This statement should be placed in the context of the precision and completeness of our taxonomic knowledge and understanding of community patterns. There may be species under threat, but for the moment they are unknown.

Generally, the larger the individual, the rarer it is in the environment. The laws of thermodynamics and trophodynamic theory dictate that the more steps up the food web (i.e. the higher the trophic level) the smaller the biomass that can be sustained for a given level of productivity. High order carnivores such as sharks and large predatory fishes are thus more susceptible to shifts in the trophodynamics of systems such as Moreton Bay. Moreover, they are the favoured target of anglers (a level of attention which may be disproportionate to their abundance in the environment) and vigilantes who perceive them as a threat to humans. Selective fishing/killing may have a serious effect on populations of such organisms and local extinction is presumably more likely in this group. Foreshadowing or determining local extinction among highly mobile animals is difficult because the effective surveying of individuals or populations is complex, time consuming and expensive. Recently developed techniques, such as the use of radio telemetry and satellite tracking, may provide information about the distribution, migration and population structure of these large members of the nekton.

Anecdotal evidence indicates that major shifts may have occurred in the structure of nekton populations in the region. For example, Welsby (1905) reported that school jew (*Johnius sp.*) were once abundant in the Brisbane River and were a major target for anglers. They are now only present in low densities and mullet and catfish dominate the system. Such phase shifts may either be a natural phenomenon driven by climatic or environmental processes, that bring about a change from one quasi-equilibril community structure to another, or they may be driven by anthropogenic influences. Such dramatic shifts in community structure have been labeled catastrophic events.

Summary and Conclusions

Despite more than 150 years of investigation of the nekton of Moreton Bay, and major advances in our understanding of the system, there remains much to learn of their biology, their interactions with the plankton and benthos, the spatial and temporal patterns within nekton communities and the processes that drive these patterns. The economic worth of the Moreton Bay is a function of its nekton communities. This has led to valuable, albeit patchy, research particularly on the biology of species targeted by recreational and commercial fishers. While it has been recognised for some time that an understanding of processes affecting nekton communities is pivotal to our capacity to manage them and their environment, it is only now that information on processes, derived from supposedly analogous systems, are being dispensed with and serious attempts at determining processes for Moreton Bay are being made.

Of great concern is the finding that of four fish species, for which there are long term catch per unit effort and catch size data, all showed a significant decrease in either catch per unit effort or size (Thwaites, 1996). Such decreases in abundance and mean size must influence structure and processes among benthic and other communities and add a further dimension to models which describe the nature and pattern of change in Moreton Bay communities.

Differentiating between changes in community structure arising from natural fluctuations in environmental factors and those arising from anthropogenic alteration of habitat quality and fishing pressure, is difficult with the general lack of information available on the nekton resources of the region. The lack of detailed studies and monitoring means that we will never know the full extent of historical changes in the Bay's nekton communities, and without a more systematic approach to gathering community data we are unlikely to detect changes in the nekton, irrespective of whether they be natural or anthropogenic. Walters (1986) inferred, from analysis of middens on North Stradbroke Island, that during the last millennium fish were caught throughout the year. Prior to this there were peaks and troughs in abundance which were indicative of either migratory behaviour among Bay-side human communities or a lifestyle less dependent on fish. Our present day community has a reliance upon the natural productivity of nekton in Moreton Bay, but how much longer will we be able to rely on its resources without a detailed knowledge of its communities and ecological processes combined with the political will to protect them?

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