Sawfish (Pristidae) of the Gulf of Carpentaria, Queensland Australia

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ABSTRACT

The sawfish group Pristidae are relatively rare and are critically endangered in many habitats around the world. Information on their distribution and life history is limited. This study has improved the knowledge of pristid distribution and abundance within the inshore and offshore set net fisheries of the Gulf of Carpentaria (GoC), Queensland (Qld). Complementing this is information on the life history and biology of each of the species with recommendations for future management strategies. *Pristis microdo*n, *P. zijsron, P. clavata* and *Anoxypristis cuspidata* ocurr throughout the Northern, Southern and Western Qld regions of the GoC, Australia.

Abundance and Distribution

This study showed that *A. cuspidata* was the most abundant species and was recorded in both the inshore and offshore set net fisheries in both its mature and immature life stages. *Anoxypristis cuspidata* abundance appeared to be greatest in the Northern region of the Gulf with a maximum catch per unit effort (CPUE) of 0.83 sawfish per 500m net day $^{-1}$. The size distribution and catch locations of *A. cuspidata* suggest that the inshore area to a depth of ten metres may be the preferred habitat for juveniles, while adults primarily occur offshore. *Pristis microdon, P. zijsron,* and *P. clavata* were recorded only in the inshore fishery with catches dominated by immature animals. The abundance of *P. microdon* and *P. zijsron* was extremely low with a maximum CPUE of 0.1 and 0.2 sawfish per 500m net day $^{-1}$ respectively and their distribution patchy. The maximum CPUE for *P. clavata* was 0.83 sawfish per 500m net day $^{-1}$, however unlike *A. cuspidata,* their distribution was more restricted. The incidental catches of *P. microdon* in the set net fisheries of the GoC appear to be seasonal. This species was predominantly caught in the inshore fishery late in the monsoonal wet season (February to April) and inhabited both freshwater and estuarine environments. These findings are supported by tag recapture and vertebral microchemistry (LA-ICPMS) analysis.

Tagging

The tag and recapture data demonstrates that *P. microdon* is capable of moving along the coastal foreshore between estuaries, and juveniles migrate upstream following the receding freshwater and downstream with the floodwaters. The findings from the LA-ICPMS analysis support the hyppothesis that *P. microdon* utilise freshwater, estuarine

and marine habitats during different stages of their life history. High Sr^{88} to Ca^{43} ratios indicative of a marine environment were recorded in the section of vertebrae representative of the mature life stage in *P. microdon*. Low ratios indicative of a freshwater environment were recorded during the juvenile life stages. This habitat preference demonstrated by juvenile *P. microdon* is possibly predator avoidance behaviour. Although *P. microdon* was not represented in the incidental catch of the offshore gillnet fishery, it is highly likely they do inhabit this fishing area based on the findings of the tag and release information and LA-ICPMS data from this study. Furthermore, *P microdon* is a bycatch species in the Northern Prawn Fishery (NPF) thereby giving credibility to the hypothesis that this species inhabits deeper offshore waters of the GoC. Unlike the commercial catch of *P. microdo*n, there appeared to be no seasonal trend in the catches of the other three sawfish species. *Pristis clavat*a, *P. zijsron* and *A. cuspidata* were recorded throughout the commercial set net fishing season. Information obtained from tag and recapture of *P. clavat*a, and *A. cuspidata* and LA-ICPMS analysis and short term acoustic tracking of *P. zijsron* indicate that these specimens may have restricted site fidelity. Observations of the reproductive organs and the capture of neonate specimens indicate that in all four pristids, pupping occurred through the wet season until the beginning of the dry season in May.

Age and Growth

The age at maturity estimates of the four pristid species in this study were similar between genera. The number of growth bands on cross-sectioned vertebrae and observations made of reproductive organs, the age at maturity for *P. microdo*n, *P. clavata* and *P. zijsron* was between 8 and 10 years. For *A. cuspidata* with age estimates based from growth bands on branchial vertebrae sections and macro-staging of reproductive organs, the age at maturity was approximately 3 years. In this study, size at maturity for female *P. microdon* was 300cm T_L. The observed size at maturity of male *P. clavata* and female *P. zijsron* in this study was 295cm T_L and 380cm T_L respectively. The observed size at maturity for *A. cuspidata* was considerably smaller than for *Pristis spp*. at 203cm T_L for males and 225cm T_L for females. All GoC pristid species had a rapid growth rate in the first twelve months of development. This first year increase in size in *P. microdon* was 52cm, in *P. clavata* it was 41cm, in *P. zijsron* it was 52cm and in *A. cuspidata* it was 82cm. In all GoC pristids the growth rate in the mature stages decreased to a total growth over the last 10 years of only 20cm in *P. microdon*, 14cm in

P. clavata, 16cm in *P. zijsron* and 4cm in *A. cuspidata*. The maximum ages of GoC pristids ranged from 35 years (*P. microdon*), 34 years (*P. clavata*), 24 years (*P. zijsron*) and to at least 9 years (*A. cuspidata*).

Diet

Prey items found in the stomachs of *Pristis* included telesot fishes and Crustacea. Prey items of freshwater origin were only recorded in the stomachs of *P. microdon*. *Anoxypristis cuspidata* appeared to have a more non-selective preference for prey items compared to *Pristis*. Prey items in the stomach of *A. cuspidata* included benthic teleost species such as *Platycephalus* spp. and pelagic species including squid *Photololigo chinensis*. It was therefore concluded that *A. cuspidata* have a benthopelagic diet.

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Chapter 1 Introduction

1.1 Aims and Scope of the study

This study is the first comprehensive assessment conducted on sawfish distribution, abundance and biology in Australia. The purppose of this Masters study was to gain a better understanding of the biology and life history of the sawfish of the Queensland (QLD) Gulf of Carpentaria (GoC). This will be used to improve the conservation and fisheries management of this rare and in some cases endangered group of batoids.

The project objectives addressed the paucity of information on QLD GoC pristids including distribution, biology and life history, as identified by several authors including Tanaka (1991), Taniuchi & Shimizu (1991), Taniuchi et al (1991), Pogonoski et al (2002), Cavanagh et al (2003), Thorburn et al (2003), Peverell (2005a). The primary objectives of this study were to:

1. Collate available sawfish catch data from the QLD GoC set net fisheries.
2. Map the spatial distribution and frequency of occurrence of sawfish species in the QLD GoC based on the net fisheries catch data and government fishery monitoring program data.
3. Derive estimates of biological parameters needed for modelling sawfish populations including; age structure of population, growth rates, and reproductive parameters (age at maturity, litter sizes, reproductive frequency).
4. Identify data gaps in sawfish life history, demographics and biology and make recommendations to Department of Primary Industries and Fisheries (DPI&F) on the requirements for sustainable management of sawfish within the inshore and offshore set net fisheries in the GoC.

The information on pristids provided by this study will also contribute to the currently limited knowledge of pristids worldwide. This study complements studies on the

biology and ecology of northern hemisphere *Pristis* species, *P. pectinata* and *P. perotettiti*.

1.2 Background

Chondrichthyan fishes (sharks, rays and chimeras) occupy niches in marine, estuarine and freshwater habitats and are most numerous in tropical and subtropical environments (Last & Stevens 1994). Although a majority of the taxa are marine, approximately 43 species from four families occur in freshwater (Compagno & Cook 1995a), one of which, the Pristidae, was the focus of this study. Unfortunately the preferred habitat of pristids adjoins lands that are densely populated and are heavily impacted by a variety of pressures rising from urbanisation, agricultural production and industry (Pogonoski 2002, Pogonoski et al 2002, Compagno & Cook 1995a).

Chondrichthyan scientists have expressed concern over the increase in shark catches and the consequences this has for the populations of some shark species in several areas of the world's oceans (Bonfil 1994, Bonfil 1996, Walker 1998, FAO 1999, FAO 2000, Stevens et al 2000, SAG 2001, Pogonoski et al 2002, Cavanagh et al 2003). The observed decline in shark abundance and diversity is mostly a result of an increase in fishing pressure over the last three decades rather than the effects of habitat loss (Cavanagh et al 2003). A lucrative market exists for shark products, in particular shark fins, with product demand primarily from Asian countries (Rose & Mcloughlin 2001, Rose 1996). The shark populations that have experienced the greatest depletions are those in regions adjacent to undeveloped countries void of fisheries management (DAFFA 2002a).

Prior to the development of the shark fin trade, shark had a relatively low market value compared to finfish. This resulted in few countries managing their shark fisheries (FAO 2000). Unfortunately pristids are a group of species that are highly susceptible to all forms of fishing and are a sought after species in the shark finning trade as their fins are very high value due to their high quality and yield of "needles" within the fins (Rose & Mcloughlin 2001, Compagno & Last 1999). This has lead to a dramatic decline in the distributional ranges and global populations of pristids (Cavanagh et al 2003, Pogonoski

et al 2002, Simpfendorfer 2000, Compagno & Last 1999). Pristid flesh is firm and white and is also traded in fish markets around the world (Camhi et al 1998).

Chondrichthyan populations are more vulnerable to depletion than finfish populations because they possess life history traits similar to those of marine mammals. All Chondrichthyans reproduce via internal fertilisation, and pristids are reported to be ovoviviparous (Last & Stevens 1994). The physical constraints of internal fertilisation and embryonic development limit individual animals fecundity and the lack of juvenile dispersal leaves the species vulnerable (under certain pressures) to localised extinction. Localised depletions have already been identified in some Australian shark species such as the grey nurse shark (*Carcharias taurus*) and great white shark (*Carcharodon carcharias*) along the east coast of Victoria, New South Wales and QLD (DAFFA 2002b, DAFFA 2002c). In contrast, teleost fish breeding populations may be very large with the possibility of numerous reproductive refuges for exploited species.

Consequently, Chondrichthyans are considered to be K selected with characteristics that include long gestation periods, giving birth to live and often large offspring, late sexual maturation, long life and intermittent breeding (Castro et al 1999). A high proportion of sharks, including sawfish, would therefore naturally be in lower abundance in comparison to teleosts, even in undisturbed habitats. These demographic features suggest Chondrichthyans are especially vulnerable to overexploitation (Castro et al 1999, Bonfil 1996) and from the little information that is known on pristids it has been suggested that this group of species share the same characteristics to most other sharks and rays (Cavanagh et al 2003, Pogonoski et al 2002, Simpfendorfer 2000, Compagno & Last 1999). These characteristics imply that a precautionary approach to management is particularly applicable to this group of fishes (FAO 2000).

1.3 Sawfish

1.3.1 Taxonomy and Morphology

Sawfish belong to the Super Order Rajomorphii within the Subgroup Elasmobranchii (Hamlett 1999). They form the Family Pristidae and are unique in that their body form

and features are more like that of a shark than those of a ray. The Pristidae comprises the two genera *Pristis* and *Anoxypristis*, and currently between four and seven species are known to science (Compagno & Last 1999). In Australian waters the only validated species records of sawfish include *Pristis microdon*, *P. clavata*, *P. zijsron*, and *Anoxypristis cuspidata* (Last & Stevens 1994).There are no confirmed records or specimens of *P. pectinata* in any museums in Australia (Pogonoski et al 2002).

Due to the similarity of sawfish species, misidentifications are frequent, creating doubt over historical capture records. In the past species misidentification in the literature has been confusing and misleading. *Pristis leichardti* for example, described by Whitely (1945), has been recorded as recently as 1986 by Bishop et al, is now considered synonymous with *P. microdon* (Thorburn et al 2003), as is *P. perotetti* a northern hemisphere *Pristis* species (Compagno & Last1999).

In Australian pristid populations the identification of interspecies morphology differentiation in *A. cuspidata* and physiological differentiation for *P. microdon* (Ishihara 1991, Peter Last CSIRO Marine Hobart pers com 2003) creates further confusion to the unresolved taxonomic issues within the Pristidae family. This has caused uncertainty in the taxonomy of Australian pristids and supports Compagno & Cook (1995a) in reporting that world sawfish systematics are unsettled. It is inferred that the genus *Pristis* fall into two well-defined groups, largetooth (which includes the species *P. microdon*, *P. perotetti*, and *P. pristis*) and smalltooth (which includes the species *P. pectinata*, *P. zijsron* and *P. clavata*), (Compagno & Cook 1995a). As a working arrangement in this study I based my identifications on the taxonomic key by Last & Stevens (1994).

Members of the Pristidae family reach extraordinary lengths, exceeding 7 metres (Compagno & Last 1999). The shark-like similarities include pectoral fins distinctly separate from the head, two enlarged dorsal fins and a prominent caudal fin (Last & Stevens 1994). The most distinctive feature characterising sawfish as a ray or batoid is the positioning of the gill slits. In sawfish the gill slits are situated ventrally on the head rather than laterally as in sharks. Pristids also possesses an extended rostrum with lateral

teeth (Bigelow & Schroeder 1953). The body form of pristids indicates that they are slow but strong bottom dwellers, resting on soft mud or sandy bottoms but also swimming just above the bottom and at times near the surface in search of prey.

1.3.2 Distribution and habitat preference

The Pristidae have a global distribution, favouring shallow coastal waters and river systems in tropical and subtropical latitudes (Compagno & Last 1999, Compagno & Cook 1995a). The pristids that occur in Australian waters, *P. microdon*, *P. zijsron* and *A. cuspidata* share similar distributional ranges, occupying waters of the Indo-West Pacific (Compagno & Last 1999, Compagno & Cook 1995a, Last & Stevens 1994). The distribitional range of *Pristis clavata* also extends into the Indo-West Pacific (Compagno & Last 1999, Compagno & Cook 1995a, Last & Stevens 1994).

Pristids are one of four cartilaginous families that occur in freshwater, the other families include Dasyatidae and Potamotrygonidae (freshwater stingrays) and Carcharhinidae (whaler sharks) (Compagno & Cook 1995a). Pristids are not classified as obligate (not known from any other environment) freshwater animals although *P. microdon* is the only Australian species known to breed in freshwater (Compagno & Cook 1995a).

The distributional range of Australian pristids has been poorly reported with few records held in Australian museums or documented in scientific literature. However, based on Australian museum records, *A. cuspidata*, *P. microdon*, and *P. zijsron* are classified as euryhaline (inhabiting marine inshore waters, estuaries, lagoons and freshwater) and *P. clavata* as being brackish marginal (inhabiting brackish to freshwater) (Pogonoski et al 2002).

Specific pristid habitats include muddy enclosed bays, estuaries, inshore coastal waters, off large continental islands and in freshwater in rivers and lakes, in water depths up to 30 metres (Compagno & Last 1999, Last & Stevens 1994). These habitats are all present in the GoC and it is not surprising that all four species of Australian pristids

inhabit these waters. Historic pristid records of distribution in Australia are discussed in Chapter 2.

1.3.3 Impacts and Threats

The global decline in sawfish populations is most likely attributed to unsustainable fishing practices and changes within the environment. These changes have been brought about largely through anthropogenic influences over the short term (Compagno & Cook 1995b). In Australia these threatening processes include, commercial net fisheries, demersal prawn and fish trawl, recreational line/net fisheries, indigenous fisheries, aquarium collectors, trophy hunters, and habitat degradation (Pogonoski et al 2002, Thorburn et al 2003, Peverell et al 2004 and Peverell 2005a - CD 1 Appendix 1).

Net fishing has been identified as being responsible for the rapid decline in global sawfish populations, in particular within artisanal fisheries where poor fisheries management exists (Kroese & Sauer 1998, Simpfendorfer 2000, and Stobutzki et al 2002). A combination of the shallow water coastal distribution of pristids, and the teethed rostrum of these sawfish make all size classes vulnerable to capture in gillnets (Simpfendorfer 2000).

Within QLD the capture of sawfish by commercial net fisheries has been poorly reported and the status of sawfish populations is unknown (Gribble 1999). Peverell (2005a) reported on the interaction of sawfish with GoC set net fisheries and has provided a summary of fishery derived data to assist this study. The incidental capture of sawfish in the NT gill net fishery is largely unknown due to poor reporting within the commercial fishery. Gillnets are an effective means of capturing sawfish (Simpfendorfer 2000, Poganoski et al 2002, Cavanagh et al 2003, Thorburn et al 2003, Peverell 2005) and Australian fisheries using these apparatus have been recognised by the Shark Specialist Group of the IUCN as being of threat to the sustainability of Australasia sawfish populations (Cavanagh et al 2003).

Fish and prawn trawling has also been identified as a key threatening process to sawfish populations (Cavanagh et al 2003). Despite the introduction of bycatch reduction devices (BRD's) and turtle exclusion devices (TED's) in the prawn trawl fleet, sawfish continue to be caught in the Northern Prawn Fishery (NPF). Independent fisheries observers records of sawfish catches in research pre-season sampling in the NPF after the introduction of BRD's and TED's indicate *A. cuspidata* (94%) was the dominant species caught followed by *P. zijsron* (4%). A total of 285 sawfish were recorded during these surveys with 152 animals positively identified and 30% being released alive (B. Hill CSIRO Marine pers com 2003). The catch of sawfish in the fish trawl fishery operating in the QLD section of the GoC is currently unknown, however there are reports of sawfish interaction (J. Stapley QLD DPI & F Fisheries Observer pers com 2003). It is assumed the impact of trawling on Australian pristid populations is not just restricted to the QLD GoC (Pogonoski et al 2002).

The reporting of sawfish capture and incidental mortality in artisanal fisheries is basically non-existent, however it was once considered to be significant in certain regions where catch monitoring was undertaken (W. White Murdoch University pers com 2004). Artisanal fisheries are generally a multispecies fishery with fishers preferring gillnets and longlines because of the by-catch of teleosts, turtles, and marine mammals (Kroese & Sauer 1998). Indigenous fishers of the GoC normally utilise discarded commercial gillnets or in some instances seine nets to capture a variety of target species for local consumption (B. Russell QBFP District Fisheries Officer Weipa pers com 2003).

Recreational fishing has been recognised as a potential threat to pristid populations both in the northern (Seitz & Poulakis 2002, Simpfendorfer 2000) and southern hemispheres (Thorburn et al 2003, Thorburn et al 2004, Hogan & Vallance 2005, Peverell 2005a). In Australia, records of sawfish capture by recreational line fishers are limited. Nelson (1994) referred to sawfish as a target sport fish within GoC rivers, estuaries and landings. Helmke (1999) monitored the catch landed in the Normanton and Burketown recreational fishing competitions and identified sawfish as part of the weigh-in catch. Sawfish are vulnerable to capture by baited line and similar to most elasmobranchs exhibiting both scavenging and predatory feeding behaviour (Last & Stevens 1994).

When sawfish are confined to drying waterholes, line-fishing becomes a threatening process and is a serious resource management and educational awareness issue (Thorburn et al 2003).

Sawfish have significant cultural and spiritual relevance to indigenous Australians within the GoC (McDavitt 2001, McDavitt 2005). However the level of harvest of sawfish by these indigenous Australians is currently unknown. From anecdotal reports the indigenous harvest in some areas of the GoC is significant (M. Doohan QLD DPI&F Senior Resource Manager, pers com 2003) and given their presumed biology and life history could threaten localised sawfish populations. Along the eastern GoC the indigenous take of sawfish is primarily used for bait or consumed as part of the local diet (Kowanyama Indigenous Ranger "Anzac" pers com 2003).

The Australian Bowhunter Association (ABA) recognises pristids as a trophy animal under their award point scheme. Currently, there is no QLD legislation in place protecting pristids from this identified threat and the current take is unknown. This activity was acknowledged as a threatening process in the Commonwealth's draft freshwater sawfish management plan (Thorburn et al 2003). Recreational fishers are permitted in QLD and the NT to use "bow and arrow" as a form of fishing apparatus. However in QLD the Fisheries Act 1994 recognises bow hunting as a form of spear fishing and is prohibited in all non tidal waters and some regulated special use zones (B. Koch QBFP Regional Manager pers com 2003).

Sawfish are known to inhabit non-tidal, predominantly freshwater environments, which are considered critical to their range because of their significance as juvenile habitat. Unfortunately this makes them vulnerable to a type of habitat loss or degradation that does not normally affect marine elasmobranch populations (Simpfendorfer 2000, Camhi et al 1998, Compango and Cook 1995a and 1995b, Zorzi 1995).

Freshwater environments tend to be less stable than marine equivalents. Short term and long term fluctuations in temperature, oxygen level, mineral content, turbidity, water flow, and major changes in river and lake beds can readily exceed the tolerances of elasmobranchs (Compangno & Cook 1995b). With the addition of anthropogenic influences such as poor land resource management, water extraction, mining and

urbanisation, freshwater and estuarine elasmobranch populations are less likely to tolerate the environmental stresses.

1.3.4 Population status

On a global and national scale pristid species have been identified as being under severe threat of extinction (Cavanagh et al 2003, Poganoski et al 2002, Stobutzki et al 2002, Simpfendorfer 2000, Stevens et al 2000, Compagno and Cook 1995, Zorzi 1995, Thorson 1982a and 1982b). These authors allege (on the lack of information on the life history, biology and demography) that like most elasmobranchs, pristids are long lived, produce few offspring and mature late in life (Walker 1998), a life history strategy that makes them especially vulnerable to overexploitation (Stobutzki et al 2002). This data gap is not just restricted to the Family Pristidae but the worldwide knowledge in chondrichthyan biology, life history and demography in general (Oliver 1996, DAFFA 2002a).

There are three examples in the literature where overexploitation of pristid populations has been documented and all are from the northern hemisphere. Thorson (1976) reported the rapid population decline of *P. perotetti* populations in Lake Nicaragua-Rio San Juan System and Simpfendorfer (2000) investigated the demography of *P. pectinata* and *P. perotetti*, two species known to inhabit the Western Atlantic. Seitz and Poulakis (2002) documented the decline of *P. pectinata* population through the reporting of anecdotal information and creel survey information.

In lake Nicaragua a 2 year prohibition on the take of sawfish was imposed however this strategy proved to be ineffective given the population had been fished down to unsustainable levels and recovery was not observed over the next 6 years of monitoring (Thorson 1982a). In some areas of the United States where sawfish were once common, changes to the fishing regulations were made. Some of these changes include the prohibition of gillnets, trammel nets, and purse seines, prohibition on the recreational capture of sawfish and the inclusion of BRD's on all commercial shrimp trawlers. In addition to these regulations an extensive education and awareness program was launched and the conservation plight of *P. pectinata* and *P. perotetti* was widely publicised through the media and, pamphlets and signage.

In recognition of these global concerns regarding the status of sawfish populations (Cavanagh et al 2003) and other threatened elasmobranchs, a Fisheries Agricultural Organisation (FAO) International Plan of Action for Sharks and an Australian National Plan of Action (NPOA) have been established (DAFFA 2002a). The NPOA identifies key threatening processes to chondrichthyan populations, data gaps and mechanisms to address these issues. Australian pristids have been identified by Stobutzki et al (2002) and Gribble (2004a &b) as being a group of species at high risk of population depletion in commercial net fisheries and as such the NPOA for shark is specifically designed to ensure their long term survival.

The status of sawfish populations in Australia is largely unknown with no scientific reports documenting the abundance of pristids, apart from Peverell (2005a) and discussed in Chapter 2. However, Pogonoski (2002) identified northern Australia as possibly one of the only remaining geographical regions in the southern hemisphere where viable populations of pristids remain. Thorburn et al (2003) reported on the distributional range of Australian pristids and identified the current state of knowledge of Australian sawfish populations as fragmentary.

1.3.5 Conservation status

The International Union on the Conservation of Nature (IUCN) Shark Specialist Group categorised the species of sawfish that inhabit the GoC as endangered on the basis of their observed decline in range throughout the southern hemisphere (Cavanagh et al 2003). The IUCN used this criterion on the absence of any other available information. Establishing the extent of population decline in pristids is difficult due to a lack of historical data on stock structure and movement patterns, information on captures across all fishing sectors and biological and abundance indices.

The decision by the IUCN shark specialist group to list GoC Pristidae as endangered was also influenced by findings of studies undertaken in the Northern Hemisphere where similar pressures placed on pristid populations have caused rapid population

declines. Thorson (1982b) documented the decline of the Lake Nicaragua sawfish population, and anecdotal reports suggest declines of sawfish species throughout the Indo-West Pacific (Compagno & Cook 1995a). Demographic analysis of the available biological data (Bigelow & Schroeder 1953, Thorson 1976, Thorson 1982a and 1982b) on *Pristis perotteti* and *P. pectinata* by Simpfendorfer (2000) suggest that Western Atlantic populations are low and will take a long time to recover. Seitz and Poulakis (2002) also reported on the population decline of Western Atlantic pristid populations.

In Australia *P. microdon* and *P. zijsron* are the only species currently listed (as vulnerable) under the Australian Environmental Protection and Biodiversity Conservation Act 1999 (EPBC 1999). No direct forms of management are afforded to the protection of pristids in QLD GoC other than the management regulations purposely implemented to sustainably manage target finfish or shark species. Both inshore and offshore commercial set net fisheries in the QLD GoC have a closed season set in accordance with the lunar cycle for spawning barramundi (Garrett, 1987), a period of approximately four months over summer.

1.3.6 Significance of Species group in the GoC

Australia has a high diversity of elasmobranch fauna of which half are endemic (Last & Stevens 1994). All of Australian elasmobranch populations have been impacted on in some form or another by human activities. Some of these elasmobranch populations, as in the case of Pristidae, have been declining as demonstrated in their now restricted range (Cavanagh et al 2003). As discussed in the sawfish distribution section of this chapter, pristids were once distributed throughout the subtropical and tropical waters of Northern Australia. Recent records indicate that only isolated areas sustain reasonable populations of sawfish, effectively acting as refugia for these species (Peverell et al 2004).

Although sawfish fishing mortality (commercial, recreational and indigenous) in the GoC is largely unknown, it appears viable populations still remain (Poganoski et al 2002). This characterises the GoC as being an extremely important region in terms of sustainable sawfish habit. The GoC's isolation has meant that habitat degradation by

anthropogenic influences has remained minimal. The role sawfish play in the ecosystem is that of a large apex predator and as a species can act as an important indicator for high biodiversity as characterised for other large elasmobranch species such as the grey nurse shark (*C. taurus*), (DAFFA 2002b).

The GoC offers a region where studies can be undertaken on the habitat utilisation of sawfish. Sawfish occupy several habitats during different times of the season and at different stages of their lifecycle. This makes pristids unique in comparison to many other elasmobranchs, as their habitat use crosses the boundaries of freshwater, estuarine and marine waters (Compagno & Cook 1995a). Therefore the sustainability of GoC sawfish populations is possibly a priority for resource managers not only their conservation status but the roles they play in maintaining the ecosystem balance.

1.3.7 Current and historical sawfish research

Historically, fisheries management in QLD has focussed on high valued finfish species not on incidental bycatch species such as sawfish (Peverell 2005a). This trend has changed with the demand for cartilaginous fish products escalating in recent years (Kroese & Sauer 1998, Rose 1996) and sawfish research has been highlighted as an area requiring urgent attention (Cavanagh et al 2003).

In the Northern hemisphere Dr. Colin Simpfendorfer and his team of researchers at the Mote Marine Laboratory, Florida are presently investigating the biology, ecology, distribution and abundance of *P. pectinata* and *P. perotetti*. In Australia, the Fisheries Research Development Corporation (FRDC) 2002/064 funded “Sustainability of Northern Australian Sharks and Rays” with Commonwealth Scientific and Industrial Research Organisation (CSIRO) as the lead agent to investigating sawfish distribution, biology and life history. This Masters study is part of this project and will assist in addressing some of the key information gaps as identified in the aims and scope of the study. This information is not only critical to the sustainable management of Australian pristids but the ecologically sustainable management of economically important net fisheries.

Historically the only published scientific literature directly on sawfish biology and life history are those by Bigelow and Schroeder (1953), Thorson (1976, 1982a and 1982b), Ishihara (1991), Tanaka (1991), Last and Stevens (1994), and more recently Simpfendorfer (2000), Seitz and Poulakis 2002, Simpfendorfer (2002), Thorburn et al 2003, Thorburn et al 2004 and Simpfendorfer (2004). Of relevance to Australian pristids, Tanaka (1991), Ishihara (1991) researched the biology and morphology of *P. microdon* and Thorburn et al 2003 and Last & Stevens (1994) provided a species synopsis for *P. microdon*, *P. clavata*, *P. zijsron* and *A. cuspidata*. All of these studies were based on few samples and a lack of mature specimens. The remaining authors from the above paragraph discussed northern hemisphere species.

1.4 Study area

The GoC was chosen as the area of operation for this study for two reasons; the first being it is a known area of sawfish abundance and secondly access to specimens was gained through the DPI&F Fisheries Observer Program. With this chosen location came significant difficulties and challenges in undertaking this study. These are discussed in the general discussion chapter under the sub heading caveats and limitations.

The GoC is located in northern Australia and is a very extensive, relatively shallow embayment of approximately 320 000 km^2. The GoC is influenced by a warm, moist northwest monsoonal circulation from December to March (i.e. wet season) each year and a cooler, drier southeast trade wind period from May to October (i.e. dry season) (Staples 1983). Sawfish distribution and abundance estimates are discussed in reference to three QLD GoC regions (Figure 1): northern region (12^o to 14^o S, 140^o to $142^o30'$ E), southern region (14^o to $18^o30'$ S, 142^o to 140^oE) and western region (14^o to $18^o30'$ S, 138^o to 140^oE).

The southern and western regions of the GoC are shallow (consistently less than 18m) and have extensive mudflats. Combined with large tidal fluctuations and wind induced wave action this causes high water turbidity in these regions. In contrast, the inshore

and offshore waters of the northern region have a steeper shoreline gradient than the south and as such are characteristically clearer.

The southern region has an extensive mangrove fringed coastline and silty undulating mud and sand bars. The western region is commonly shallow with wide, firm mud bars extending well offshore. The substratum offshore in all three regions is predominantly mud and sand with rubble beds and isolated emergent reefs to a depth of 40 metres (J. Stapley QLD DPI & F Fisheries Observer pers com 2002). The river watersheds of the southern and western regions of the GoC are larger than those from the rivers in the northern region (Ryan et al 2002).

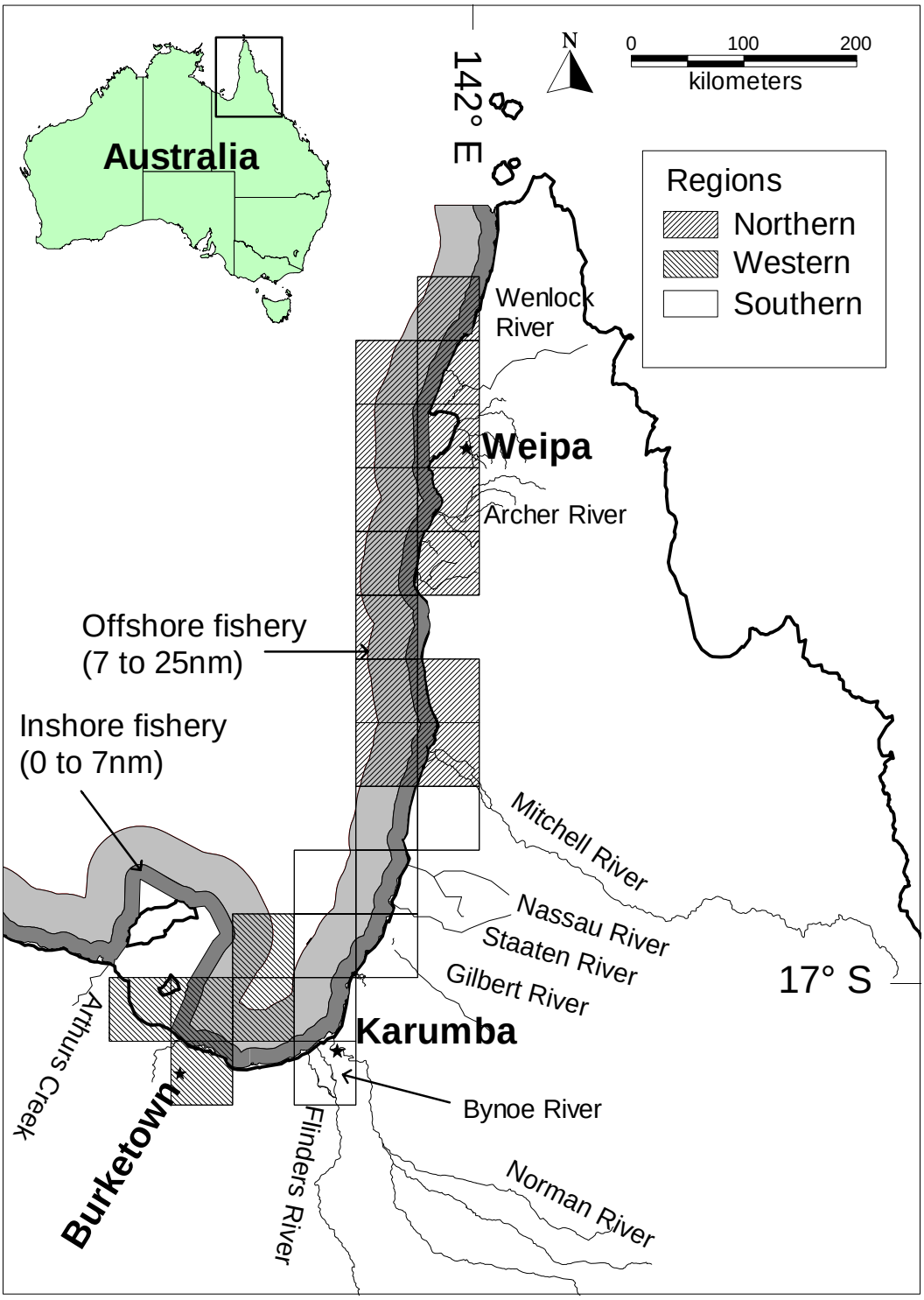

Figure 1: Area of fishing operation for inshore (N3) and offshore (N9) set net fisheries of the Queensland Gulf of Carpentaria; and distribution of regional grid references used in this study. Each square grid is representative of a 30 minute commercial logbook grid reference (30 nm x 30 nm).

Chapter 2: Sawfish Distribution, Abundance & Maturation

2.1 Introduction

Information on the distribution and abundance of Australian pristid populations is limited. On the foundation of limited museum specimens and independent survey data such as Taniuchi et al (1991), Last & Stevens (1994) published a broad scale distribution map for Australian pristids. The spatial resolution of this distribution map has been further refined in more recent times with the inclusion of pristid records from baseline survey data such as Thorburn et al (2003) and Thorburn et al (2004).

The first documented pristid sighting in Australia by a European was by Edward Leichhardt, in the Leichhardt Expedition in 1844-45 (Leichhardt & Ludwig 1847). Leichhardt describes the sighting of a dead sawfish in the freshwater of the Leichhardt River and concludes from this observation that they are very close to the coast. Earlier reports of sawfish occurrence within the GoC can be found in the drawings, story telling and cultural dance of Aboriginal peoples throughout coastal northern Australia. Through Aboriginal culture these animals symbolize a connection to the land and sea as well as providing, at certain times, of the season critical food resources (McDavitt 2005). The importance of pristids in Aboriginal culture in the GoC is evident and furthermore indicates that as a species group they were once widely abundant in the GoC.

Allen (1982) reports that *Pristis* species prefer a muddy substrate and in particular *P. microdon* prefers the deeper water found in river channels of estuarine and freshwater drainages (Wilson 1999, Last & Stevens 1994). *Pristis microdon* have been reported upstream to a distance exceeding 100km (Last & Stevens 1994) and are known to inhabit estuarine waters of salinity ranges between 20ppt to 35ppt (Taniuchi & Shimizu 1991, Thorburn et al 2003, L. Jnr. Squire Director CMA pers com 2003). It is suggested *P. clavata* also occurs some distance upstream, inhabiting low salinities (Last & Stevens 1994). *Anoxypristis cupsidata* has been recorded in brackish waters (salinity range 20 to 25ppt) in the Oriomo River estuary in Papua New Guinea (Taniuchi & Shimizu 1991)

and offshore in water depths exceeding 120 metres (Gloerfelt-Tarp & Kailola 1984, Pogonoski et al 2002).

Within the QLD portion of the GoC there are a number of aquatic systems that support pristid populations. The status of these populations is unknown. *Pristis microdon, P. clavata, P. zijsron* and *A. cuspidata* are known bycatch species in the GoC NPF (Stobutzki et al 2002), gill net fisheries (Peverell 2005a) and fish trawl fishery (Zeller 2005). In addition, *P. zijsron* and *A. cuspidata* have also been recorded in Arthurs Creek, a coastal estuarine system in the central GoC (QLD Museum records).

From other fisheries dependent sources *P. microdon* has been recorded in the Gilbert River (Thorburn et al 2003, Taniuchi et al, 1991, and L. Jnr. Squire Director CMA pers com 2003); Wenlock River (L. Jnr. Squire Director CMA pers com 2003, Thorburn et al 2003); Flinders and Bynoe River (L. Jnr. Squire Director CMA pers com 2003); and Norman River (QLD Museum records; L. Jnr. Squire Director CMA pers com 2003). *Pristis clavata* and *P. zijsron* have been recorded in Missionary Bay, Weipa (Thorburn et al 2003, L. Jnr. Squire Director CMA pers com 2003, J. Salini CSIRO Marine Research Cleveland pers com 2003).

Sawfish records in the NT are poorly documented. Only one specimen a *P. microdon* from the Goomadeer River, is held at the Northern Territory Museum and Art Gallery. Thorburn et al (2003) reported *A. cuspidata* from the Liverpool and Blythe Rivers and *P. microdon* from the McArthur, Wearyan and Robinson Rivers.

It is reasonable to assume (on the absence of accurate catch records), based on similarities in habitat, and regular supply of pristid rostrums being sold through the Darwin Mindl beach market that the NT gill net fishery would interact with pristid populations. Independent fishery observer survey reports, funded as part of FRDC funded “Sustainability of Northern Australian Sharks and Rays” project (2002/064), confirm these inferences (R. Buckworth, Senior Fisheries Biologist NT Fisheries per com 2004).

Captures of sawfish in the GoC are often sporadic and seasonal, unlike traditional catch sampling of teleost where large densities of animals are encountered year round (QLD Fisheries Observer unpublished data). It was therefore the purpose of this study to obtain as much biological information as possible from every sawfish specimen encountered. The collection of this information in a systematic way was restricted by field conditions and the logistics involved in dealing with large and potentially dangerous animals.

This chapter provides critical ecological information that complements the limited findings of previous studies on pristids undertaken in northern Australia by (Taniuchi et al (1991), Thorburn et al (2003), Thorburn et al (2004), and various government reports). This chapter is the first study to collate pristid catch data based on fisheries dependent and independent sources from the GoC. The findings of this chapter will form the foundation from which future resource management decisions for GoC pristids will be based seeing there is no other data available on these species.

The aims of this chapter were;

1. Map the spatial distribution and frequency of occurrence of Gulf of Carpentaria pristids;
2. Report on pristid size frequency within the Gulf of Carpentaria;
3. Document notes on the reproductive strategy of Gulf of Carpentaria pristids;

2.2 Methods

2.2.1 Data description

The QLD sector of the GoC covers 270 000 km^2 and supports a diverse commercial fishing industry worth approximately AU$67 million annually (L. Williams Economist QLD Fisheries Service pers com 2001). Within the QLD managed sector of the GoC, ninety-two inshore commercial set net fishing licences (N3 fishery symbol) and six offshore commercial set net fishing licences (N9 fishery symbol) are currently operational (M. Doohan Fisheries Manager QLD Fisheries Service pers com 2003).

Both the inshore and offshore commercial set net fisheries have a closed season (October to January) corresponding to the lunar cycle for spawning barramundi (Garrett 1987).

The inshore set net fishery is a multispecies teleost fishery that targets barramundi and threadfin salmon (Polynemidae) from the shoreline seaward to 7 nm (QFMA 1999). A number of area closures, mainly governing the freshwater reaches of rivers and cultural areas of significance to indigenous owners have been established. The offshore commercial set net fishery is predominantly for shark (mainly *Carcharhinus tilstoni* and *C. sorrah*) and grey mackerel (*Scomberomorus semifasciatus*) and extends from 7 nm offshore out to 25 nm (Figure 1).

Information on sawfish was obtained from three sources: researcher surveys of catches made by commercial fishing vessels; voluntary reporting of commercial catch; and fishery independent set net sampling. Observations were made throughout the fishing season (February to September) for 2000 to 2003. Information on *P. microdon* seasonality was acquired through fisheries observer data and catch rates in the three GoC regions.

The inshore set net fishery uses monofilament gillnets of between 162.5 and 245mm stretched mesh with an approximate drop (depth of net) of between 3 and 6 m. The offshore fishery used 162.5mm stretched mesh nets consistently with an approximate mesh drop of 13 m. The gear in both fisheries is predominantly anchored off the head rope and is surface set. These nets will reach the bottom during all periods of the tide, hence sampling the full water column. The use of hydraulic net hauling devices is permitted in both fisheries, and is used principally by the offshore fishery where longer and deeper nets are fished.

2.2.1.1 Researcher Surveys of Commercial Catch

Research surveys on commercial vessels were undertaken on an opportunistic basis as time and space on board vessels became available. The mandate of the research observer was to record total catch statistics focusing primarily on target species.

Sawfish captures were recorded as part of the bycatch species composition, and were identified with appropriate taxonomic keys published in Last and Stevens (1994).

2.2.1.2 Voluntary Reporting of Commercial Catch

The fifteen inshore commercial fishers that assisted in the research observer program also provided information about their catches of sawfish when research observers were not on board. These commercial fishers fished in all three study regions, and were trained in sawfish identification and biological sampling procedures when the author was on board their vessels during researcher surveys. In addition, a formal training workshop with sawfish specimens was held in 2001 with the fishers to further improve their identification and reporting skills. A sawfish identification guide with photographs that highlight key morphological features was distributed to all inshore and offshore set net fishers (CD 1 Appendix 2). Researchers used photographs taken by fishers of sawfish that were released alive and of recently deceased specimens to validate commercial fisher sawfish identifications.

2.2.1.3 Fishery Independent Samples

The QLD Fisheries Service undertakes an ongoing multi-teleost species long term monitoring program that obtains fisheries independent data on the status of barramundi stocks in the GoC. The Flinders, Staaten, Mitchell, and Archer Rivers (Figure 1) were all surveyed during March and April each year. Fishing apparatus for the research surveys includes the use of 50, 100 and 150mm monofilament nets of 33 mesh drop and up to 200 meters in length (R. Garrett Principal Fisheries Biologist QLD Fisheries Service pers com 2004). Data from sawfish catches in this fishery were recorded as part of the monitoring program.

2.2.1.4 Biological Parameters Recorded

In light of the conservation concerns for pristids, where possible all pristids were tagged and released alive. Morphological measurements taken (nearest 0.5cm) included total length (T_L), lower jaw to total length (LJT_L), and lower jaw to fork length (LJF_L) and

gender was determined by examining the presence or absence of claspers. Whole weight (W_W) was recorded on an opportunistic basis to the nearest kilogram (kg).

Pristid sex was determined by observation of the presence or absence of claspers. Reproductive stage for male and female specimens was recorded using the technique described in Stevens & McLoughlin (1991). Reproductive staging in females was determined by autopsy and observations of the uterus and ovary. In deceased animals 8 vertebrae were extracted from below the first dorsal fin for use in age and growth investigations. These samples were stored frozen. Tissue samples of either muscle or fin were taken on an opportunistic basis and preserved in dimethyl sulfoxide (DMS) for future genetic analysis.

2.2.3 Data analysis

Sawfish records were collated in an Access® database. Preliminary analysis was conducted in Excel®. Analysis of size distribution data between the inshore and offshore set net fishery for *A. cuspidata* was conducted in Genstat® using a Kruskal-Wallis non-parametric one way analysis of variance. Regression analysis was used to determine if a significant relationship existed between the morphometric measurements of LJT_L and T_L, for the four sawfish species examined (Table 1). This relationship was used to provide an estimate of the total length of recaptured sawfish, which had had their rostrums removed for ease of release from commercial fishing nets.

Fore each species catch per unit of effort (CPUE) was recorded as number of sawfish caught per 500m net day^{-1} (24hrs) for all three data types. These data were assigned to a thirty minute of latitude commercial grid reference (a 30 by 30 nautical mile grid) for mapping purposes. This scale of data presentation is necessary to comply with confidentiality provisions of QLD commercial fishing logbook reporting. The data was pooled for the three years from 2000 to 2002 and for the two QLD GoC set net fisheries for ease of reporting. It was assumed that the gear employed by the three sources of data collection had the same “catchability” and represented an equal chance of capturing sawfish.

Table 1. Parameters of the regression relationships between lower jaw total length (LJT_L) and total length (T_L) in the form of $T_L = a * LJT_L + b$ for pristid species of the Queensland Gulf of Carpentaria

Species	a	(s.e)	b	(s.e)	R^2	n
Pristis microdon	**1.47**	**0.044**	**-5.71**	**6.550**	**0.99**	**12**
Pristis clavata	**1.2**	**0.009**	**8.75**	**0.993**	**0.99**	**14**
Pristis zijsron	**1.56**	**0.040**	**-12.63**	**5.818**	**0.99**	**17**
Anoxypristis cuspidata	**1.41**	**1.638**	**2.98**	**0.018**	**0.99**	**10**

2.3 Results

2.3.1 Fishing effort observed

From 2000 to 2002, commercial fishing effort was observed over approximately 70% of the available fishing area for the inshore set net fishery and 66% for the offshore set net fishery. This coverage was widely spread geographically (Figure 2). In this study, the combined fishing effort observed by researcher surveys and voluntary reporting of commercial catch accounted for 3.3% and 12.6% of the total 2000 to 2002 fisher days reported in the inshore and offshore commercial fisheries, respectively. All licensed operators in the offshore set net fishery and approximately 7% of inshore operators were included. In total, 582.72 km and 256.8 km of net in the inshore and offshore fisheries respectively were observed over 1428 effort days.

2.3.2 Geographic distribution and relative abundance

Sawfish distribution and relative abundance varied considerably between and within the three GoC regions and also among commercial logbook grids (Figure 2). *Pristis microdon, P. clavata* and *P. zijsron* were recorded only in the inshore fishery. *Anoxypristis cuspidata* was recorded in both fisheries.

Pristis microdon, P. clavata, and *P. zijsron* were each recorded in the northern, southern and western regions of the GoC although *P. microdon* and *P. clavata* was rarely found north of Kowanyama (Figure 2). *Anoxypristis cuspidata* was recorded in the northern and southern regions of the GoC and was rarely found west of Burketown. During the

months of February to April *P. microdon* was taken more frequently in the creeks and estuaries and *P. clavata*, *P. zijsron* and *A. cuspidata* along the coastal flats and bays.

Anoxypristis cuspidata and *P. clavata* had the highest CPUE at 0.83 sawfish 500m net day^{-1}. *Anoxypristis cuspidata* was recorded in many more commercial logbook grids than the other sawfish species. The highest catch rate of *A. cuspidata* was recorded in the northern region of the GoC. *Pristis zijsron* had a maximum CPUE of 0.21 sawfish 500m net day^{-1}, which was the lowest catch rate of all of the sawfish species. Despite this, *P. zijsron* was recorded in more commercial logbook grids than either *P. clavata* or *P. microdon* (Figure 2).

Pristis clavata and *P. zijsron* were both patchy in their distribution (Figure 2) and were recorded in all three GoC regions. The abundance of *P. clavata* appears to be stronger in the western region of the GoC (Figure 2). *Pristis zijsron* appears to be more abundant in the northern and western regions of the GoC than in the southern GoC.

Pristis microdon was widely distributed along the northern GoC, and the maximum catch rate recorded was 0.02 sawfish per 500m net day^{-1}. It was recorded at the mouths of the major rivers; the Mitchell, Gilbert, Archer, Nassau and Staaten Rivers (Figures 1 & 2). Analysis of the catch dates for *P. microdon* from records from the intensive tagging program in the Mitchell River showed that 95% of the catch was recorded in the wet season months of February to April.

2.3.3 Size distribution, Sex ratio, and Maturity

The size distributions of *P. microdon*, *P. clavata*, *P. zijsron* and *A. cuspidata* included both juveniles and adults (Figure 3) and all appear to have a peak from 70 to 120cm T_L. These peaks represent immature stages in all four species. The size distributions for *P. microdon* and *A. cuspidata* were multi-modal, with the former having another peak between 200 and 260cm T_L, and *A. cuspidata* a peak from 270 to 330cm T_L. This second peak for *A. cuspidata* represents adult individuals caught in the offshore fishery. *Pristis microdon* has a more complex size distribution pattern.

The size classes of *A. cuspidata* in the offshore fishery were significantly larger than those recorded in the inshore fishery (Kruskal-Wallis one-way test, $H = 62.61$, $p < 0.001$). The largest *A. cuspidata* recorded in the offshore set net fishery was 330cm T_L and the smallest in the inshore set net fishery at 75cm T_L.

The sex ratio of male to female was nearly 1:1 among all four sawfish species caught in the inshore fishery (Table 2). The sex ratio of *A. cuspidata* in the offshore fishery however, was dominated by female animals at a ratio 2.1 females to 1 male (Table 2). Of the 74 *A. cuspidata* recorded in the offshore fishery, 16 male and 15 female specimens were reproductively staged and were identified as being sexually mature. All female *A. cuspidata* examined were found to possess large yolky oocytes with an average egg diameter of 25mm (Figure 5). These animals were all caught during the month of August, in both 2000 and 2001.

Pristis species taken in the inshore set net fishery were predominantly immature except for five individuals: a female *P. zijsron* caught just after the wet season at 380cm T_L (post partum); two male *P. clavata* of 295cm and 306cm T_L (long rigid claspers); and two female *P. microdon*, the first of 582cm (with full term embryos - Figure 6 and 34 large yolky oocytes with an average egg diameter of 125mm - Figure 7) and the second at 303cm T_L (full term embryos, pupping when caught). These mature *P. microdon* were taken in the months of March and April 2002 coinciding with large freshwater flows at the mouths of the Leichardt and Mitchell Rivers during the 2001 and 2002 wet season.

Thirteen neonate (new born) *P. microdon* were captured in commercial gill nets between January to early April in 2001 and 2002. Umbilical scaring was identified on the underside of these individuals which ranged in size from 72 to 93cm T_L. *Pristis microdon* of these size classes were not recorded outside these wet season months. Four full term embryos of between 87.5 and 90cm T_L were collected from the same female *P. microdon* (582cm T_L) which had large ovarian ocyetes.

Table 2. Sex ratios (M - male, F - female) and frequency of occurrence of mature specimens recorded in the inshore and offshore set net fisheries of the Queensland Gulf of Carpentaria, 2000 to 2002. Total lengths (T_L) $\overline{X}$ (range) cm are provided for mature animals.

	Ratio		Male			Female		
Inshore fishery	**n**	**M:F**	**n**	**$\overline{X}$ (range)**	**% Mat**	**n**	**$\overline{X}$ (range)**	**% Mat**
Pristis microdon	66	1:1.05	38		0	28	(303-582)	7
Pristis clavata	24	1:0.91	12	300 (295-306)	8	10		0
Pristis zijsron	19	1:1.33	8	174 (87-449)	7	9	(380)	7
Anoxypristis cuspidata	37	1:1.15	7		0	11		0
Offshore fishery								
Anoxypristis cuspidata	74	1:2.1	16	230 (203-315)	77%	15	293 (225-329)	100%

2.4 Discussion

2.4.1 Spatial distribution and CPUE

Very little is known of the distribution and abundance of Australian sawfishes. Last & Stevens (1994) coarsely mapped the distributional range of Australian pristids using data from museum records and historical photographs. The data from this current study has further refined the spatial resolution of pristid distribution within the Queensland GoC. It is evident that the inshore net fishery of the QLD GoC interacts with *P. microdon, P. clavata, P. zijsron* and *A. cuspidata*. In this study, the only sawfish species recorded in the offshore fishery was *A. cuspidata*. However, anecdotal information (chiefly preserved *Pristis* rostrums and historic specimen photographs) from offshore set net fishers suggests that the fishery has limited interactions with large *Pristis* specimens throughout the fishing season. This conclusion is further supported by Stobutzki et al (2002), where *Pristis* were recorded in the Northern Prawn Fishery trawl bycatch. If these QLD GoC *Pristis* species possess similar life history traits to that of *P. pectinata*, a northern hemisphere sawfish species, it maybe reasonable to suggest that mature animals are highly migratory and inhabit waters in excess of 50 m (Simpfendorfer 2002).

2.4.1.1 *Pristis microdon*

Little is known of the biology or life cycle of *P. microdon,* the freshwater sawfish. Last & Stevens (1994) documented the range of this species as extending to all GoC river systems, and provided a brief description of the species biology based on a small number of juvenile specimens. *Pritis perotetti,* a freshwater species from Lake Nicaragua, Rio San Juan system, is considered synomonous with *P microdon* (Simpfendorfer 2000). Although *P. perotetti* has been extensively studied (Thorson 1976, 1982a & 1982b), *P. microdon,* a tropical "partially" marine species has little information available. In the current study *P. microdon* appears to pup in freshwater but can move into estuarine and coastal marine habitats. In contrast Thorson (1982b) reports that *P. perotetti* of Lake Nicaragua spend much if not all of their lives in freshwater and that recruitment from downstream seems to be minimal. Reproduction of *P. perotetti* can occur in freshwater and comparisons between the reproductive strategy of this species and *P. microdon* will be discussed in more detail in chapter 4.

Catches of *P. microdon* were concentrated in the commercial fishing grids that include the river mouths of the Archer, Nassau, Staaten, Mitchell, and Gilbert Rivers (Figure 2). This finding is possibly the result of the species preference for freshwater habitats during this time of the year for breeding purposes or to exploit the abundance of prey items such as the freshwater prawns (*Macrobrachium australiense, M. rosenbergi* and *M. handschii*).

The peak catch rates for *P. microdon* correspond with the monsoonal wet season, when the salinity levels at the river mouths and along the coastal shoreline are very low. However, *P. microdon* are known to inhabit tidal waters and will tolerate salinity levels of a marine environment (L. Jnr. Squire Director CMA pers com 2003).

There is growing evidence, both documented (Ryan et al 2000, Stobutzki et al 2002 and Thorburn et al 2003) and anecdotally from commercial, recreational and traditional fishing sources, to support the hypothesis that mature *P. microdon* inhabit marine waters during the post wet season months and enter less saline waters inshore during the wet season months to pup. In June 2003 a mature female *P. microdon* (in pup) was captured by a commercial long line fisher operating off the Wessel Islands, Northern

Territory (G. Lawrence Commercial Shark Fisher pers com 2003). Research fisheries observers identified the specimen from photographs and the retained rostrum. In the QLD GoC study reported here no *P. microdon* were captured upstream of river mouths in post west season months and two mature *P. microdon* were taken at river mouths in March and April. Further studies are required to validate this hypothesis.

Anecdotal information obtained from commercial and traditional fishers from the GoC suggest that freshwater flows associated with monsoonal weather patterns maybe the environmental cue responsible for triggering pupping in all GoC sawfish species. In this study, pupping in a *P. microdon* of 303cm T_L was observed on one occasion, a female (582cm T_L) carrying full term embryos was examined on another occasion and a number of neonate *P. microdon* were captured in the inshore fishery during the wet season. Thus, breeding *P. microdon* populations have been at least partially protected by the seasonal closure of the inshore and offshore set net fisheries from October to January.

These results also suggest pupping in *P. microdon* occurs on an annual basis and late in the wet season. Evidence of an ovarian cycle and gestation period running concurrently, that is females carrying developing oocystes and embryos at the same time, is representative of an annual reproductive cycle. This evidence is supported by other large elasmobranchs which have annual reproductive cycles such as the scalloped hammerhead (*Sphyrna lewini*) (Carrier et al 2004).

2.4.1.2 *Pristis clavata*

The dwarf sawfish is a small robust animal reported to attain a maximum length of 140cm T_L (Last & Stevens 1994). However in this study, three specimens larger than this size were recorded; two mature male specimen of 295 and 306cm T_L; and an immature female of 210cm T_L. These findings suggest this species attains a much larger maximum size in GoC waters than previously suspected. This study also shows that the distribution of *P. clavata* extends into all regions of the QLD GoC, but its abundance is low everywhere and highly variable. Catches of *P. clavata* were made during the post wet season months, however only along the coastal shoreline where the waters are predominantly marine at this time of the year.

2.4.1.3 *Pristis zijsron*

In this study, the green sawfish was not recorded during the first three months of the commercial fishing season (February to April), however this species is thought to inhabit freshwater environments (Compagno & Cook 1995a). The catch records show that *P. zijsron* inhabits all regions of the QLD GoC with a pattern of relative abundance similar to that of *P. clavata*, that is, in low numbers and with a highly variable frequency of occurrence. *Pristis zijsron* was caught only along the coastal shoreline. A post partum female specimen measuring 380cm T_L was recorded in May 2001. A collaborative study of the sustainability of Australian sharks and rays by Commonwealth Scientific Industrial Research Organisation (CSIRO), and the Fisheries agencies in Western Australia, Northern Territory and QLD has recorded instances of *P. zijsron* pupping in January (R. McAuley Fisheries Biologist Western Australian Fisheries pers com 2003). This very scant dataset suggests pupping for this species may occur during the wet season, as has been suggested earlier for *P. microdon*.

2.4.1.4 *Anoxypristis cuspidata*

The narrow sawfish was the most abundant of all sawfish species recorded in this study. This species is regarded as being a marine sawfish (Gleorfelt-Tarp & Kailola 1984, Taniuchi & Shimizu 1991, Stobutzki et al 2002), and was recorded both in the inshore and offshore fisheries of the QLD GoC. The CPUE of *A. cuspidata* varied considerably with observed catch rates greatest in the northern region of the QLD GoC.

Anoxypristis cuspidata is also the most commonly caught sawfish within the NPF (Stobutzki et al 2002) and it is most likely trawled from the sea bottom as opposed to being captured during setting and retrieving the fishing gear (ie. fishing through the entire water column). By comparison, the offshore set net fishery sets surface nets and *A. cuspidata* forms part of the incidental bycatch. These results suggest that this species not only inhabits the sea floor but also the mid water column. As such *A. cuspidata* can be best referred to as a benthopelagic animal.

No mature *A. cuspidata* were recorded in the inshore fishery out of the total of 34 specimens recorded between 2000 and 2002 (Table 2). This suggests that the inshore set net fishery area in the GoC may be an important juvenile habitat for this species. The size classes of *A. cuspidata* were significantly different in the inshore and offshore set net fisheries, with the offshore set net fishery predominantly catching large mature animals (Table 2 & Figure 3). Female *A. cuspidata* were found to be vitellogenic (yolky oocytes present) in August (the dry season). If this species has a gestation period of five months, as suggested for *P. microdon* (Compagno & Last 1999), then pupping in *A. cuspidata* could also occur over the monsoonal months.

2.4.2 Conclusion

Given the rarity of Pristids, it can be challenging to obtain life history information necessary to model sawfish population dynamics such as stock structure and age and growth. However, the Queensland GoC pristids may represent one of the best-conserved sawfish populations internationally, and this circumstance provides an opportunity to undertake such biological studies, given the cooperation of all sectors of the fishing industry.

Sawfish populations have been conserved in the Queensland GoC due to a number of factors including relatively minor coastal development, low levels of habitat degradation, and a multitude of fishing spatial and temporal closures, which help reduce levels of commercial set net fishing effort. It seems that management initiatives, introduced in the 1980s to protect the other GoC fisheries resources have fortuitously provided some protection for sawfish populations over the reproductively critical monsoonal wet season. Whether this level of protection is sufficient to sustain GoC sawfish populations is not known, and additional fishery management measures maybe required. The population of pristids in the GoC should be monitored very closely because of the absence of mature *Pristis* specimens from the catch data in this study. Further investigations will be required to determine the causes or reasons behind there absence.

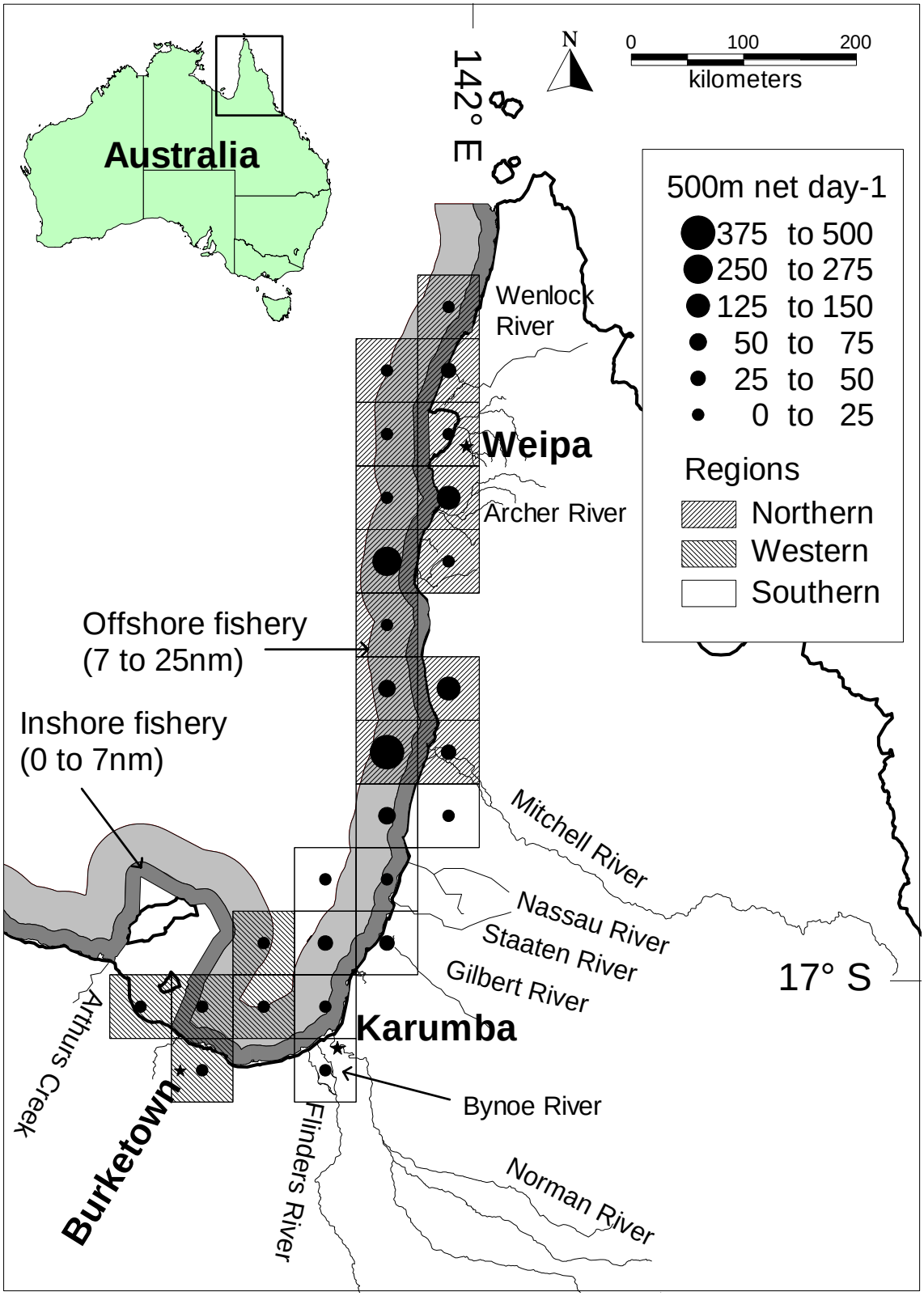

Figure 2: Area of fishing operation for inshore (N3) and offshore (N9) set net fisheries of the Queensland Gulf of Carpentaria; and distribution of fishing effort (days observed) for each 30 minute commercial logbook grid reference, pooled for the years 2000 to 2

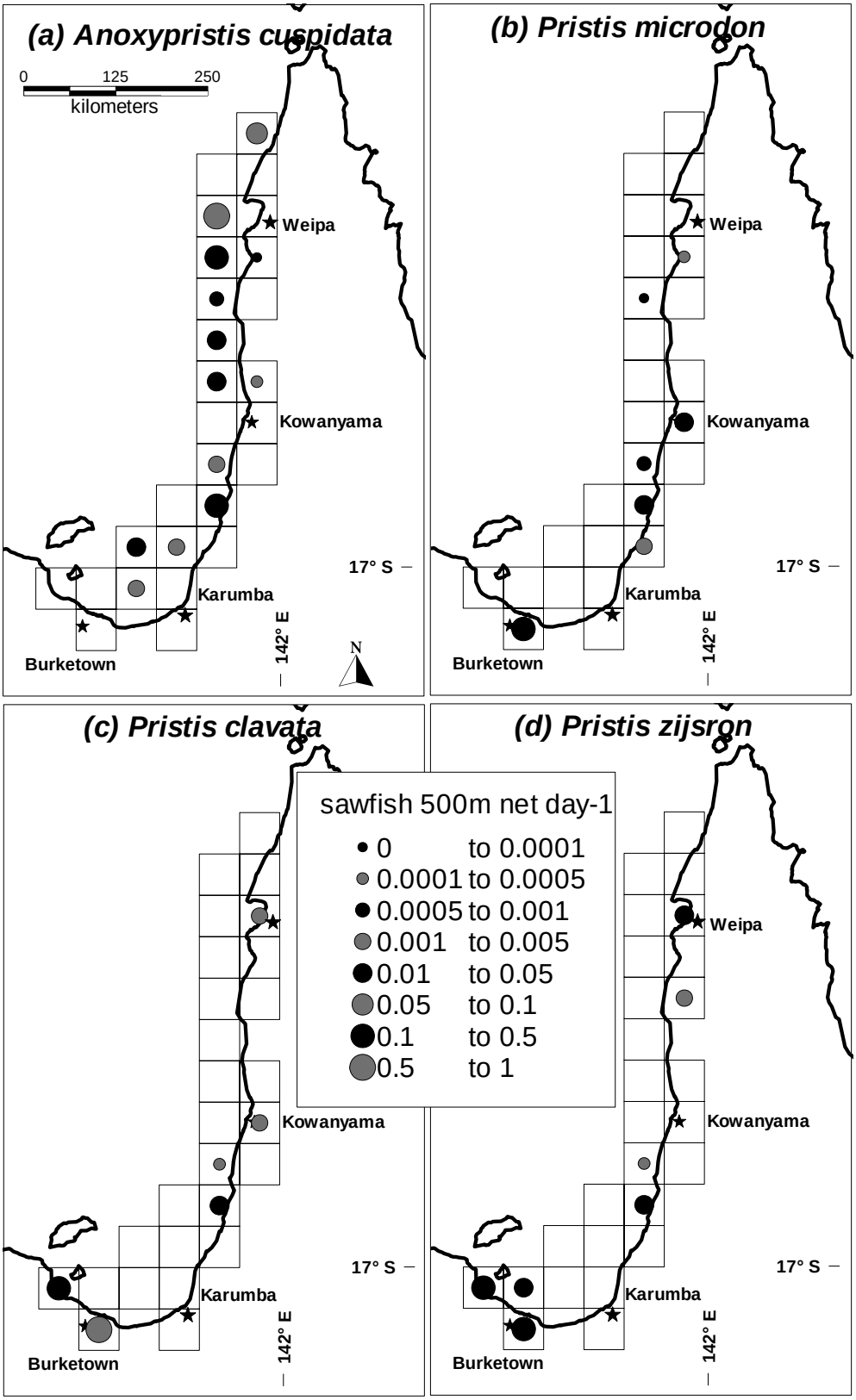

Figure 3: Sawfish CPUE (number of sawfish 500m net day^{-1}) pooled for the inshore and offshore set net fishing seasons for the Queensland Gulf of Carpentaria from 2000 to 2002 for (a) *Anoxypristis cuspidata*, (b) *Pristis microdon*, (c) *Pristis clavata,* and (d) *Pristis zijsron*

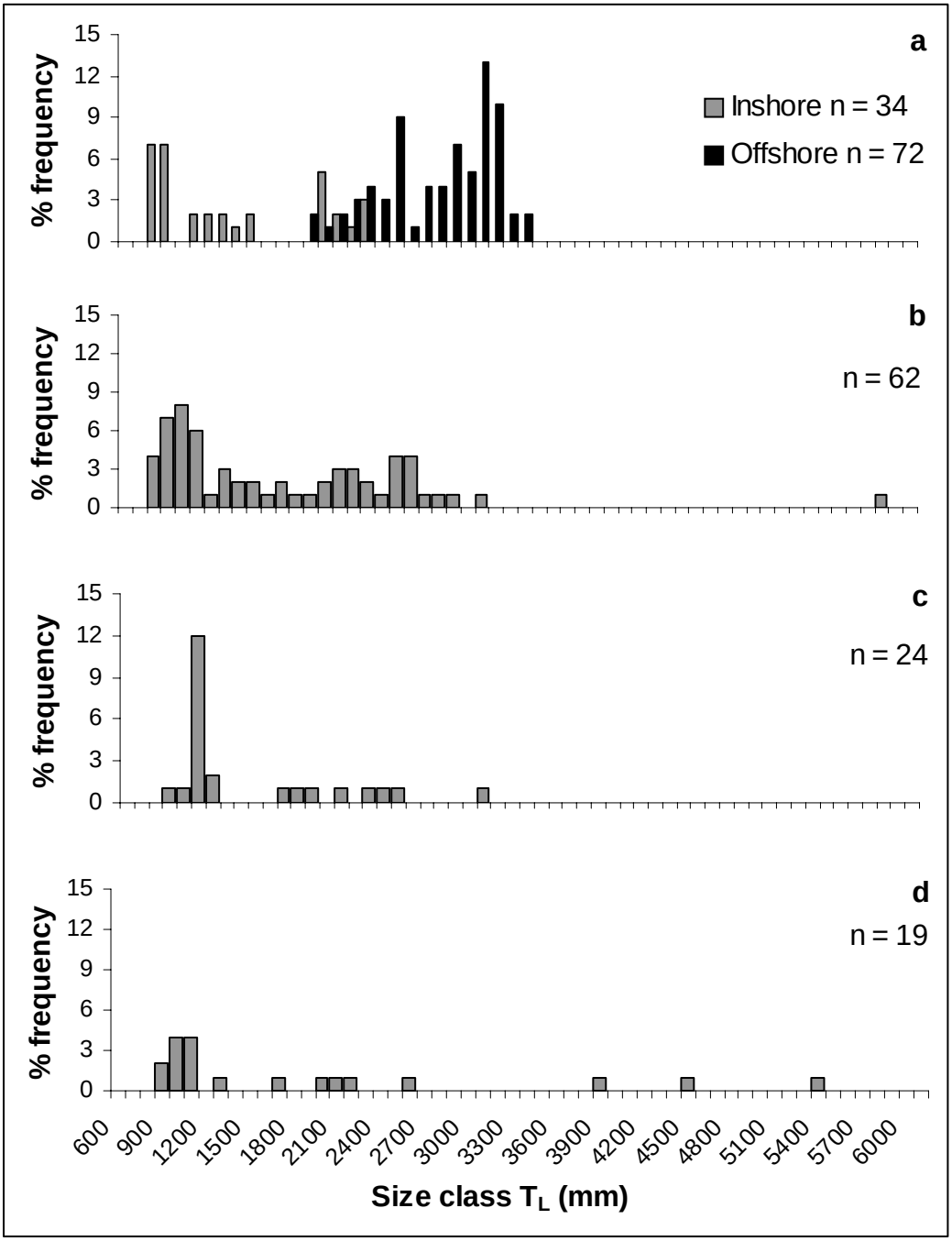

Figure 4: Size frequency ($T_L$mm) records for the inshore (grey) and offshore (black) set net fisheries between 2000 and 2002 from the Queensland Gulf of Carpentaria for (a) *Anoxypristis cuspidata*, (b) *Pristis microdon*, (c) *Pristis clavata* and (d) *Pristis zijsron*.

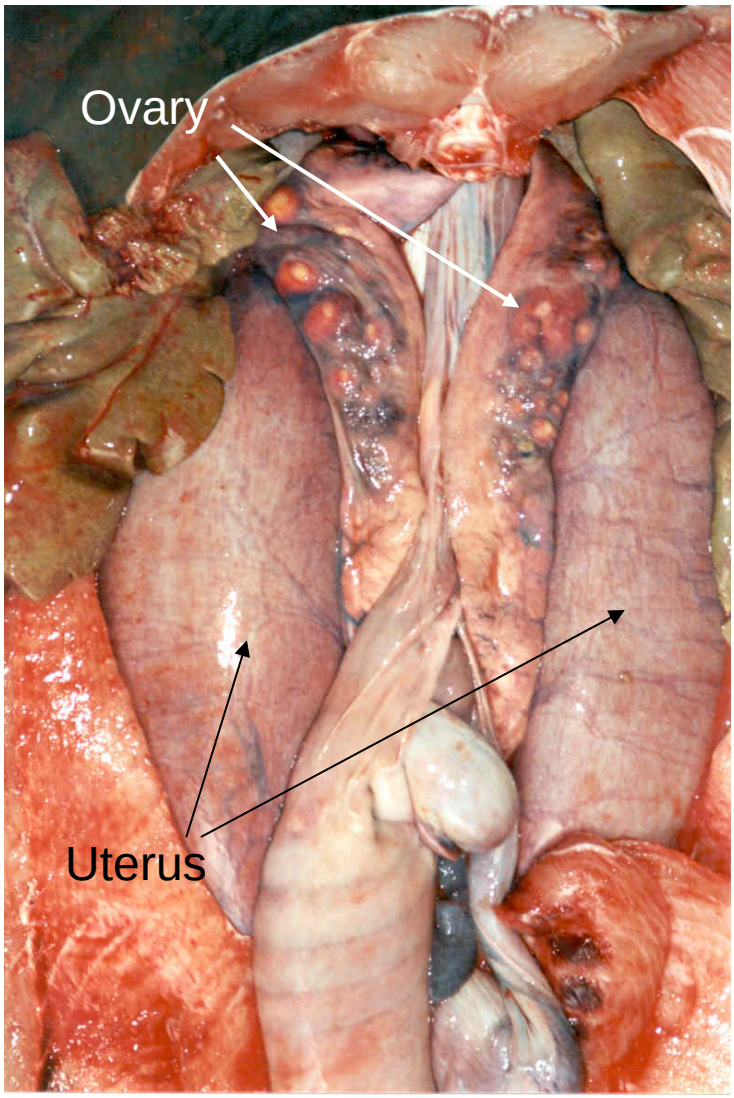

Figure 5: Body cavity of a mature female *Anoxypristis cuspidata* of 285cm total length caught in the dry season month of August. Note the swollen uteri and the presence of yolky oocytes in the ovary

5

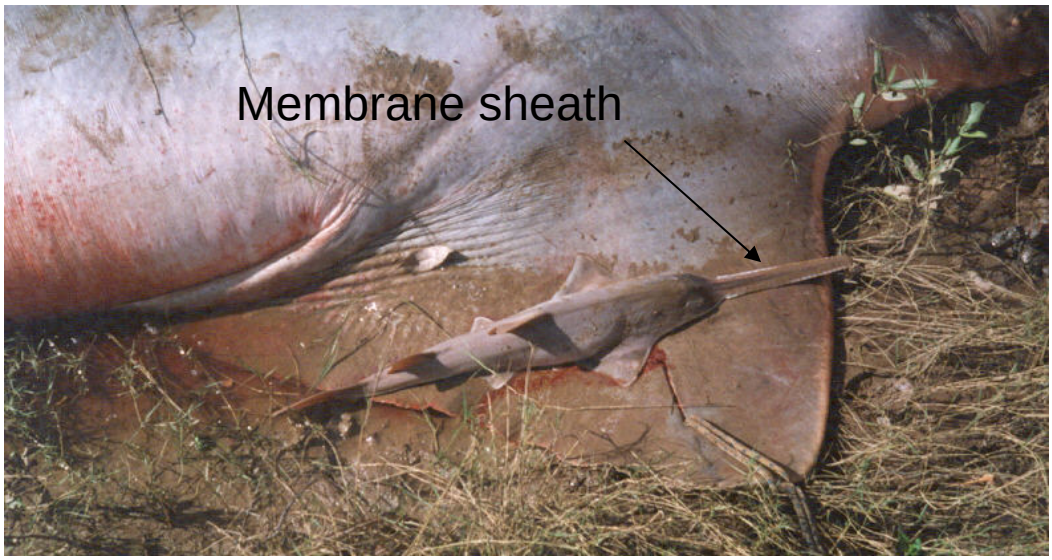

Figure 6: *Pristis microdon* full term embryo of 89cm total length dissected out of a deceased 582cm total length female. Note the membrane sheath over the rostrum, an adaptation designed to protect the mother from the sharp rostral teeth of its offspring during

5

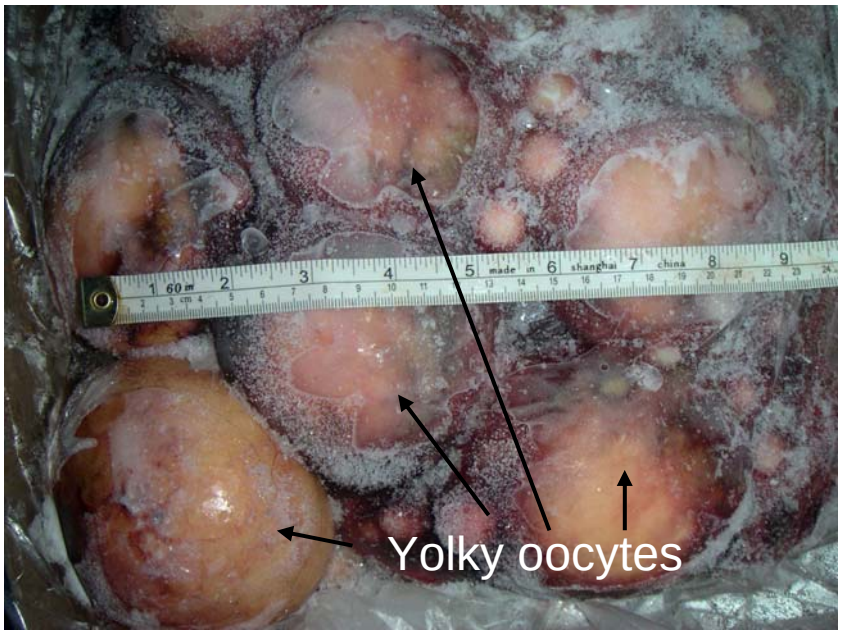

Figure 7: *Pristis microdon* yolky oocytes found in the ovary of a 582cm total length female carrying full term embryos of total lengths ranging in size of 72 to 93cm total length.

Chapter 3 Age & Growth

3.1 Introduction

Age, length and weight data are important in fisheries biology because they can be used to calculate parameters of species growth, mortality rates, age at maturity and life span. This information can then be incorporated in yield models for estimating sustainable harvest levels for a fishery (Berkeley 1983, Gruber & Stout 1983, Last & Stevens 1994). Knowing the form of a species growth curve, based on size at age data, can have serious implications on the way it is managed, as size influences reproductive output in many marine species (Narimatsu et al 2005, Rahman & Sedberry 2003). Larger animals are generally more fecund and are less likely to be predated on.

The age structure of most elasmobranch species is unknown primarily because many species are difficult and expensive to sample. Generally species are highly mobile, traditional skeletal ageing techniques are not suitable and as a resource they have not been systematically exploited commercially until recently (Cailliet 1983a, Gruber & Stout 1983, Schwartz 1983, Walker 1998). Therefore systematic sampling has not been recorded nor have scientific samples been collected.

Due to an increase in worldwide fishing pressure for shark over the past 20 years the abundance of many species has declined dramatically and their range restricted (Cavanagh et al 2003). Management of shark resources has been hindered by the absence of species specific biological information.

3.1.1 Structure & processing samples

Scientists investigating elasmobranch age and growth commonly use structures such as vertebrae (Tanaka et al 1978, Tanaka 1991), spine (McFarlane & Beamish 1987) or caudal thorns (Gallagher & Nolan 1999). Although uncommon, other hard structures have been investigated as possible ageing mediums such as the upper jaw (Tanaka 1990). Although these structures have been reported in the literature vertebrae analysis is the most widely reported (Cailliet & Goldman 2004) and was the focus of this study.

All structures used in age and growth studies share a common element which covers three lines of evidence. Firstly, the deposition of the calcified cartilaginous skeleton of an elasmobranch is a one-way process with no indication of re-absorption (Sminkey & Musick 1995). Secondly, Stevens (1975) reported finding a correlation between increased shark body size and increases in vertebral centrum diameter, i.e. vertebrae increase in size in proportion to increases in fish length. Thirdly, recognised differences in the mineralisation of high and low density structure in the vertebrae occur during different growth phases during the life of the animal (Campana et al 2001). These growth phases are visualised as banding within the vertebral structure of elasmobranchs.

Growth band pairs are composed of one calcified opaque band and one less calcified translucent band which are formed seasonally (Wintner & Cliff 1996). It is inferred that the opaque band is formed during the warmer summer months when growth is most rapid and the translucent band is formed during the cooler winter months when growth is considerably slower. Paired growth bands or "band pairs" which are formed on a yearly basis are referred to as annuli or annual rings and form the basis for nearly all elasmobranch age and growth studies (Campana et al 2001).

Cailliet & Goldman (2004) recommended that vertebrae be used in elasmobranch age and growth studies and samples should be taken from the thoracic section of the vertebral column. This section of the vertebral column contains large vertebrae and when analysed are statistically easier to read than smaller vertebrae dissected from the caudal region of the same specimen (Officer et al 1996). For logistical reasons elasmobranch vertebrae samples are usually dissected from specimens caught on the fishing grounds. This is because specimens are often too large to transport whole back to the laboratory. The vertebrae can either be kept frozen to be processed back in the laboratory or cleaned and air dried in the field for dry storage. In some instances vertebrae samples can be fixed in 10% formalin for 24 hours and then preserved in 70% alcohol (Cailliet & Goldman 2004). In the ageing study of spot tail shark (*C. sorrah*) and common black tip shark (*C. tilstoni*) Davenport & Stevens (1988) successfully aged specimens from vertebrae that had been fixed in 70% alcohol for up to 4 years.

The preparation of vertebrae samples for age and growth studies can vary depending on the species and the ageing technique being employed. Vertebrae samples normally consist of a core section that contains 7 to 10 centra. The connective tissue surrounding the vertebrae can be removed by soaking the centrum in bleach for hard to remove tissue. Soaking the centrum in distilled water does not affect the staining process (Schwartz 1983); a common ageing technique discussed later in this chapter. When using bleach Cailliet & Goldman (2004) recommend a 5% solution of sodium hypochlorite. Bleaching is proportional to centrum size and soak times vary accordingly. Winter (2002) suggest for long term storage to keep vertebrae samples in the freezer in case required later for staining. Another factor when considering the long term storage of centra in alcohol is the risk of reducing the resolution of the growth band pairs especially those located on the distal margin (Winter 2002).

Sectioning of vertebrae is the most common preparation method and is cited in many elasmobranch age and growth publications. In a review of elasmobranch age verification and validation Cailliet & Goldman (2004) reported that in 82 studies 76% of these used sectioned vertebrae. Vertebrae sections are normally cut using a revolving diamond blade to a thickness of 250 to 500 microns. A binocular microscope with transmitted light is generally used for identification of growth band pairs and image analysis (Cailliet & Goldman 2004). The development of more advanced computer software has also enabled scientists to capture centra images and to enhance the resolution of growth band pairs in vertebrae by manipulating light intensities and image contrast (Cailliet & Goldman 2004).

Growth band pairs in elasmobranch centra can also be read from whole vertebrae viewed under transmitted and reflected light. This method is often combined with a staining technique, for example the ageing study of spot tail shark (*C. sorrah*) and common black tip shark (*C. tilstoni*) by Davenport & Stevens (1988). A limitation of using whole vertebrae rather than sectioned vertebrae is the inability of the reader to consistently distinguish and count opaque and translucent band pairs in the centra (Cailliet & Goldman 2004). Growth band pairs in whole centra can often be obscured by the opaque or translucent bands on the opposing centra half when illuminated from

below (Cailliet & Goldman 2004). Distinguishing age in older animals has also proven to be problematic as band pairs become more tightly grouped at the outer edge of the vertebrae. These growth band pairs when counted can mistakenly be grouped together, thereby effectively causing age to be underestimated (Cailliet et al 1983a).

3.1.2 Ageing techniques

Where there is no established ageing methodology for a particular species two essential criteria must be followed: (1) a recognisable pattern in the ageing structure (eg. vertebrae) must be visible either by direct viewing or after some form of presentation; and (2) a regular time scale must be allocated to the visible pattern (Bagenal & Tesch 1978). It is also extremely important that the chosen ageing methodology is representative of all stages of the animal's life history and that the time scale is validated (Bagenal & Tesch 1978). Growth estimates generated from unvalidated growth band pairs in vertebra centra are viewed as speculation.

Environmental factors such as water temperature, salinity and availability of food resources can have a strong influence over the formation of growth bands, as reported by Casey et al (1985) for the sandbar shark (*C. plumbeus*). Tanaka (1991) also suggested that a change in diet due to the tropical wet and dry seasons in the freshwater sawfish *P. microdon* affected growth band formation. In teleost fishes, spawning activity can cause multiple banding in otoliths (McPherson 1991), and temperature has been found to influence the clarity of growth bands (Bagenal & Tesch 1978). Such factors may also influence the formation of paired growth bands in sawfish vertebra.

Often the resolution of growth banding in elamobranch centra is enhanced to improve reader consistency. Cailliet and Goldman (2004) report on the use of 12 of these growth band enhancement techniques by various authors, however many simply used staining. Some of the more common growth band enhancement techniques include the stains silver nitrate, Alizarin red S, cystal violet, and ninhydrin, as well as X-radiography, alcohol immersion and cedarwood oil. All of these growth band enhancement techniques have proven to be successful in elasmobranch ageing studies, however in

this section I will only be discussing in detail the use of silver nitrate and Alizarin red S techniques. These were simple effective and easy to use given resources available.

Silver nitrate stain was an effective tool in enhancing the growth banding in the vertebrae of leopard shark (*Triakis semifasciata*), common thresher (*Alopias vulpinus*), blue shark (*Prionace glauca*) and great white shark (*Carcharodon carcharias*) (Cailliet et al 1983a). Similarly, the stains Alizarin red S, crystal violet and ninhydrin provided positive results when used in ageing studies on lemon shark (*Negaprion brevirostris*) (Gruber & Stout 1983), black tip shark (*C. limbatus*) (Wintner & Cliff 1996) and spot tail shark (*C. sorrah*) and common black tip shark (*C. tilstoni*) (Davenport & Stevens 1988) respectively.

Growth banding is representative of high and low densities of calcium within the vertebrae (Schwartz 1983). The success of vertebrae staining can vary between elasmobranch species. This is because each species possesses a different life history and the deposition of calcium within the vertebrae is influenced by the surrounding environment (Schwartz 1983). Staining results can even vary within species depending on the quality of the vertebra being used; a factor of processing or from environmental conditions as previously mentioned. The time to absorb stain can vary with freshly cleaned vertebrae absorbing the stain quicker than dried vertebrae. Vertebrae size can also influence the stain absorption time. Staining is not an effective enhancement technique of growth bands in specimens that have a poor deferentiated calcium pattern, poor calcification, or narrow and tightly spaced growth bands (Cailliet et al 1983a).

3.1.3 Back calculation

Back calculation is an approach to reconstructing the growth of an individual fish over its entire lifespan, allowing a characterisation of the whole fish population by providing additional cohort data for previous years (Gutreuter 1987). Back calculation can only be achieved if there are growth bands on the ageing structure that can be related to a time scale, thereby making it possible to trace the growth history of that individual fish (Smith 1983). It is also important that the relationship between vertebral size and animal size in known to permit sizes at band formation to be determined. Cailliet & Goldman (2004) advocate that back calculation should be used when sample sizes are small and

where samples have not been collected continuously throughout the calendar year. Back calculation greatly increases the amount of growth information that can be derived from each specimen (see formula, Smith, 1983).

Back calculation is seen regularly as an analysis tool in elasmobranch age and growth studies because of the challenges in obtaining large sample sizes from species that are often large, are highly mobile, and exhibit seasonality (Cailliet et al 1983a). By using back calculation it is possible to identify fast and slow growing seasons or years. This information can be used to establish correlations with environmental factors and ultimately provide baseline data for constructing predictive growth models (Smith 1983). Back calculation is therefore viewed as being a powerful tool for the fishery resource manager and stock assessment biologist.

3.1.4 Precision and bias

It is extremely important in all age and growth studies that the counting of growth bands in the growth structure of specimen (i.e., vertebra, otolith, spine) can be reproduced consistently between readers. It is also critically important to remember that although the results of a study may indicate high precision, the age estimates may not be accurate. Accurate age determination can only be achieved through properly designed validation studies where absolute age is known and not just the frequency of growth band formation (Beamish & McFarlane 1983, Campana 2001). Therefore precision should never be used as a substitute for accuracy. There are a number of different methods for evaluating precision among age determinations however the most commonly used in elasmobranch studies is the average percent error (APE) technique of Beamish & Fournier (1981).

Precision provides a measure for gauging the relative ease of determining the age estimates, intra-reader variability and inter-reader comparisons to judge the skills of one reader to another (Campana 2001). Precision cannot identify which reader was more accurate or if either was biased. Biased reading of growth banding in a structure can occur when the reader has a “predetermination” of age based on knowledge of length (i.e., prevent subjectivity) (Capana 2001). Bias is very difficult to counter when the

study involves a small sample size of specimens of juvenile origin. The reader subconsciously gets a “feel” for the size of the structure and the presumed number of growth bands present in relation to the length of the specimen.

To overcome bias, scientists who age elamobranchs commonly use two or more independent readers. By comparing the variability of the results between each reader using regression analysis or paired t-test it is possible to establish whether the description and interpretation of a growth band is accurate, the preparation of the ageing structure is adequate (resolution of growth band), and whether or not the reader is too familiar with the specimen being analysed. If bias in growth band counts has been identified and if no consensus of the specimen age can be reached between readers, the sample is often eliminated from the study (Campana 2001). This can be a difficult decision to make especially where small samples are used, as in most studies on protected species where the animal is rare in abundance.

3.1.5 Age verification and validation

In elasmobranch age and growth studies growth banding is assumed to be an accurate indicator of age (Cailliet & Goldman, 2004). Very few studies on elasmobranch ageing have actually tested this assumption by validating the temporal periodicity of growth band formation or to obtain absolute age by validating each growth band within the centra (Campana, 2001). In a majority of elamobranch studies scientists have provided verification of their age estimates through in determinant methods such as centrum edge analysis and relative marginal increment analysis (Cailliet & Goldman, 2004).

Age verification is substantially different to age validation. Age verification methods support or are correlated with a particular method of ageing, but are not directly or logically linked (Campana, 2001). Therefore the results of a verification method may well be reinforcing the interpretation of an incorrect age. Ideally verification methods should be used in collaboration with proper age validation studies as the method provides a measure of accuracy for age estimates or validation methods. Age validation refers to cross-checking the estimated age of a specimen against its true age (Campana, 2001).

Prior to 1983, age validation efforts in fisheries science were considered poor (Campana 2001). With advances in technology and availability of resources, uncertainties in age validation have been identified for a number of aged fish species such as *Melanogrammus aeglefinus* (Campana 2001). Beamish & McFarlane (1983, cited in Campana 2001) reported only 66% out of 500 publications reporting fish age estimates even attempted to validate the accuracy of their age determination, and a mere 3.3% were successful in doing so over the entire age range of the fish species concerned. This has resulted in a number of ageing studies on teleosts and elasmobranchs being reviewed and the establishment of age validation processes (Campana 2001). Given the logistical difficulties in obtaining sufficient samples and working on large mobile animals, age validation in elasmobranchs has been identified as being more difficult in comparison to ageing studies on bony fishes (Campana 2001).

Campana (2001) and Cailliet & Goldman (2004) provide a comprehensive review of elasmobranch age verification and validation techniques. These include: size mode analysis, tag and recapture, chemical marking and laboratory growth studies, radiocarbon dating, centrum edge and marginal increment analysis, and captive rearing.

3.1.5.1 Size mode analysis

This methodology involves identifying and monitoring the progression of discrete length modes and their centrum characteristics over the animal's life span (Cailliet et al 1983a). Its use as a growth tool is primarily for age verification and not validation (Cailliet & Goldman 2004). Size mode analysis has also been referred to as length frequency analysis. This methodology is used on species that are generally easy to capture such as schooling teleost fishes. This is because the analysis requires a large number of samples recorded throughout the year and from across the whole population (Cailliet et al 1983a). Verification of age is obtained when a comparison of the average size modes of a randomly sampled population coincides with the mean or median sizes in an age class as determined by aging studies (Cailliet & Goldman 2004).

For example Kusher et al (1992) in the study of *Triakis semifasciata* identified a seasonal pattern of growth which was comparable to the von Bertalanffy generated size at age from vertebral sections. Length mode analysis is not an effective method of age verification where length modes in a species population are difficult to define. This is particularly the case for slow growing species such as the lemon shark *Negaprion brevirostris* (Gruber & Stout 1983). Size mode analysis is also of limited use when studying rare, threatened and endangered species because of the low number of samples permitted for use and often the large amounts of effort required obtaining them such as in the current study.

3.1.5.2 Tag recapture - mark analysis and laboratory studies

In addition to size mode analysis tag and recapture is another technique where growth estimates in elasmobranch ageing studies can be verified. A tag and recapture study provides an excellent means for obtaining empirical growth data when the fish are measured at tagging and recapture and the time at liberty is known (Cailliet 1990). The growth model parameters as determined by ageing studies or other means are compared to the tag and recapture information for verification. In sharks, calculation of growth parameters and/or age verification using tag and recapture data have been accomplished for *C. plumbeus* (Casey & Natanson 1992), *Negaprion brevirostris* (Gruber & Stout 1983), *G. cuvier* (Natanson et al 1999), *C. tilstoni* and *C. sorrah* (Davenport & Stevens 1988). Information on movement patterns and population exploitation of a species can also be investigated using tag and recapture (Kohler & Turner 2001).

Tag and recapture data is more commonly used in elasmobrach ageing studies to verify the growth rate of a species within a particular length mode or to verify the number of growth bands over a particular timeframe (Cailliet et al 1983a and 1983b, Pratt and Casey 1983, and Casey et al 1985). The later method is often combined with chemical marking and studies can be undertaken in a controlled environment such as an aquarium, or in the wild (Casey et al 1985, Cailliet et al 1986).

Utilising free swimming specimens, although providing a direct observation of growth, has several inherent problems, such as the capture and tagging of sufficient specimens

and their subsequent recapture, and quality assurance over length measurements (Cailliet et al 1983a). The tagging technique must not harm or inhibit the specimen's natural growth or increase its acceptability to predation (Cailliet et al 1983a, Laird & Stott 1978).The tag must be easy to recognise if the technique is to be successful.

Chemical marking is the most widely accepted method of age validation and involves injecting the animal intramuscularly with a chemical such as tetracycline (OTC) (Gruber & Stout 1983), strontium chloride (Campana 2001), or calcein (Gelsleichter et al 1997). The principal behind this technique is that the chemical binds with calcium and forms a permanent mark on the vertebra or spine at the time of injection. In the case of OTC this mark can only be viewed under ultraviolet light. The combination of body growth information and a discrete mark in the vertebrae permit direct comparison of time at liberty with growth band deposition. Hence the periodicity of growth band formation can be determined (Cailliet & Goldman 2004).

A more visible form of marking normally accompanies chemical tagging such as fin clipping, external dart or disk tags to make for ease in identification of known marked animals (Kohler & Turner 2001, Thorson 1982a). A limitation to chemical marking as an age validation technique is that it still relies on the recapture of tagged specimens and their inherent logistical problems with obtaining representative sample sizes and quality assurance over the data. In the case of large elasmobranchs such as sawfish the holding properties of external tags require considerable attention.

3.1.5.3 Centrum edge an relative marginal increment analysis

As noted in the introduction centrum edge analysis differs from marginal increment analysis in that each growth band is plotted as a function of month or season with the mean marginal increment describing a sinusoidal cycle with a frequency of twelve months (Campana et al 2001, Wintner et al 2002). Analysing samples obtained across a large geographic area can cause problems in marginal increment analysis because of seasonal variations in catchments due to environmental influences such as water extraction and rainfall. These factors can influence the rate of growth in fish by affecting the availability and consumption rate of food resources. Errors can also arise

in the analysis of older samples where growth bands form so closely together that they cannot readily be distinguished from one another. Therefore this technique is basically only useful where clearly defined growth bands are formed, which is common in the young, of fast growing species (Campana et al 2001).

3.1.6 Growth models

Size at age information can be summarised in a growth curve that best fits the available data. A number of different growth models exist; the most commonly used in fishes are the von Bertalanffy and Gompertz models (Cailliet & Goldman 2004). Ricker (1979) concluded that Gompertz models are more commonly applied to larval fish whilst the von Bertalanffy growth model best describes fish growth. A comprehensive review on elasmobranch growth models was discussed in detail in Cailliet & Goldman (2004) and the von Bertalanffy growth model was the most widely accepted.

3.1.7 Sawfish age and growth

The Family Pristidae is poorly studied in comparison to other more commonly fished elasmobranch families such as Carcharhinidae. Very little is known about the life history of the Australian members of the sawfish family (Last & Stevens 1994). Primarily, all current age and growth descriptions on these species derive is from studies undertaken by the late Dr Thomas Thorson (Thorson et al 1966, Thorson 1976, 1982a & 1982b), statements made by Bigelow & Schroeder (1953) and *P. microdon* vertebra studies by Tanaka (1991).

Thorson studied *P. perotteti* for a decade (1975-85) after identifying the species' "extraordinary" preference for freshwater habitat (Lake Nicaragua-Rio San Juan System) and its vulnerability to commercial exploitation by net and line fishing. Based on the findings of a tag and release program and using the earlier observations of Bigelow & Schroeder (1953), Thorson (1982a) estimated that *P. perotteti* in lake Nicaragua grew 35-40cm in their first year and 12cm in the tenth, reached sexual maturity at ten years of age and had a life span of over 30 years.

Thorson (1982a) experienced problems with the quality assurance of data recorded by the commercial fishing sector due to the size, difficulties in handling such large live animals and the literacy of fishers. Thorson (1982a) even questioned the reliability of accurate total length measurements undertaken during research surveys because of live handling issues. Following this work, Thorson believed the information on *P. perotteti* to be insufficient to provide for an accurate growth curve and recommended continuation studies investigating life history. Simpfendorfer (2000) created age-structured life tables for *P. perotteti* and *P. pectinata* based on the findings of Thorson (1976 & 1982a) and Bigelow & Schroeder (1953) and due to the uncertainties in the growth/ageing/maturity data had to generate a series of population scenarios to investigate their demography.

Tanaka (1991) investigated the age and growth of *P. microdon* from a limited number of specimens collected in the GoC and Papua New Guinea and was the first to look at sawfish vertebrae as a medium to derive age estimates. Clear growth banding in the vertebrae of *P. microdon* was reported by Tanaka (1991) with the first band being interpreted as the birth mark and each subsequent band being formed annually. Using this interpretation Tanaka (1991) estimated that specimens ranging in size from 77.8cm to 361cm T_L were from between zero and forty-eight years old. The growth rate of *P. microdon* was estimated to be 18cm in the first year and 10cm in the tenth year. In his interpretation of the growth banding, Tanaka (1991) made very little attempt in understanding growth band periodicity and no attempt was made to verify possible causes of the banding. From the studies of Tanaka (1991) it was assumed *P. microdon* is long-lived (> than 44 years) and reaches sexual maturity at about sixteen years of age.

Providing life history parameters for pistids is a key aim of this thesis. Fisheries resource managers, scientists and conservation groups have expressed their grave concerns over the sustainability of QLD pristid populations due to fishing hence understanding their demography is a key to their management. Therefore it is critical to determine the age and growth of the four species under investigation.

The specific aims of this chapter were:

1. To determine the size at age (von Bertalanffy growth curves) of *P. microdon*, *P. clavata*, *P. zijsron* and *A. cuspidata* in the Gulf of Carpentaria.
2. To validate the periodicity of vertebral band formation, using a combination of oxytetracycline injections and centrum edge analysis.
3. To determine the longevities and age at maturity of *P. microdon*, *P. clavata*, *P. zijsron* and *A. cuspidata* in the Gulf of Carpentaria

3.2 Methods

3.2.1 Collection of samples

The methods section in Chapter 2 provides detailed information on the collection of samples from the commercial fishery and field surveys. Most pristid vertebrae samples were collected on an opportunistic basis from mortalities within fishing operations with only 6% (n=9) from independent research netting. Samples were collected from freshwater, estuarine and marine environments from the north, south and western regions of the GoC (Peverell 2005a). Concerns held by Gulf fishers over the sustainability of pristid populations restricted the number and range of samples collected in this study

3.2.1 Vertebrae preparation

An age and growth sample consisted of a block of seven vertebrae taken from the vertebral column positioned below the leading edge of the first dorsal fin; this will be referred to subsequently as the “core” sample. Vertebra samples were frozen until processed at the DPI & F Northern Fisheries Centre wet ecology laboratory. Two adjoining vertebra were chosen from each core sample to be trimmed of muscle tissue and sinew before being decalcified using a 4% sodium hypochlorite solution (Calliet et al 1983a). The vertebrae soak time varied between 5 and 35 minutes depending on the size of the sample. The samples were then rinsed in distilled water for 20 minutes and air-dried overnight before being processed the following day.

3.2.2 Centra sectioning and staining

The number of pristid vertebrae samples available for this study was low in comparison to other elasmobranch age and growth studies and initially the quality or clarity of their growth banding was unknown. Initial exploration of silver nitrate and Alizarin red S stains (Figure 8), thin sectioned centra (Figure 9) and half sectioned centra were undertaken to establish which technique was more effective and reliable in enhancing growth band resolution. From the exploratory study it was determined all *Pristis* species would have their vertebrae read through thin sectioned samples under transmitted light whilst *Anoxypristis* would be read from half sectioned vertebrae using a combination of transmitted and reflective light. Two staining techniques, Alizarin red S and silver nitrate, were very effective in enhancing growth bands in juvenile *Pristis* species. The stains were of little use however when it came to enhancing banding in vertebrae of older specimens. This is because the growth bands on the distal edge of the vertebrae in mature specimens were more closely spaced than those found in immature specimens.

The basis of the decision to use a particular staining or sectioning technique was the clarity of the image and its usefulness in discriminating banding rather than on any statistical testing.

3.2.2.1 Thin and half vertebrae sections

The thin vertebrae sections were cut along the longitudinal plane (sagittal) of the vertebrae to a thickness of 250 to 300 microns using a circular diamond saw. Half vertebrae sections were cut in the same manner. Vertebrae of specimens less than 100cm T_L were blocked in Huntsman crystic/hetron polyester resin (clear casting resin) for ease of sectioning. For details of the vertebra blocking methodology refer to CD 1 Appendix 2. Sections were polished with waterproof silicon carbide paper P # 4000 mounted on a polishing disk. Polished sections were then set on an analytical microscope slide using clear casting resin and cover slipped.

3.2.3 Growth band interpretation

Pristids like most elasmobranchs exhibit growth bands within their vertebrae. The growth bands are of opaque and translucent appearance which combined or paired form

a pattern of wide and narrow bands respectively. In this study it was assumed that an annual cycle of growth was represented by a pair of growth bands. It is widely accepted that opaque banding in centra is typical of periods of rapid growth indicative of high deposits of calcium. Alternatively, translucent zones are representative of slow growth (Casey et al 1985) (Figure 9).

In this study the birth band was defined as the centre most opaque portion of the centra. Opaque bands present beyond the birth mark were considered annual marks (Figure 9). In some cases where there was very little contrast between the opaque and translucent zones an age estimate was determined by counting the number of bands based on the discontinuous profile of the outer axis of the vertebrae section.

In half sectioned vertebra the narrow darker banding was identified to be the translucent band and the broader white band the corresponding opaque band. In those samples found to be more difficult to read the problem was often resolved by manipulating the vertebrae surface and light source, hence reflecting the light source through the vertebra. This created an "x-ray" appearance that often made distinguishing banding a lot easier.

3.2.4 Vertebra aging

Sectioned vertebra centra were viewed under a stereomicroscope (6.5 magnification). Optimas® macro an image analysis program was used to customise the data recording process and to measure growth band increments in the centra. Data generated through Optimas® was automatically entered into an Excel® spreadsheet along with captured images. The image enhancement function in Optimas® was used to help restore the level of resolution lost by the computer screen.

Ages were estimated through counts of paired growth bands (opaque and translucent band) on the centra, without knowledge of the specimen size or sex. The primary reader counted ages in all vertebrae once on two separate occasions whilst the independent secondary reader only counted the ages once. If 2 of the 3 age counts between readers was out by more than 1 year then the consensus age was used. If any of the age estimates differed by more than one year, the vertebrae was judged unreadable. In these cases, a different vertebral centrum from the same individual was processed, and the

procedure repeated. Consistency between readers was tested using a Komogrov Smirnoff test statistic on the comparison of age distributions produced by each reader. Indexed average percent errors (IAPE) were calculated for *P. microdon* and *A. cuspidata* only as there was too few samples for the other pristid species.

The index of average percent error calculated according to Beamish & Fournier (1981) was used to measure the precision of the growth band counts between readers of *P. microdon* and *A. cuspidata* samples. Ages of less than one year were also excluded in the calculation of IAPE's.

The IAPE equation (Beamish & Fournier 1981)

$$IAPE = \frac{100}{N}\sum_{j=1}^{N}\left(\frac{1}{R}\sum_{i=1}^{R}\frac{(X_{ij} - X_j)}{X_j}\right)$$

Where: N = number of sharks aged

R = number of times sharks are aged

X_{ij} = the *i*th age determination of the *j*th shark

X_j = the mean age estimate of the *j*th shark

Age bias plots and regression analysis were used to detect bias errors within the age estimates. The difference in age interpretation between repeated readers was used to measure the consistency of the age estimates. The resultant age frequency distributions were compared using a two paired non parametric test (Komologorov-Smirnov) to determine if the age frequency distributions produced by the readers were significantly different ($P<0.05$).

3.2.5 Edge Analysis

The periodicity in the outer margin of successive growth bands in GoC pristids was explored for seasonal influence in *P. microdon* (n=41), *A.cuspidata* (n=65), *P. clavata* (n=19), and *P. zijsron* (n=18), based on Kusher et al (1992). Of these totals the outer margin could not be identified in 4 *A. cuspidata*, 2 *P. clavata* and 1 *P.zijsron* samples.

Readers identified the distal most band on the vertebrae, and characterised it as either opaque or translucent. The same methodology used for counting paired growth bands was used to record vertebrae edge characteristics, that is two separate recordings from two readers were undertaken in the absence of capture date. Proportion of individuals with opaque edges was plotted against capture month to identify the timing of vertebral band formation.

The identified outer growth band of the vertebra was correlated against monthly minimum air temperature data for the GoC to investigate a seasonal pattern in its formation. The air temperature data was recorded from four locations in the GoC; Kowanyama, (154^{o}. 839, 141^{o}. 7475); Normanton, (17^{o}. 6872, 141^{o}. 0733); Burketown (17^{o}. 7425, 139^{o}. 5475); and Mornington Island (16^{o}. 6640, 139^{o}.1837); for the years ranging 2001 to 2007 by the QLD Climate Service of the Bureau of Meteorology. The monthly data was averaged over the 7 year period and plotted alongside species vertebrae edge data for comparison.

3.2.6 Analysis

3.2.6.1 Growth model

Size at age data was pooled for specimens recorded in the three regions of the GoC due to small sample sizes. The relationship between lower jaw total length (LJT_L) and vertebral diameter (CD) was investigated using linear regression in Genstat ®. Because of the paucity of the data both sexes were combined for growth analysis except in the case of *A. cuspidata*. A von Bertalanffy growth function (von Bertalanffy 1938) was used to model the pristid size at age relationships:

$$L_t = L_\infty * (1 - e^{-k(t-t_0)})$$

Where: L_t = length at time t

L_∞ = mean asymptotic length

k = rate at which the curve approaches asymptote

t_0 = age at size zero

A birth month of January was used as a bench mark to back calculate size at age data in pristids less than 1 year of age. This data was then plotted as a percentage of the first year. January was chosen as the birth month from observations of umbilical scaring in new born pups in all species in February, at the beginning of the fishing season.

Given the small sample sizes and uncertainty in predictions, for pristid longevity estimates to remain biologically reasonable the oldest age was estimated at 95% of the L_∞ predicted by the von Bertalanffy function. Age at maturity was estimated from observations reported in Chapter 2 in respect to size at maturity or from published literature (Compagno & Last 1999).

3.2.6.2 Back calculation

Increment measurements of growth bands for ages one year and above for *P. microdon* were used in the back calculation equation of Campana (1990) to estimate body lengths at previous ages.

$$L_a = L_c + [(V_a - V_c) \times (L_c - L_0) / (V_c - V_0)]$$

where:
L_0 = size at birth
V_0 = vertebra radius
L_a = length at age
L_c = length at capture
V_a = vertebra distance from focus to annulus a
V_c = vertebra radius at capture

Growth band increments were measured using the macro function in Optimas®. No increment measurements were recorded for the other two *Pristis* species given the too few samples and *A. cuspidata* vertebrae were half sectioned and read whole. Reading half sectioned vertebrae in *A. cuspidata* negated the possibility of obtaining accurate increment measurements required for back calculation. A size at birth of 85cm T_L (average observed size at birth from data recorded in this study) was used as the biological determined constant in the back calculation equation. The back calculation length-at-age data were not plotted for separate sexes given the paucity of data. Exponential regression models in Genstat ® were used to statistically compare the size at age data for back calculated (BC) and observed (OD) data sets for age classes between 1 and 5 years of age.

A modified von Bertalanffy growth function (von Bertalanffy 1938) was fitted to the back calculated data.

$L_t = L_\infty * (1 - e^{-k(t-t_0)})$

Where: L_t = length at time t

L_∞ = mean asymptotic length

k = rate at which the curve approaches asymptote

t_0 = age at size zero

3.2.7 Age Verification and Validation

3.2.7.1 Tag and recapture

The tagging of sharks using conventional tags (such as those used in this study) has been recognised as a valuable means for studying various aspects of their life history, migrations and movements, and population structure (Kohler & Turner 2001). In previous tagging studies on sharks it was assumed that tagging does not affect natural growth, a potential source of error in any tagging program. Gruber & Stout (1983) tested for this effect when tagging *Negaprion brevirostris* and found no significant difference in the captive growth rates of tagged and non-tagged specimens under the same conditions. In the absence of tag and recapture data on Australian pristids it was therefore assumed in this study that natural growth rates in sawfish would not be affected although in future studies this should be investigated.

Pristids were tagged and released on an opportunistic basis by scientists and commercial fishers. The coverage of the tagging program included the east coast north from Cairns and all QLD GoC waters. It was considered the wider the tagging program coverage the better the chances of obtaining recapture information. Hallprint type SSD-WT steel tipped dart tags were inserted intramuscularly below the first dorsal fin.

The pristid tagging program was cooperative, involving the joint participation of scientists, commercial fishers and other industry persons such as aquarium collectors. The involvement of fishing industry volunteers in the tagging program can raise some issues of data quality, such as species identification and standardisation of size

measurements. Therefore to maintain a high level of quality assurance over the tag and release information two sawfish identification workshops were left for commercial fishers, and easy to interpret waterproof sawfish identification sheets (see CD 1 Appendix 2), user-friendly sampling procedure sheets and water proof disposable cameras were provided to fishers. A method of tying knots in a length of string that reflected the length of the animal and could be accurately measured later was devised. Commercial fishers readily adopted these simple but accurate sampling procedures. Researchers also validated species identification by commercial fishers through the use of photos, video footage (CDrom Appemdix 3) and retention of deceased specimens.

The growth of recaptured sawfish was calculated by subtracting the length (T_L cm) at tagging from length (T_L cm) at recapture. A time at liberty was also calculated in the same manner using tag and recapture dates. Growth rate was calculated for each individual by dividing growth by time at liberty and expressed as cm growth per day^{-1}. The tagging growth data was then compared to the predicted growth rates of animals of the same size class generated from size at age data fitted to the von Bertalanffy growth function.

3.2.7.2 Oxytetracycline (OTC) and captive growth

Pristids that were kept by Cairns Marine Aquarium provided a unique opportunity to make comparisons between the growth rates of wild animals to animals in captivity. The vertebra from deceased pristids in captivity was also used to assist in the interpretation of growth band periodicity.

The growth data recorded from pristids in captivity included T_L, LJT_L, F_L, LJF_L (as defined in Chapter 2) and whole weight (W_W). This data was recorded in the same manner as described in the methods section of Chapter 2. Pristid length measurements were obtained on an opportunistic basis normally prior to the animals being shipped abroad to other aquarium facilities. Obtaining subsequent length measurements from those animals sent abroad was not possible given logistical difficulties and the overseas management's policy on handling these animals unnecessarily.

Obtaining secondary measurements in Australia after a set captive time was also difficult given many specimens have similar distinguishing features and are of the same size class. It was not possible to tag individuals as they were for ultimate sale overseas in an "undamaged" state. This was overcome by recording morphological key features in individual animals like mapping the number and position of the rostra teeth and injuries or marks on the fins and body.

As part of the tagging program OTC was injected into sawfish on release at a dosage rate of 20mg per kg^{-1} body weight. Only those animals caught during the research surveys of commercial catch and independent sampling were injected with OTC. Cairns Marine Aquarium staff administered the OTC injection to all captive *Pristis* species and vertebrae from deceased animals were made available for this study. Captive *Pristis* were fed all they would eat once daily and were kept in undercover circular tanks at a constant salinity of 35ppt and temperature 25^{o}C.

Vertebrae impregnated with OTC were processed as per sections 3.2.1 and 3.2.2. The vertebrae were illuminated with "D block" UV light source (excitation wave length of 355-425mm), and digital photographs of OTC-marked vertebrae taken with a camera mounted on a stereomicroscope. Distances from the translucent band margins and OTC band to the edge of the vertebrae were measured using Optimas®.

3.3 Results

3.3.1 Age and growth relationships

The number of vertebrae samples represented in this age and growth study was greatest for *A. cuspidata* (n = 65) and *P. microdon* (n = 41), (Table 3). Only preliminary age and growth findings are reported for *P. clavata* (n = 19) and *P. zijsron* (n = 18) as there were too few samples (Table 3). Samples in this study were dominated by immature specimens up to 260cm T_L (Figure 10, Tables 1, 3 & 4). A wide range of sizes was recorded for *Anoxypristis* and the data was dominated by females in the upper size classes greater than 280cm T_L (Figure 10, Table 2). There were insufficient samples to separately test the sexes therefore all size at age data for *Pristis* were pooled. The size at age data was also pooled for *A. cuspidata* as there was no significant difference

($p>0.05$) between sexes in either the slope or intercept terms. In all species LJT_L increased allometrically with CD for combined sexes. The regression was significant ($p<0.001$) for all pristid species with an adjusted R^2 value of 0.97 for *P. microdon*, *P. zijsron* and *A. cuspidata* and 0.99 for *P. clava*ta.

P. microdon	(n = 40)	$LJT_L = -30.31 + 31.33 * 1.0023^{CD}$	($r^2 = 0.97$)
P. clavata	(n = 15)	$LJT_L = -0.75 + 0.0906 * CD$	($r^2 = 0.99$)
P. zijsron	(n = 17)	$LJT_L = -4.89 + 7.87 * 1.0049^{CD}$	($r^2 = 0.97$)
A. cuspidata	(n = 61)	$LJT_L = -0.79 + 0.1095 * CD$	($r^2 = 0.97$)

Table 3: von Bertalanffy growth parameters for *Pristis microdon* and *Anoxypristis cuspidata*, sexes combined. Preliminary growth parameters are provided for *Pristis clavata* and *Pristis zijsron*. Note OD = observed data and BD = back calculated data.

Species		$L\infty$	k	t_0	r^2	n
P. microdon	OD	638	0.08	-1.55	0.98	41
	BD	588.96	0.08	-1.84	0.98	83
A. cuspidata	OD	409	0.31	-0.47	0.95	65
P. clavata	OD	508	0.08	-2.09	0.99	19
P. zijsron	OD	540	0.12	-1.12	0.99	18

There was very little systematic differences between readers for both *P. microdon* (P = 0.862, n = 33) and *A. cuspidata* (P = 0.940, n = 58) using a Kolmogorov-smirnoff non parametric t-test (Figure 11Figure 12). Age classes less than 1 year of age were excluded from the analysis because they usually cause higher IAPE due to higher proportional error in these size classes (eg Simpfendorfer 1993). The IAPE's calculated for *P. microdon* and *A. cuspidata* in this study were 6.1 and 4.9 respectively. The APE's calculated for both species were within the acceptable limits of 10% for shark ageing as reported in a review paper on accuracy, precision and quality control in age determination by Campana (2001).

3.3.2 *Pristis microdon*

The age structure of *P. microdon* in this study ranged from young of the year (< 1year) to 28 years (Figure 13). This data is made up of young of the year animals (20%) followed by the 1 to 8 year size classes (78%). The analysis showed that there was no

significant difference (in either shape or displacement) between observed and back calculated size-at-age data for *P. microdon* (P<0.001) (Figure 14).

A rapid juvenile growth rate was identified for *P. microdon* with 40% of the birth length (76cm T_L) added during the first year. The estimated size at birth is 14cm less than the maximum observed size (91cm T_L) at birth recorded in this study (Chapter 2). The average growth estimate for the first year were 52cm T_L and 17cm T_L in the fifth year (Table 4). *Pristis microdon* longevity was estimated to be 80 years (638cm T_L) although asymptotic growth was reached at 35 years at 606cm T_L.

Age at first maturity data for *P. mcirodon* was limited to two specimens recorded as part of this study. The smaller of the two specimens was a pupping female of 303cm T_L (Chapter 2 Table 3). This specimen was estimated to be approximately 8 years of age and at approximately 22% of its asymptotic size. A second mature female specimen was recorded at 582cm T_L and was pregnant at the time of capture. This specimen was estimated to be 28years old. There are 23 year classes missing between the oldest and second eldest animals recorded in this study. This single record greatly influences the curvature of the growth curve, thus growth predictions in the 8 to 28 year classes should be treated with caution. This data record is extremely important as it represents the only data available on the age of this species in the larger mature size classes.

Table 4: Length at age of observed and back calculated data for *Pristis microdon*. Lengths expressed as T_L - average total length, T_L max – maximum total length, T_L min – minimum total length and n - represents the number of samples. Length measurements are in centimetres.

	Observed							Back calculated				
Age	**0+**	**1+**	**2+**	**3+**	**4+**	**5+**	**28+**	**1+**	**2+**	**3+**	**4+**	**5+**
$\overline{X}$ **T_L**	90	128	158	195	245	255	582	143	173	201	239	250
T_L max	101	140	180	219	253	277	582	162	197	224	253	265
T_L min	83	119	143	170	229	234	582	121	156	176	209	228
n	8	5	7	11	7	2	1	28	24	19	9	3

3.3.3 *Anoxypristis cuspidata*

The age structure of *A. cuspidata* in this study ranged from young of the year (< 1year) to 5 years (Figure 15). From length frequency data it appears the inshore set net fishery only interacts with *A.cuspidata* young of the year and 1 year olds whilst the offshore

fishery interacts with 2 to 5 year old animals (compare Figure 3 in Chapter 2 & Figure 15 in this Chapter).

The juvenile growth rate was most rapid for *A. cuspidata* than any other pristid species. It is estimated that 146% of the birth length (56cm T_L) is attained in the first year. The average growth estimates in the first year and second year are 82cm T_L (Table 5). *Anoxypristis cuspidata* longevity was estimated to be 27 years (409cm T_L) although asymptotic growth was reached at 9 years at 389cm T_L. This dataset would be strengthened if more data can be obtained for the 160 to 190cm T_L size classes and the missing size classes greater than 320cm T_L.

Observation of 12 mature males and 15 mature females indicate size at maturity for males was 203cm T_L and 225cm T_L for females. These size classes are estimated to be 2 and 3 years, respectively (Figure 15). The average size of female *A. cuspidata* recorded in the offshore set net fishery was 293cm T_L and at this size would have been mature for approximately 1 to 2 years. The oldest female specimen recorded in the offshore set net fishery was 5 years old (329cm T_L).On the basis of these findings it would indicate that *A. cuspidata* matures at approximately 27% of asymptotic size.

Table 5: Length at age of observed for *Anoxypristis cuspidata*. Lengths expressed as T_L - average total length, T_L max – maximum total length, T_L min – minimum total length and n - represents the number of samples. Length measurements are in centimetres.

Age	0+	1+	2+	3+	4+	5+
$\overline{X}$ T_L	100	138	220	274	310	325
T_L max	115	164	247	302	330	338
T_L min	83	118	182	227	298	316
n	8	6	13	19	15	4

3.3.4 *Pristis clavata* and *Pristis zijsron*

The age structure of *P. clavata* and *P. zijsron* in this study ranged from young of the year (< 1year) to 9 years for *P. clavata* (Figure 16) and 18 years for *P. zijsron* Figure 16). It is estimated that 41% of the birth length (81cm and 76cm T_L) is attained in the first year for *P. clavata* and *P. zijsron*. The average growth estimates for *P. clavata* and *P. zijsron* in the first year are 41cm and 52cm T_L, slowing to 24cm and 33cm T_L in the second year.

Pristis clavata and *P. zijsron* longevity was estimated to be 94 years (508cm T_L) and 53 years (540cm T_L) respectively. Asymptotic growth was reached at 34 years (389cm T_L) and 24 years (513cm T_L) for both species. Size at maturity data for *P. clavata* and *P. zijsron* is limited and only based on direct observations recorded during this study. These records included two mature male *P. clavata* measuring 295cm and 306cmT_L respectively and a post partum female *P. zijsron* of 380cm T_L. These three specimens are estimated to be 8 years for *P. clavata* and 9 years for *P. zijsron*.

Datasets for both species are limited in both sample size and spread across all size classes. Thus the conclusions drawn from data should be treated with caution and only used as a preliminary guide in the absence of more data.

Table 6: Length at age of observed for *Pristis clavata*. Lengths expressed as T_L - average total length, T_L max – maximum total length, T_L min – minimum total length and n - represents the number of samples. Length measurements are in centimetres.

Age	0+	3+	4+	5+	6+	8+	9+
$\overline{X}$ T_L	98	175	201	225	244	299	300
T_L max	107	180	203	230	244	299	300
T_L min	80	171	200	220	244	299	300
n	10	2	2	2	1	1	1

Table 7: Length at age of observed for *Pristis zijsron*. Lengths expressed as T_L - average total length, T_L max – maximum total length, T_L min – minimum total length and n - represents the number of samples. Length measurements are in centimetres.

Age	0+	1+	2+	3+	5+	8+	10+	16+	18+
$\overline{X}$ T_L	95	128	162	220	255	380	438	449	482
T_L max	102	128	166	220	257	380	438	449	482
T_L min	83	128	157	220	254	380	438	449	482
n	8	1	2	1	2	1	1	1	1

3.3.5 Edge analysis

A distinguishable pattern of growth was observed in the vertebrae of all of the pristid species. However, establishing a finite time scale between the formations of each growth band proved difficult given the opportunistic nature of the sample collection and the low numbers recorded.

A birth band was evident in the vertebrae of all GoC pristids with the exception of some neonate specimens (Figure 9). Observation of thin sectioned vertebrae in neonate *Pristis* specimens revealed a continuous opaque band that extended to the vertebrae margin (Figure 18). This evidence indicates that there is possibly a few weeks or months of free swimming growth before the birth band is deposited.

For all GoC pristids there appears to be a strong temporal pattern in the deposition of opaque and translucent banding in the vertebrae. In all species the opaque band observed in the outer margin of the vertebrae coincided with warm summer months between November and May (Figure 19). Opaque band deposition therefore appears to occur in the early months of summer, with the deposition of translucent banding in late winter. For example, the *P. microdon* vertebra sample in Figure 21 displays a translucent margin and was from an animal recorded in July (early dry season), whilst the specimen in Figure 9 displays an opaque margin and was recorded in March (towards the end of the wet season).

Air temperature data logged for the GoC provides further evidence to support the conclusion of seasonal growth band formation in GoC pristids. There is a distinct correlation between vertebrae growth band formation and air temperature in all species (Figure 19). This seasonal data combined with paired growth banding is indicative of an annual growth pattern in GoC pristids.

Analysis of the vertebra of captive *P. microdon* specimens revealed no distinct paired banding during the animals captive life even though the animals were kept over both summer and winter periods (Figure 20). This growth pattern was not observed in the vertebra of wild caught *P. microdon* of similar size (Figure 21). No vertebra samples of the other three pristid species held in captive environments were available during this study.

3.3.6 Age verification and validation

3.3.6.1 Tag and recapture

All tag and recapture data reported in this study are from animals with less than two years growth from their initial date of capture. Between the years 2000 and 2003 a total of 67 *P. microdon*, 4 *P. clavata*, 3 *P. zijsron* and 58 *A. cuspidata* were tagged in the GoC set net fishery. A further 5 *P. microdon* and 1 *P. zijsron* were tagged and released on the QLD east coast north of Cairns. The program was successful in obtaining recapture data for 4 *P. microdon*, 1 *P. clavata* and 3 *A. cuspidata* in the GoC and 1 *P. microdon* released on the east coast of QLD.

Although considerable time and effort was spent working with industry to reduce recording error in the collection of pristid measurements this program was not without is problems. Information regarding the pristid tagging program was not received by a number of fishers for reasons outside the scope of this study. A negative growth was recorded for a *P. microdon* tag return. This particular specimen was tagged and released by a commercial fishermen trained in the measurement procedure, however the specimen was recaptured by an amateur fisher who had no experience in the procedure. Pristids are difficult animals to handle and errors in measurement recording are bound to occur in any study that relies on voluntary and sometimes untrained community help. Recapture specimen FR1290 was tagged and recaptured by the author and a high degree of confidence has been placed over the tagging data.

From limited tag return information the results indicate that *P. microdon* and *A. cuspidata* exhibit rapid growth in their juvenile life cycle stages (Table 8). The fastest growth rate recorded for *P. microdon* was 0.131 cm day^{-1} and for *A. cuspidata* was 0.121 cm day^{-1}. The growth rate of 0.043 cm day^{-1} for the single *P. clavata* tag return is considerably lower than the growth rates estimated for *P. microdon or A. cuspidata*. Due to a limited number of tag returns it was not feasible to fit von Bertalanffy growth functions to the data. However when the tag and recapture growth data is compared against the estimated growth rate of same sized cohorts generated from size at age data, there appears to be very little difference (Figure 22).

The estimated ages represented by the tag and recapture data for *P. microdon* range between 1.5 and 4.5 years. These year classes represent juvenile animals. The growth rate was slightly higher than the estimated growth rate in the two smaller specimens (FR1290 - 0.09 cm day^{-1} and B11182 - 0.107 cm day^{-1}) whilst the larger third specimen (B11358 - 0.1 cm day^{-1}) had a slightly slower growth rate. A majority of the growth experienced by the later specimen was during winter days (65%), a time when growth is considered to be slower.

Of the two *A. cuspidata* recapture specimens there was too few days at liberty for recapture specimen FR1255 (58 days) to determine an accurate growth rate to compare to the von Bertalanffy growth curve. Although this specimen had grown 7 cm post-tag release. The size at capture of specimen B11295 is representative of a 3 year old animal and the tag and recapture growth rate of 0.047cm day^{-1} was considerably slower than that predicted by von Bertalanffy growth curve. The average predicted growth rate of a 2 to 3 old *A. cuspidata* is approximately 54cm (Table 5) whilst the annual recapture growth was only 17cm in tag in tag number B11295.

Table 8: Pristid tag recapture information for the GoC and east coast tagging program between the years 2000 and 2003. Total length (T_L) refers to the size at tagging. Pristid growth rate was measured as cm growth per day^{-1}.

Species	Tag#	Site	Liberty days	T_L (cm)	Growth T_L (cm)	Growth rate	Annaul growth (cm)	Movement (km)
P. microdon	FR1290	EC	232	231	10	0.043	17	0.002
P. microdon	B11358	GoC	187	191	25	0.131	48	83
P. microdon	B11182	GoC	224	153	41	0.107	39	100
P. microdon	B11180	GoC	410	unknown	unknown	unknown		1
P. microdon	FR1075	GoC	100	247	-4.5	unknown		220
P. clavata	B11191	GoC	121	98	3	0.02	7	23
A. cuspidata	B11295	GoC	575	264	27	0.047	17	5
A. cuspidata	FR1255	GoC	58	258	7	0.121	44	11
A. cuspidata	FR1210	GoC	21	191	0	unknown		61

3.3.6.2 Oxytetracycline injected animals

A total of 10 *P .microdon,* 4 P. *clavata,* 2 *P. zijsron,* and 10 *A. cuspidata* were injected intramuscularly with OTC, however none of these specimens were recaptured. These animals were all tagged and released in the GoC.

The vertebrae from two deceased captive *P. microdon* was analysed for an OTC mark. The specimen (S1237) was captured at 134.9cm T_L and in 420 captivity days had grown 60.9cm (Figure 23). On inspection of the vertebrae a fluorescent band was evident at the margin of the outer translucent band (Figure 23). A continuous opaque band succeeded the fluorescent mark in the vertebrae. The specimen was held in a stable environment for 420 days.

The second specimen S859 was captured at 181cm T_L and in 141 days had grown 49cm. On inspection of the vertebrae a fluorescent band was evident at the margin of the outer thin opaque band. This specimen was estimated to be two years old. A similar profile of continuous opaque deposition succeeded the fluorescent band in the vertebrae, indicative of captive growth (Figure 24).

3.3.6.3 Captive growth

Captive growth measurements were recorded for four immature *P. microdon* (Table 9). No captive growth information was available for the other three pristid species. The captive specimens S1231 and S1239 represent animals from the one year age class, S1237 from the 2 year class and S859 from the fourth year class. In comparison to the size at age data fitted to the von Bertalanffy function for the same year classes all captive growth rates are faster than those of non captive animals (Figure 25). The growth rates of *P. microdon* held in captivity ranged between 0.123 and 0.208 cm day^{-1} (Table 9).

Table 9: Growth and weight data collated for *Pristis microdon* specimens held in captivity. Total length (T_L) measurements are in centimetres, whole weight (W_W) data is in kilograms and growth rate is reported as cm day^{-1}. (*denotes male specimens)

Species & sample #	Captive days	T_L (cm)	Growth (cm)	W_W (kg)	Growth rate	W_W Gain (kg)
	0	105				
S1231*	119	128.4	23.4	10.3	0.200	
	174	164.6	36.2	13.9	0.208	3.6
	0	104.5				
S1239*	119	127.7	23.2	11	0.195	
	247	158.2	30.5	14.4	0.123	4.4
	0	181				
S859*	141	220	39		0.277	
	0	134.9				
S1237	420	194	60.9		0.145	

3.4 Discussion

3.4.1 Pristid Growth

In this study, estimates of growth and longevity of GoC pristids were obtained from analysis of vertebrae. The use of thin sectioned vertebrae for *Pristis* and half sectioned vertebrae for *A. cuspidata* were appropriate techniques for investigating age in these species with consistent growth counts between readers. The index of average percent error for growth counts in *P. microdon* and *A. cuspidata* are comparable to other elasmobranch studies (Brown & Gruber 1988, Wintner & Dudley 2000, Campana 2001). Staining of pristid vertebrae with Alizarin red S and silver nitrate was explored in this study and proved to be successful especially for *Pristis* species (Figure 8).

The size at age data in this study is the most comprehensive dataset ever compiled for Australian pristids. However this study still lacks the robustness of most other elasmobranch studies because of the paucity of species data across the full range of size classes and between sexes. As noted earlier these species are rare or endangered and

consequently sample collections were small and mainly limited to the collection from incidental captures by commercial fishermen. Typiclly those elasmobranch species which have been exploited for their fins, meat and sport fishing value have been more comprehensively studied such as blackip whaler shark (*C. limbatus* and *C. tilstoni*), common thresher shark (*A. vulpinus*), shortfin mako (*I. oxyrinchus*), (Cailliet et al 1983b, Stevens & McLoughlin 1991,)

The pristid species known to inhabit the GoC have been previously reported to be large in size (Compagno & Last 1999, Last & Stevens 1994). Maximum sizes for *P. microdon*, *P. zijsron* and are reported to exceed 600cm T_L whilst *A. cuspidata* is known to reach 470cm T_L. A limitation of this study is the fact that all *Pristis* age and growth estimates have been based primarily on immature animals. In all species except *P. clavata*, no samples were recorded at their known reported maximum size. This data suggests that either the animals in these missing size classes inhabit deeper water found offshore or that their population has been systematically fished down to smaller sized animals.

In this study new data on the maximum size and age of maturity of *P. clavata* is reported with the capture of two mature specimens of 295cm and 306cm T_L respectively. This species was previously reported to have a maximum length of 250cm T_L (Compagno & Last 1999) and 233cm T_L (Thorburn et al 2003). The maximum size estimated for *P. clavata* of 485cm T_L in this study is supported by anecdotal reports from set net fishers in the GoC where it was widely accepted within the GoC commercial fishing sector that large *P. clavata* were once thought to be female *P. zijsron* (A. Vickers Commercial offshore gill net fisherman pers com 2004).

Somatic growth was observed in the four sawfish species, with statistically significant linear relationships between vertebrae diameter and LJT_L ($p<0.001$). The absence of data prevented analysis to test for differences in growth rates between sexes, in particular mature specimens; therefore it was assumed that the growth rates of male and female pristids were similar. In some elasmobranch species there are no significant differences in growth rates between the sexes, such as *C. obscurus* and *C. plumbeus*

(Natanson et al 1995, Sminkey & Musick, 1995). In contrast Davenport & Stevens, (1988) reported significant differences in the growth rates of *C. tilstoni* and *C. sorrah* between sexes. Therefore in future age and growth studies on GoC pristids this is an issue which requires investigation.

All GoC pristids are relatively long lived animals, with the exception of *A. cuspidata* (9 years) with longevity of; *P. microdon* (35 years), *P. clavata* (34), and *P. zijsron* (24), respectively. The findings of this study support the longevity assumption of Cailliet & Goldman (2004) that pristids are long lived species. In the current study it was estimated that *P. microdon, P. clavata* and *P. zijsron* attain 40%, 41% and 41% respectively of their original birth length during the first year. The pattern of growth of *A. cuspidata* is similar to that of *Pristis* although they appear to grow substantially faster, attaining 146% of their birth size in the first year.

The observed rapid growth rate in this study of young of the year pristids is feasible because they are nutritionally supported by an absorbed yolk sac for a period of time after birth. Hence new born individuals do not have to exert energy in the search of food resources but reserve this energy for growth. The nutritional value of the absorbed yolk sac is demonstrated in the embryonic growth of *P. microdon* where during a gestation of approximately 5 months (Compagno & Last 1988) an embryo can attain an observed size at birth of 90cm T_L (as seen in this study). This is equivalent to an embryonic growth rate of 0.60mm day^{-1}, approximately four times greater than the growth rate estimated for the first year. It is assumed that similar rates of embryonic growth in all pristid species given size at birth and gestation period between species are similar (Compagno & Last 1999).

The growth curve for *A. cuspidata* covers the ages 1 to 5 years and a maximum size of 338cm T_L (Table 5). The literature suggests that a more realistic maximum size is 470cm (Compagno & Last 1999). This would suggest that the samples collected during this current study are from juveniles and young adults. Data from the commercial catch information for the inshore (0 to 7nm) and offshore (7 to 25nm) net fisheries show that

there is a significant difference in the both the size and maturity with larger mature animals found offshore.

Given the *A. cuspidata* growth curve is derived from smaller size classes, it can be assumed that these animals are faster growing than larger specimens (that would be at the asymptote of the growth curve), presumably located in deeper waters. Therefore the growth curve is most likely an overestimate of the growth rate for this species and will need to be re-estimated when lager specimens are available. This conclusion is supported by the growth data of a tagged specimen measuring 264cm T_L which had an annual growth rate of 17cm (0.047cm day^{-1}) (Table 8). This annual growth is considerably slower than the growth of 36cm over twelve months for animals of similar size as estimated from the growth curve (Table 5).

There are only three published studies on pristid growth to compare the results from this study and they are; Thorburn et al (2004) who reported on the findings of a fisheries survey in the Fitzroy River Western Australia; Tanaka (1991) who reported the von Beralanffy growth parameters for *P. mcirodon* in northern Australia and Papua New Guinea; and Thorson (1982b) who reported data for *P. perotetti* from tagging studies in Lake Nicaragua. The growth coefficients estimated for GoC pristids was slightly higher than those estimated previously for *P. microdon* K=0.07 (Tanaka 1991), and similar to northern hemisphere pristids *P. pectinata* K= 0.08, and *P. perotetti* K= 0.08 Simpfendorfer (2000). The growth coefficients for *Pristis* indicate that they exhibit a medium rate of growth and *A. cuspidata* a fast rate of growth in comparison to other elasmobranchs (Bransetter (1987).

Anoxypristis cuspidata exhibited the most rapid juvenile growth rate of all GoC pristids growing an estimated 82cm in the first year. In comparison the growth rates of 52cm, 41cm and 52cm T_L in the first year for *P. microdon*, *P. clavata* and *P. zijsron* are comparably smaller however are similar to the rate of growth in *P. perotetti* of 35 to 40cm T_L for the same period (Thorson 1982b).

The growth estimates identified in this study for *P. microdon* and those of Thorson (1982b) for *P. perotetti* are not the same as those reported by Thorburn et al (2004). In Thorburn's study the single tag and recapture of an immature *P. microdon* in the Fitzroy River had only grown 3cm in 120days. This animal was tagged and recaptured in winter and no data was available on ambient water temperature over this period. It is therefore highly likely that growth rates in *P. microdon* and presumably in other pristid species are heavily influenced by the ambient environment they inhabit, such as water temperature which is known to effect metabolic rate in sharks (Casey et al 1985). Similarly, a captive *P. microdon* in a Hong Kong Aquarium of 200cm T_L has been reported to be at least 10years (P. Last CSIRO Marine Research pers com 2004). No data was available on the environmental condition this captive specimen has been kept under. Therefore these examples demonstrate that growth rates in juvenile *P. microdon* can be highly variable most likely due to environmental influences within their habitat. Thus, caution should then be taken when interpreting growth banding in the vertebrae of animals captured in different regions and habitats especially in temperate areas.

The findings in this study and those reported by (Thorson 1982b) for *P. perotetti* are substantially different to those of Tanaka (1991) who reports a much slower growth rate of 18cm T_L for *P. microdon* in the first year and 10cm T_L in the tenth year. The age estimates reported by Tanaka (1991) are not biologically reasonable in light of maximum sizes for *P. microdon* and new information on tag and recapture and captive growth. Tanaka (1991) reported an age estimate of 44 years for a *P. mcrodon* measuring 361cm T_L. This length is 295cm less than the maximum known length reported by (Compagno & Last 1999) and 221cm T_L less than observed in this study. Based on Tanaka's growth rates these animals would have been over 150 years old.

The discrepancies between growth rates in this study and those reported by Tanaka (1991) are most likely caused from differences in opinion regarding the timing of growth band deposition within the vertebrae. Tanaka (1991) made no attempt to verify or validate growth band periodicity, which may have lead to an over estimation of age.

The rapid growth rate estimated in the first year of GoC pristids is not commonly observed in a majority of other elasmobranch species. A summary table of elasmobranch age and growth studies by Cailliet & Goldman (2004) revealed most species were described as being slow growing. There are, however some species that exhibit similar and in some cases more rapid growth rates for the same first year of growth. For example the small sized Australian sharpnose shark (*Rhizoprionodon taylori*) is reported to attain up to double its birth length in the first year however the second year growth is substantially slower (Simpfendorfer 1993). It is also common that fast growing elasmobranchs such as the sharpnose shark only attain small maximum sizes. There are a few species which do not fit this trend and attain large sizes although have rapid growth in early years of life. For example the blue shark (*Prionace glauca*) and the tiger shark (*Galeocerdo cuvier*) have rapid growth rates of up to 100% in their first year but attain maximum sizes similar to that of pristids (Stevens 1975, Cailliet et al 1983a, Branstetter et al 1987, Natanson et al 1999, Wintner & Dudley 2000). Gulf of Carpentaria pristids are therefore in a minority group of elasmobranchs which share rapid early growth rates but still attain very large maximum sizes. This life history strategy is most likely an adaptation to limit juvenile mortality, a stategy more commonly observed in smaller shark species such as theAustralian sharpnose shark (*R. taylori*), (Simpfendorfer 1993)

Although growth rates from captive and tagged animals in this study are variable and the numbers of specimens small, the data indicates that in the case of *P. microdon* the species could well possess a much faster growth rate in immature years than the growth rates estimated by the length at age analysis in this study. Evidence from tag and recapture growth rates of 0.13cm day^{-1} or 47.5cm a year differs from the von Bertalanffy estimated growth rate of 36cm a year from vertebrae aging for the same aged animal. Similarly, the maximum captive growth rate of 0.34cm day^{-1} or 124cm T_L a year greatly exceed that of 36cm a year estimated from the von Bertalanffy growth curve. Thus, the estimated growth rates predicted from vertebrae aging in this study maybe slightly slowerof true size-at-age in immature size classes. Obviously P. microdon growth rates are highly variable and are influenced by the condition of the ambient environment.

Environmental factors such as seasonal conditions and access to available food resources would have an effect on the growth of pristids in the wild as they have in other elasmobranch species such as the sandbar shark (*C. plumbeus*) (Casey et al 1985). Growth rates exceeding 100cm per year have been observed in captivity for juvenile *P. microdon* and *P. zijsron* (L. Jnr. Squire Director CMA pers com 2003). Thus captive growth and tag-and-recapture data (rather than vertebrae aging on its own) demonstrates that the growth rates predicted from size-at-age data for immature *P. microdon* in this study are biologically attainable.

The life history strategy of GoC pristids in immature years to grow rapidly is possibly an adaptation developed to avoid predation in the younger years. This strategy is thought to be the case in other elasmobranchs species where smaller more vulnerable sharks are predated on by other shark and fish species (Branstetter 1990). This may well be the case for immature *P. microdon* , which is known to travel long distances up rivers possibly to avoid predation from larger sharks (Chapter 4). The stomach contents of bull shark (*C. leucas*) and scalloped hammerhead (*Sphyrna lewini*) have been observed to contain juvenile *Pristis* and *A. cuspidata.* (J. Stapley DPI&F Fisheries Observer pers com 2003). These two predatory shark species inhabit inshore shallow waters which are known habitat for juvenile pristids (Last and Stevens 1994).

3.4.2 Age at Maturity

Age at maturity of GoC pristids is based on the observed size at maturity data in this study (see Chapter 2). Although limited in its robustness due to a small number of samples this information is extremely useful as data available on Australian pristid reproduction and maturity is very limited. On the basis of this information it is inferred that the size at maturity for GoC *Pristis* species is approximately 8 to 9 years at a size of a 300cm T_L and approximately 2 to 3 years for *A. cuspidata* at a size of 203cm for males and 225cm T_L for females.

Size at maturity for *P. microdon* was established at approximately 300cm T_L. This length is inferred from the capture of a pupping *P. microdon* of 303cm T_L (Chapter 2 Table 3). At this length the specimen is estimated to be approximately 8 years of age.

Thorson (1976) predicted age at maturity for *P. peretetti* to be approximately 10 years at a size of 305cm T_L. To complement this data, a much larger pupping *P. microdon* of 582cm T_L was recorded in this study and at this size was estimated to be 28 years old. This much older specimen would have had a reproductive output of 18 years based on the age at maturity estimate reported in the current study.

Tanaka (1991) reported a mature male *P. microdon* at 361cm T_L and predicted its age to be 44 years and an immature specimen of 247cm T_L to be 16 years old. As with age estimates these growth and maturity data do not agree with the findings of this study for the same species nor to that of Thorson (1982b) for *P. peretetti* who estimated age at maturity of 10 years.

The longevity estimates at asymptotic growth reported in this study of; *P. microdon* (35 years), *A. cuspidata* (9), *P. clavata* (34), and *P. zijsron* (24) and the age at maturity data would indicate that these species mature at 22%, 34%, 24% and 27% of their approximate life span. A combination of *Pristis* species longevity and the relatively late maturation makes a long period where these inshore animals are vulnerable to netting prior to them reproducing and they remain vulnerable to capture throughout their life.

Pristis perotetti has a similar unfavourable life strategy reaching maturity at approximately 33% of it lifespan according to the available data. This life strategy is also reported by Simpfendorfer (2000) for *P. perotetti* where population recovery times were estimated to take tens of years.

Contrary to the life strategy of *Pristis* species, *A. cuspidata* has a much faster growth rate, and although they reach maturity at approximately 27% of their asymptotic age they are considerably younger maturing animals at 2 to 3 years of age compared to 8 to 10 years in *Pristis*. Thus, *A. cuspidata* is a more productive species than *Pristis,* and consequently are observed to be more abundant in the operational waters of the inshore and offshore set fishery (0 to 25 nautical miles) in the GoC. A more thorough demographic modelling needs to be carried out in order to confirm this conclusion (Simpfendorfer 2000).

The largest *P. clavata* recorded in this study was a mature male of 306cm T_L and was estimated to be 9 years old. A smaller mature male of 295cm T_L was also recorded and estimated to be 8.5 years. The largest *P. zijsron* recorded in this study was a mature male of 482cm T_L at an estimated age of 18 years old. A smaller mature female was recorded at a length of 380cm T_L (see Chapter 2) and was estimated to be 9 years. The age at maturity data reported for the above species are very similar to that reported for *P. microdon* and older than that reported for *A. cuspidata*. Thorson (1982b) reported that *P. perotetti* matured a little later than the GoC *Pristis* species at 10 years of age, although the estimated size at maturity is very similar. From the limited data there appears to be distinct life strategies between *Pristis* and *Anoxypristis*.

Size at birth for *P. microdon*, *P. clavata*, *P. zijsron* and *A.cuspidata* was 76cm, 81cm, 76cm and 56cm T_L respectively, which although large is consistent with the observations made both during the current study and anecdotally by fishermen of newly pupped individuals. As noted in the results (Chapter 2), a foetus extracted from the largest female recorded in this study was 91cm T_L, significantly larger than that observed in the catch records and predicted from the vertebrae analysis. A possible explanation for this would be that the size of the foetus is dependent on the size of the mother, which would follow the similar strategy in other large sized elasmobranchs such as tiger sharks (Simpfendorfer 1992).

3.4.3 Age validation and verification

The growth curves developed in this study are biologically reasonable but have not been fully validated. Many attempts have been made to validate the periodicity of growth patterns observed in the vertebrae of elasmobranchs (Cailliet & Goldman 2004). The results of these studies have met with varied degrees of success, mainly because of the difficulties in accessing sufficient samples throughout the season for marking and the subsequent recovery of these animals after sufficient time at liberty. The rarity of sawfish made data sampling challenging because of time and spatial constraints over the project. The conservation status of pristids also meant that commercial fishers were encouraged to tag and release alive all pristids, thus further limiting the number of available samples.

Post release mortality is a factor that might have had an affect on the recapture of GoC pristids and there is no data to quantify this. It is thought however that the post release mortality of tagged *A. cuspidata* is high. This assumption is based on the observations from autopsied animals of internal injuries inflicted during the capture process (as discussed in chapter 2). Similar causes of mortality have been observed in the tagging program of the gummy shark (T. Walker Principal Marine Scientist MAFRI pers com 2004). In comparison to commercially targeted shark species *A. cuspidata* are considered "soft" that is they respond physiologically and more than likely phycologically to shock in a more humonal nature. For example, as reported by L. Jnr. Squire Director CMA who has not been able to successfully keep this species in captivity. It is thought that *A. cuspidata* stress easily during and after capture and are very slow to recover and in the case of captive animals die (L. Jnr. Squire Director CMA pers com 2003). Therefore it is recommended that in any future tagging studies attempts should be made to incorporate the observations discussed above into the sampling program.

From a limited number of samples a pattern of seasonal deposition was evident in the paired growth banding in the vertebrae of GoC pristids. It was inferred from this seasonal pattern that paired growth band deposition in the vertebrae accurs annually. A broader opaque band formed in summer and narrower translucent bands in winter. These findings were supported by correlations of the band formation with variation in air temperatures for the region (Figure 19)

In addition to the edge analysis findings captive growth indicated a similar pattern of seasonal growth deposition in the banding of *P. microdon* vertebrae. Captive animals were kept in an environment mimicking summer water temperatures and were fed *adlib*. The time of capture was marked with an OTC band. The growth band which formed during captivity was opaque even though the animals were held in captivity over the winter season where a translucent band would have normally been deposited.

Analysis of vertebrae of captive *P. microdon* along with the seasonal pattern of band deposition highlighted by vertebrae edge analysis and correlating air temperature data strongly suggests that increased growth rates in GoC pristids is influenced by seasonal

temperatures. This also supports the assumption of annual paired banding in pristid vertebrae.

This seasonal pattern of growth band deposition is commonly seen in other elasmobranch species (Natanson et al 1995, Carlson et al 1999, Carlson & Baremore 2005, Neer & Thompson 2005). Although only a limited number of OTC marked animals were released during this study it is hoped that future opportunities will allow the recapture of these animals to validate the findings reported in this study.

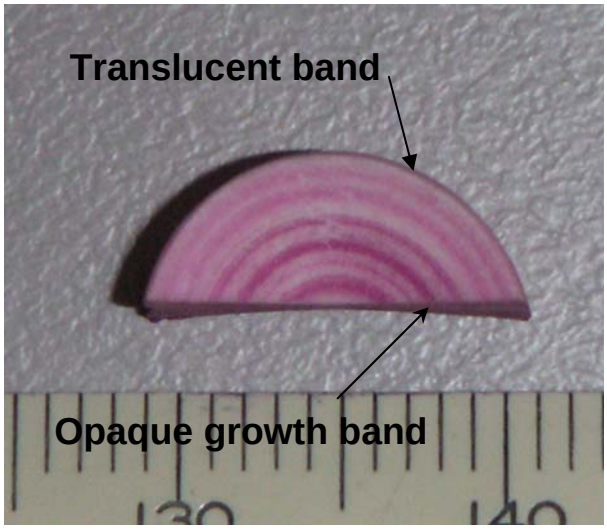

Figure 8: Alizarin red S stained half sectioned vertebrae of a *Pristis zijsron* of 254cm total length with an age estimate of 5 years. Note the translucent band on the outer margin of the vertebrae. This animal was caught in the winter month of September.

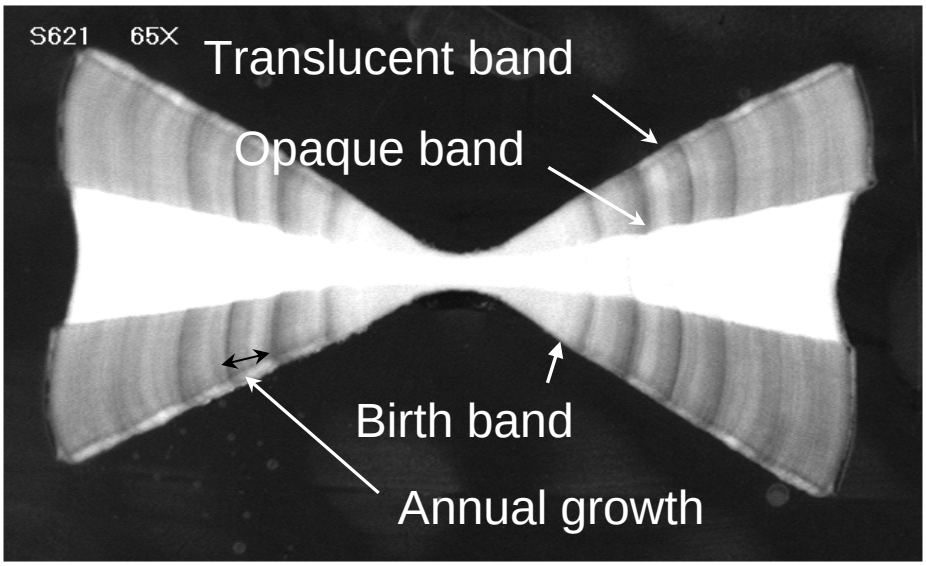

Figure 9: A *Pristis microdon* thin vertebra section displaying birth and opaque and translucent growth banding. The vertebra section is viewed under 6.5 magnification using reflected light.

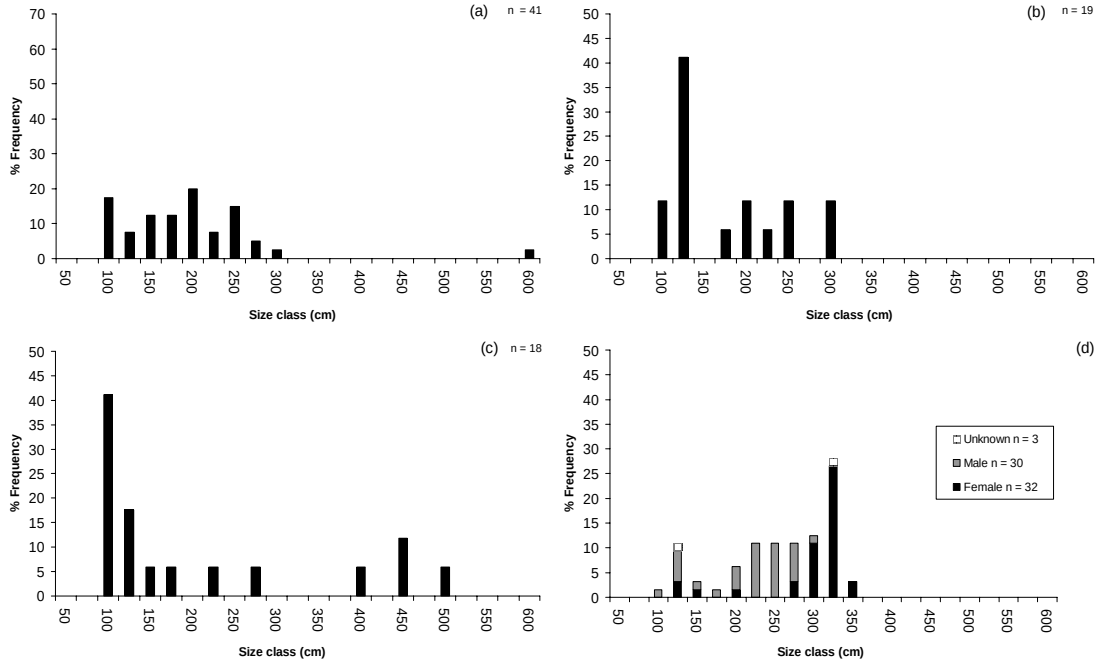

Figure 10: Length frequency of four sawfish species used in age and growth studies from the Queensland Gulf of Carpentaria. (a) *Pristis microdon*, (b) *Pristis clavata*, (c) *Pristis zijsron*, and (d) *Anxypristis cuspidata*. The sexes were pooled for pristid species and length measurements are given in total length.

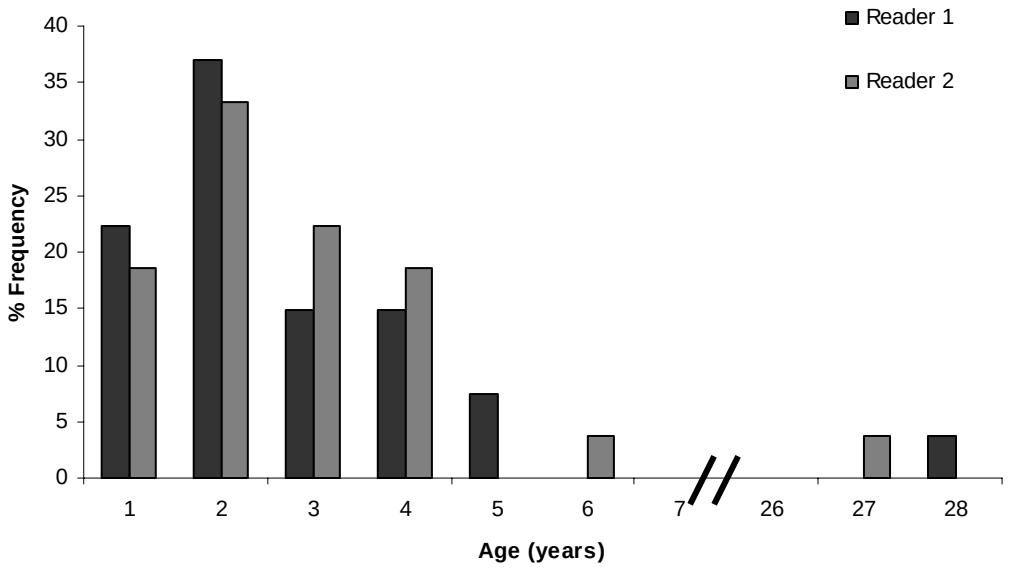

Figure 11: *Pristis microdon* age distribution histogram comparing results of the second read of the primary reader to that of the secondary reader for age classes greater than 1 years (n = 33).

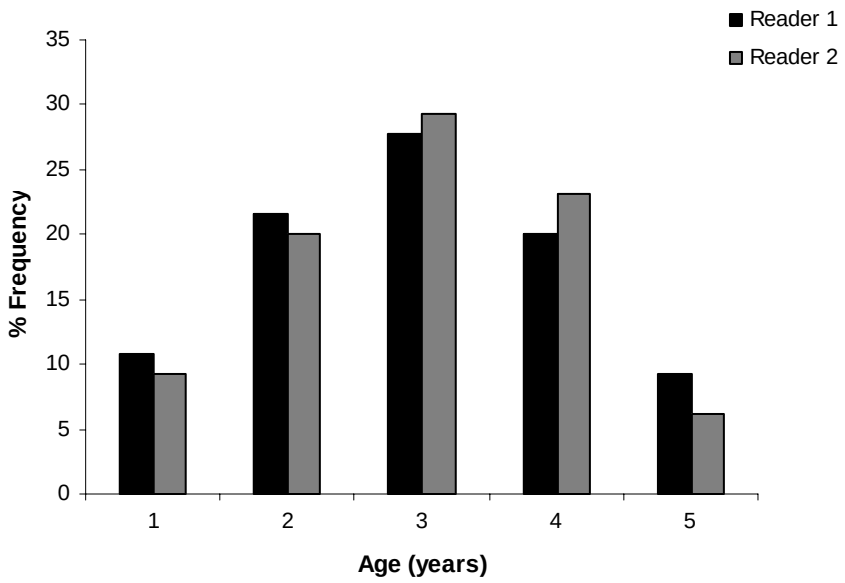

Figure 12: *Anoxypristis cuspidata* age distribution histogram comparing results of the second read of the primary reader to that of the secondary reader for age classes greater than 1 year (n = 58).

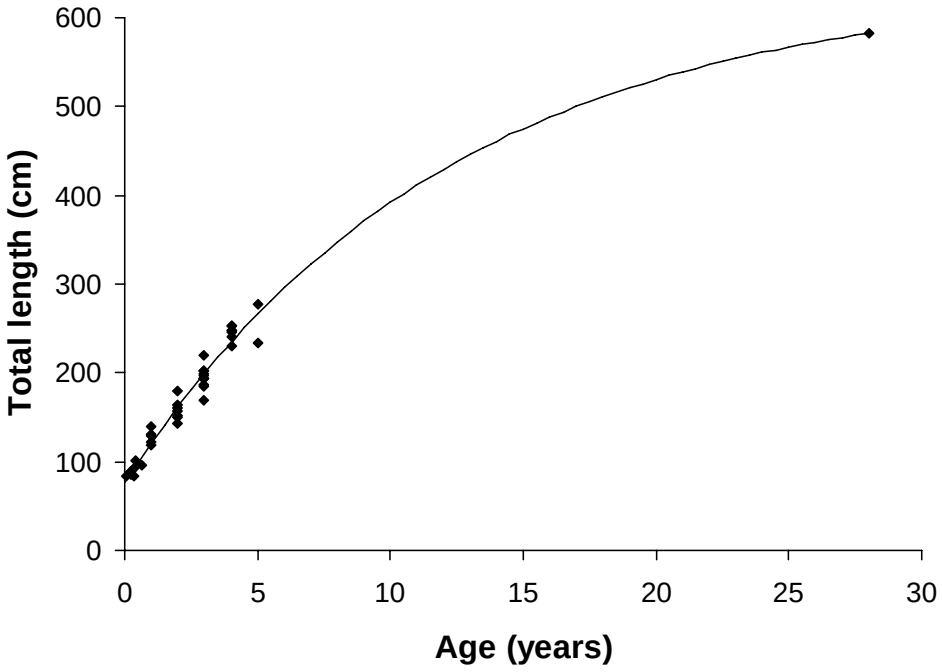

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Figure 13: Size at age data for Gulf of Carpentaria *Pristis microdon* (n=41). Data is pooled for both sexes and the regression line indicates von Bertalanffy growth functions.

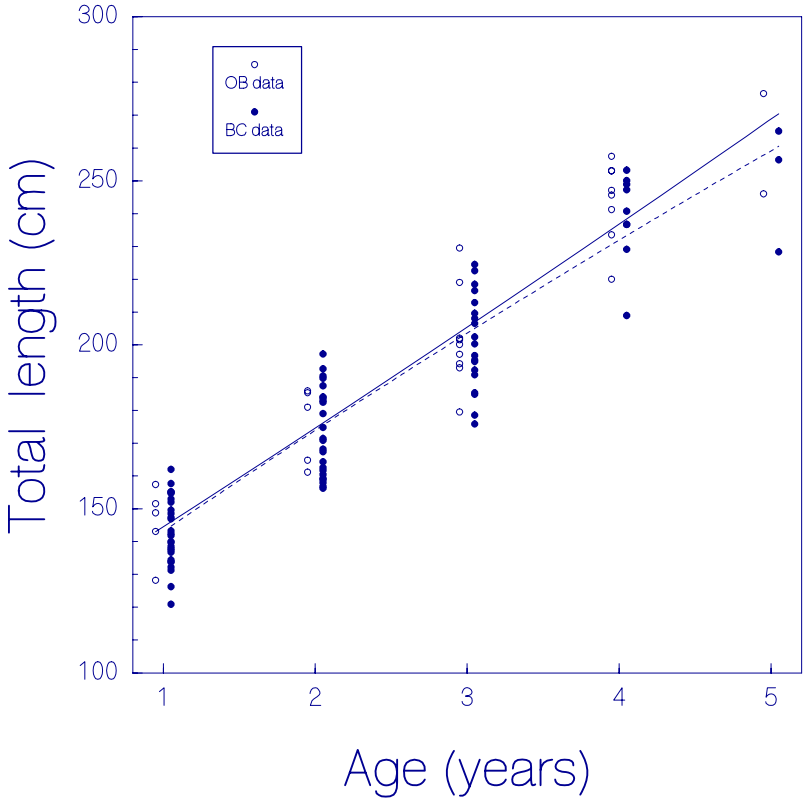

Figure 14: Non-linear regression analysis (non- significant F= <0.001) comparing the differences between observed (OB) and back calculated (BC) size at age data for *Pristis microdon* between the ages of 1 to 5 years.

5

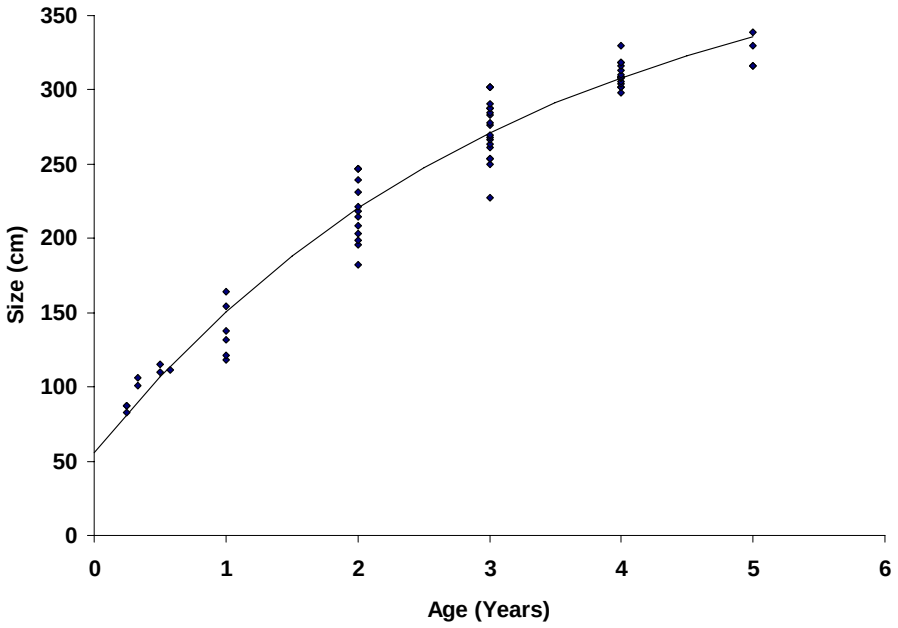

Figure 15: Size at age data for Gulf of Carpentaria *Anoxypristis cuspidata* (n=65). Data is pooled for both sexes and the regression line indicates von Bertalanffy growth functions.

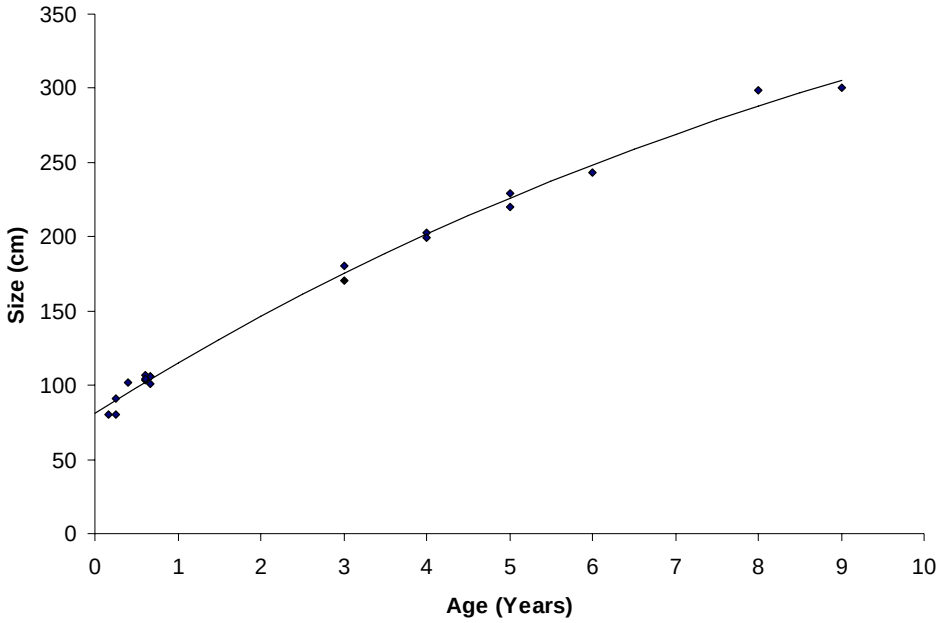

Figure 16: Size at age data for Gulf of Carpentaria *Pristis clavata* (n=19). Data is pooled for both sexes and the regression line indicates von Bertalanffy growth functions.

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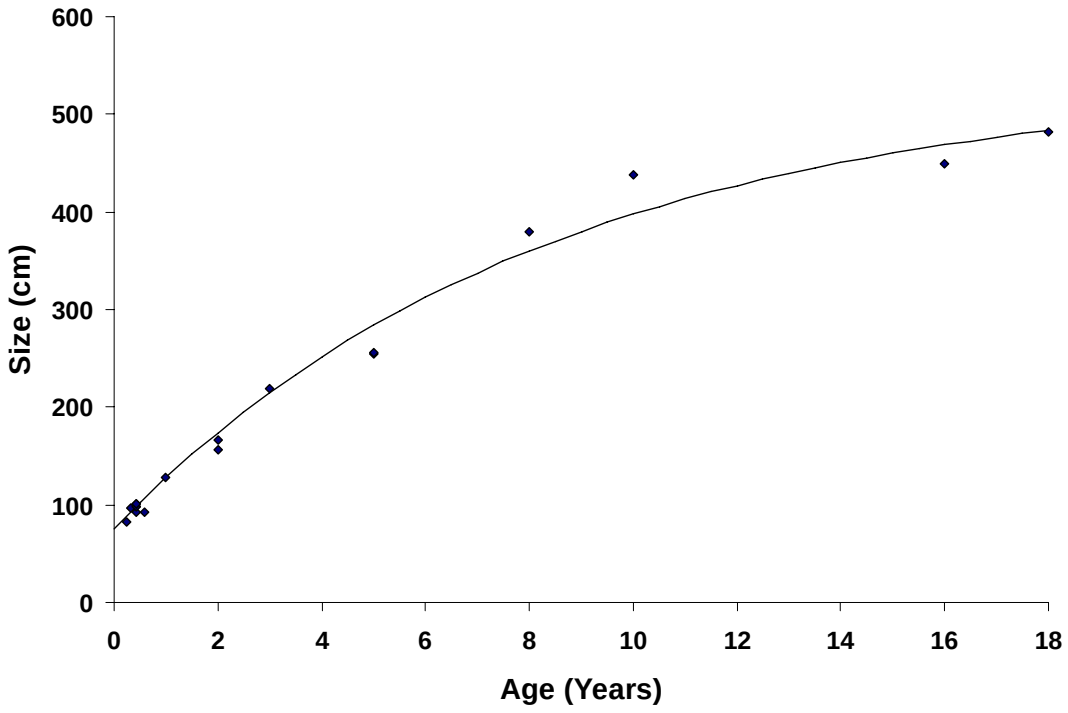

Figure 17: Size at age data for Gulf of Carpentaria *Pristis zijsron* (n=18). Data is pooled for both sexes and the regression line indicates von Bertalanffy growth functions.

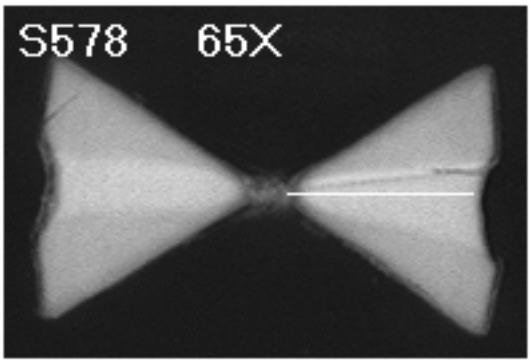

Figure 18: A thin vertebra section of a neonate *Pristis microdon* of T_L 83cm. Note the absence of the translucent birth band on the distal edge

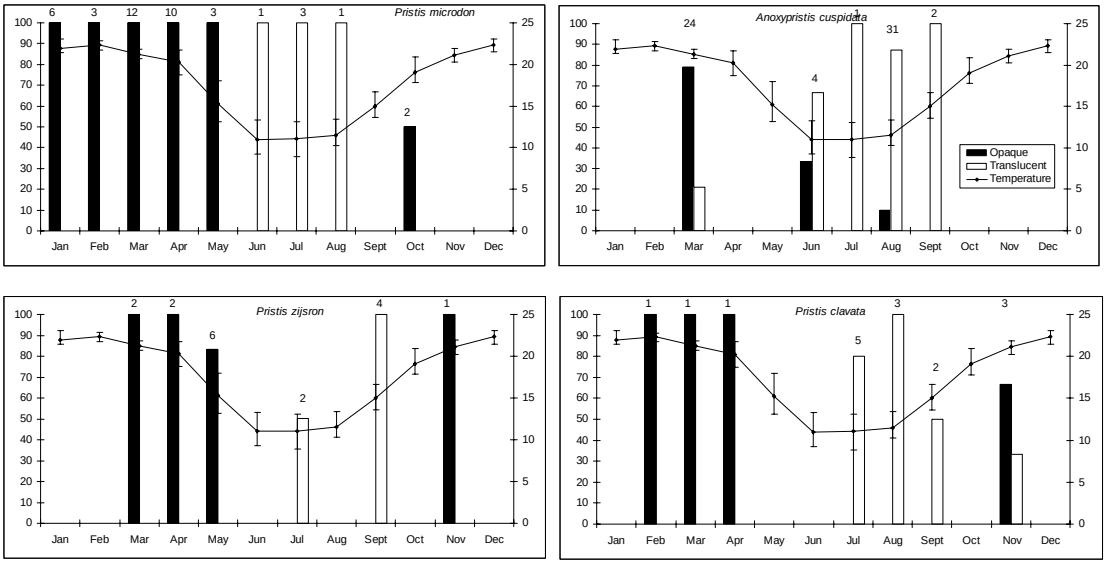

Figure 19: Proportion of Pristid individuals with opaque and translucent vertebral edges separated by month. A strong seasonal pattern of opaque band deposition in all species is evident in the summer months when the air temperatures are greatest during the monsoon.

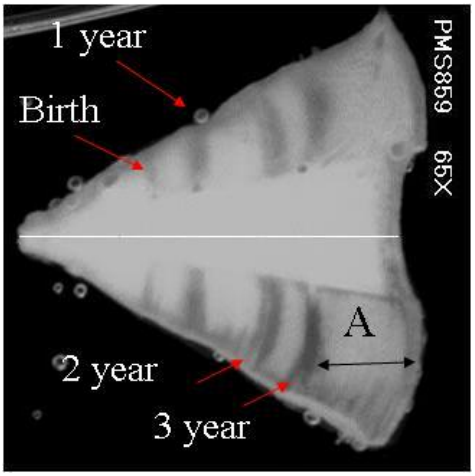

Figure 20: A thin sectioned vertebra of a captive *Pristis microdon* of 220cm T_L. The specimen had experienced a captive winter however does not display a normal translucent band. A wider than normal opaque band exists (A).

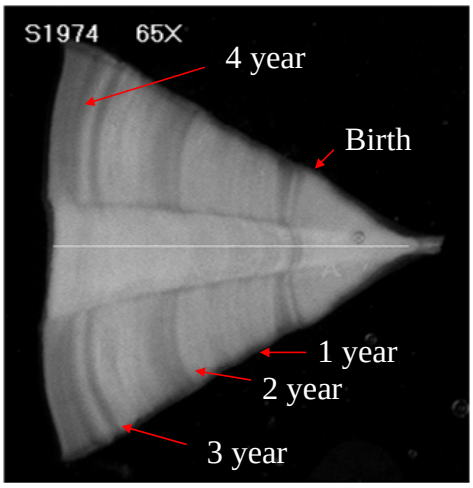

Figure 21: A thin sectioned vertebra of a wild caught *Pristis microdon* of 219cm T_L. The specimen was caught in the winter month of July and has a translucent margin on the distal edge of the vertebra.

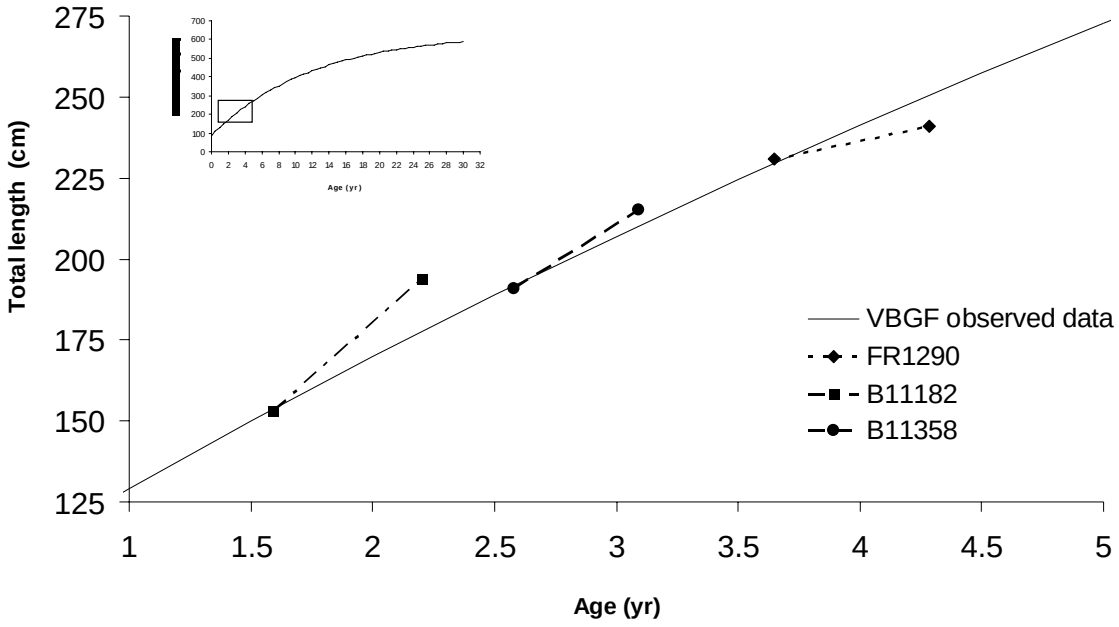

Figure 22: Comparing the relative growth rates of tag and recaptured *Pristis microdon* to the von Bertalanffy growth. Growth estimates are slightly slower for the same year classes as the tag and recapture animals except for tag number FR1290 which was marginally slower

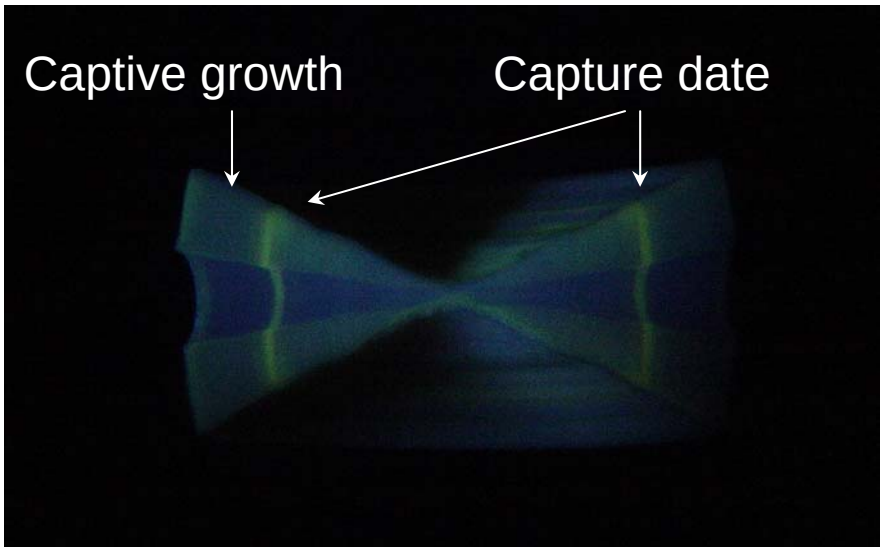

Figure 23: Photograph of a half sectioned vertebra of a captive *Pristis microdon* (specimen S1237) viewed under ultraviolet light. The specimen had been injected with oxytetracycline at a dose rate of 20mg kg^{-1}. This specimen was captured at 134.9cm T_L and in 420 captivity days had grown 60.9cm. The fluorescent band is representative of capture date and captive growth can be measured from the fluorescent band to the distal margin of the vertebra. Photo: courtesy of PhD student Will Robbins (James Cook University School of Marine Biology).

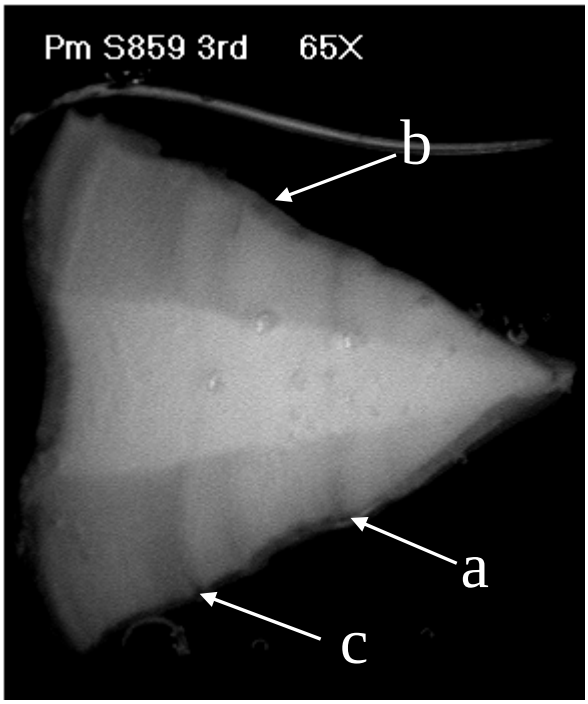

Figure 24: Thin vertebrae section of captive *Pristis microdon* specimen S859. The embedded letters represent (a) – first translucent band, (b) – second translucent band, and (c) fluorescent band and beginning of continuous opaque band representative of captive growth. This specimen was captured at 181cm T_L and in 141 liberty days had grown 49cm.

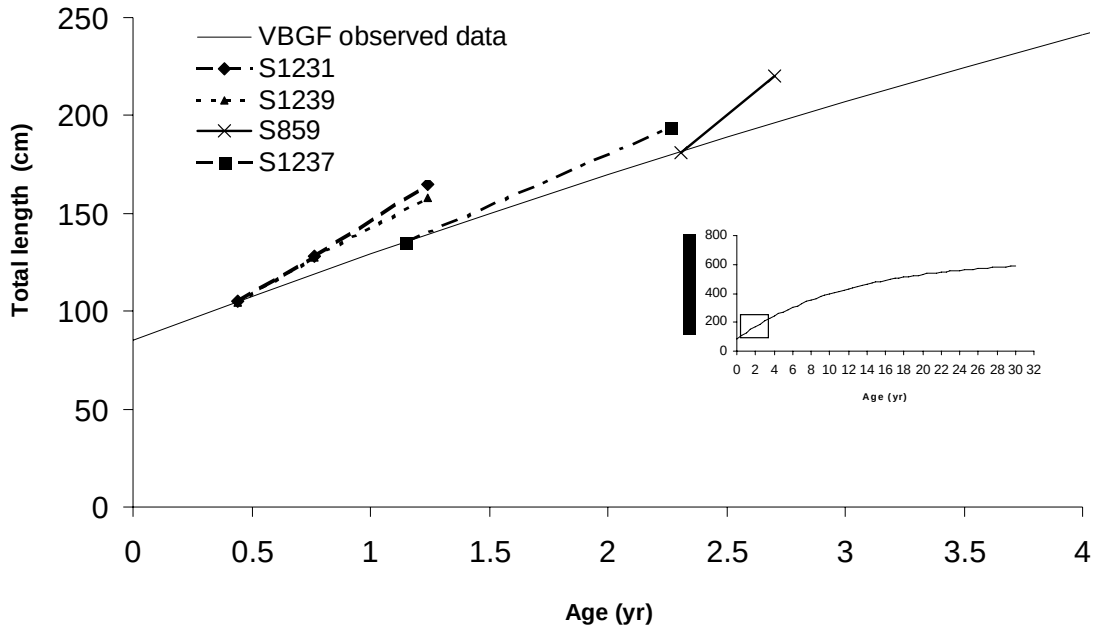

Figure 25: Comparing the relative growth rates of captive *Pristis microdon* to the von Bertalanffy growth curve. Growth estimates are considerably slower for the same year classes in comparison to captive growth rates.

Chapter 4 Habitat Utilisation and Diet

4.1 Introduction

There are approximately 950 species of chondrichthyan (cartilaginous fishes) worldwide (Last & Stevens 1994) and they are known to occupy a wide range of habitat types including fresh, estuarine and marine, shallow coastal and deep oceanic water in tropical, temperate and artic regions (Simpfendorfer & Heupel 2004). Last & Stevens (1994) provide a broad description of the habitat and distributional ranges of the 296 elasmobranch species known to Australia. However, problematic for resource managers is the lack of critical information on the localised ranges of these species and how they utilise habitats within their range.

In Australia the reporting of pristid records by fishermen, the general public and even some scientists have been inaccurate because of misleading descriptive common names. These common names have caused confusion on all levels of reporting. For example the freshwater sawfish (*P. microdon*) as its common name suggests was, until recently, thought to only inhabit freshwater (Hungerford 1977, Last & Stevens 1994, Thorburn et al 2003). Reports on their wider distribution into marine waters are only now just being considered and will be discussed later in this chapter. Confusion within the community exists where fishers assume *P. microdon* can only be caught in freshwater. Therefore speculation can be cast over the identification of *Pristis* recorded in estuarine and marine waters where they may have been wrongly identified for the green (*P. zijsron*) or dwarf sawfish (*P. clavata*). Commercial trawl and gill net fishermen of QLD have always assumed that the broad billed sawfish (*P. microdon*) was the female partner to the long narrow billed sawfish (*P. zijsron*) (A. Vickers Commercial offshore gill net fisherman pers com 2004). Fishermen recognised that they grew to approximately the same size although never suspected that they were two separate species.

Similar to freshwater sawfish, the descriptive common name dwarf sawfish (*P. clavata*) was used as it was thought the species only attains small body size of up to 2m total length (Hungerford 1977, Last & Stevens 1994). This has since been proven inaccurate as discussed in Chapters 2 & 3 of this study. Furthermore, there are no distributional records of this species ever occurring on the east coast of QLD despite their range having being documented here (Last & Stevens 1994). It is possible historically they

may have once occurred on the QLD east coast however there is no evidence to support this theory such as preserved rostrums or photos. Thus poor reporting on pristid information and morphology may have lead to misidentification of species and inaccurate reporting of their distributional range and subsequent use of habitat.

In more recent times scientists have used tracking techniques such as acoustic and satellite tracking to investigate the utilisation of habitat in elasmobranchs (Simpfendorfer & Milward 1993, Heupel & Hueter 2001, Eckert & Stewart 2001, Simpfendorfer et al 2002). This is because of technological advances in this equipment and because it has become cheaper and more readily available. However traditional methods such as analysis of catch data are still widely used to draw conclusions about habitat use. For example Simpfendorfer et al (2004) investigated bull shark (*C. leucas*) size partitioning and habitat utilisation in an estuarine system of southwest Florida using longline catch rates. In this study it was reported young of the year preferred the estuarine river whilst animals greater than 1 year old preferred the adjacent embayments.

In addition to catch data, tag and recapture data can be used to ascertain spatial movement and behavioural patterns of species at varying life cycle stages between and within similar habitat types. For example tag and recapture has demonstrated the migratory patterns of juvenile mangrove jack (*Lutjanus argentimaculatus*) from one freshwater system to another and then as an adult to a coastal inshore reef (Russell & McDougal 2005). This data is especially useful when identifying key areas zoned for protection where knowledge of a species movement patterns within a habitat can influence the design or purpose of the protected area such as its size.

Advances in telemetry equipment have provided scientists with many options which has allowed for studies in elsamobranchs that occupy a wide range of habitat types, from freshwater and coastal regions to pelagic and demersal habitats to water depths greater than 200m. For example Wilson et al (2005) reported the temporal and spatial movement patterns of whale shark (*Rhincodon typus*) in coastal water off Ningaloo Reef, Western Australia using satellite pop up archival tags. The results of horizontal and vertical movement patterns demonstrate that this species uses coastal and offshore

habitats to water depths of up to 950m. Results such as these were previously unattainable using conventional analysis of catch rates.

Even though technological advances have made it possible to undertake studies such as those of Wilson et al (2005) there are still very few quantitative studies investigating habitat use in elasmobranchs (Simpfendorfer & Heupel 2004). Of these studies a majority of them investigate juvenile elasmobranchs which inhabit inshore coastal habitats. For example Morrissey & Gruber (1993) discusses the habitat association between juvenile lemon sharks (*N. brevirostris*) and seagrass. These data are all important; however information on habitat utilisation of mature animals is of equal importance to management. These inshore habitat areas are normally discussed in relation to reference terms such as “nursery areas” or “pupping grounds”. A possible explanation to why these habitats and life cycle stages have been investigated more thoroughly than offshore habitats and mature animals is because of accessibility to samples. Larger mature sharks are normally found offshore in deeper water, thus, making habitat studies logistically more difficult and costly to undertake.

Laser ablation inductively-coupled plasma mass spectrometry (LA-ICPMS) is another technique which has been developed in more recent times and is an addition to fisheries science to investigate habitat utilisation in teleosts (Gemperline et al 2002). LA-ICPMS is an analysis tool designed to measure micro-element concentrations deposited in hard structures of the body during growth such as strontium (Sr^{88}), barium (Ba^{138}), calcium (Ca^{43}), magnesium (Mg^{26}) and manganese (Mn^{55}). LA-ICPMS is a common technique used in geological science, however it has been adapted to point sampling and has been adopted within fisheries science to analyse specific growth bands in otoliths (Milton et al 1997) and habitat use patterns in teleosts (Gillanders & Kingsford 1996, Swearer et al 1999, Lo-Yat et al 2005). Its application as a tool for investigating elasmobranch life history has never been trial before although in principle it should work because elasmobranch vertebrae are known to possess varying concentrations of micro elements such as calcium (Casey et al 1985, Davenport & Stevens 1988, Cailliet & Goldman 2004).

Laser ablation inductively-coupled plasma mass spectrometry has a number of advantages over conventional methodologies such as tag and recapture for investigating

species habitat utilisation. The success of tag and recapture methodology relies heavily on a large sample size (because of the different size classes) and on the return of a sufficient number of tags. Tag and release programs also rely on a large number of participates in order to obtain data. By doing this it increases the risk of error in the recording and transfer of data. These problems were encountered by Thorson(1982a) in the tag and recapture program for *P. perotetti* in Lake Nicaragua-Rio San Juan System. The limitations of tag and recapture as a technique for obtaining growth and movement data for GoC pristids in this study has been discussed in Chapter 3 with procedures put in place to minimise human error.

The use of LA-ICPMS in the analysis of trace elements in calcified structures or vertebrae can alleviate most of these problems (Gillanders & Kingsford, 1996). Essentially LA-ICPMS analysis provides the scientist with a historical diary of the habitat preferences of the animal over its life span. Laboratory experiments have established that some micro-element concentrations in the environment are mirrored in the calcium structures of fishes (Gillanders & Kingsford, 1996).

In otoliths LA-ICPMS analysis can distinguish between when a fish spends periods of time in freshwater or saltwater habitats. This is achieved through the identification of varying concentrations of Sr^{88}, Ba^{138} and Ca^{43} within the environment (Gemperline et al 2002, Bath et al 2000). The measure of Sr^{88} and Ca^{43} ratios within otoliths using LA-ICPMS can give a salinity history of a specimen over its entire lifecycle (Campana & Tzeng 2000). Typically the concentration of Sr^{88}in marine water is significantly higher than that for freshwater (Coutant & Chen, 1993, Gillanders & Kingsford, 1996). Thus habitat utilisation over the entire lifespan of the animal can be established. It is therefore possible that this technique could determine habitat use in *P. microdon* and other elasmobranch species such as the bull shark (*C. leucas*) that have a suspected life history ranging between freshwater and marine.

Swearer et al (1999) used this technique to successfully study the dispersal histories of larval reef fish and Gillanders & Kingsford, (1996) used it to investigate the early life history of blue groper (*Achoerodus viridis*). By establishing the relationship between larval growth rates and otolith chemistry it was possible for Swearer et al (1999) to demonstrate larval retention within near coastal waters or larval development within

open ocean waters. Gillanders & Kingsford, (1996) established the origin of *A. viridis* recruitment on rocky reefs. In both studies strontium occurred in significantly higher concentrations in otoliths originating from marine waters.

In this study it was assumed that the elementary cartilaginous skeleton of *P. microdon* and *P. zijsron* are a "closed system" with respect to Ca and other micro element deposition. Once incorporated into the cartilaginous tissue the trace element composition isn't lost due to resorption or remodelling (Sminkey & Musick, 1995). It is likely that the observed density differences in centrum band pattern are due to differences in mineralization during different growth phases (Cailliet et al 1983a). These differences in microelement concentration within the vertebra could therefore be identified in the laser ablation analysis and should give evidence to the life history of the animal.

To further understand the behaviour of eslambranchs and their association with certain habits it is important to investigate their diet or feeding biology as this can provide valuable information on seasonal and temporal trends in habitat utilisation. The diet of a predatory species such as pristids, provides a better understanding of the species natural history (Wetherbee & Cortes 2004). This knowledge is gained from information known on the habitat association of their prey items. Thus if you know the habitat preference of the prey items it is assumed this habitat is occupied at some stage by species that predate on them.

As with other areas of elasmobranch biology, investigations on dynamics of feeding and processing of food lag behind such studies on other marine fishes and vertebrates (Wetherbee & Cortes 2004). Elasmobranch dietary studies have been restricted because of sampling logistics and accessing adequate sample sizes. Sharks in particular also have a habit of regurgitating their stomach contents once captured (Simpfendorfer 1998). Because of these limitations common elasmobranch dietary studies simply describe stomach contents of a particular species in a particular location. Few studies investigate feeding patterns, rate of consumption and the fate of food once ingested (Wetherbee & Cortes 2004).

4.1.1 Sawfish habitat utilisation

There is an almost complete lack of data on habitat usage and movement patterns of sawfish both in Australia and worldwide. Thorson (1982a) is one of the only sources of published literature on sawfish life history. In this paper Thorson critically examines the connectivity between the coastal and lake sawfish populations of 377 *P. perotteti* tagged and released in Lake Nicaragua-Rio San Juan System. These animals were representative of mature and immature size classes. Of the Lake Nicaragua-Rio San Juan System sawfish population, Thorson (1982a) concluded that they were a discrete population getting all of their ecological needs from the lake. Only a few specimens left the lake system to migrate to inshore coastal habitat. Therefore it can be concluded that *P. perotetti* exhibits restricted site fidelity if environmental conditions suit.

In Australia information on pristid habitat utilization is limited to the work conducted by Thorburn et al (2002), Thorburn et al (2004) and Last (2002). Apart from these studies information was gained through direct observation and anecdotal reports from recreational, commercial and indigenous fishers. Although very little is known on *P. micordon* it appears, just like *P. perotetti* (Thorson 1982a) and the bull shark (*C. leucas*) (Thorson 1973, Snelson et al 1984, Simpfendorfer et al 2004) juveniles have a preference for freshwater and brackish habitats. Although not identified by Thorson (1982a) for *P. perotetti*, size partitioning was evident between young of the year and 1 year old *C leucas* in south west Florida. This might be the case for *P. microdon* where Tanaka (1990) reported the catch of immature individuals in freshwater rivers of northern Australia. Habitat partitioning may reduce intra-specific predation risk and increase survival of young animals (Simpfendorfer et al 2004).

Within the GoC, sawfish have been found to occupy a diverse range of habitats, namely marine, estuarine and freshwater (Last & Stevens 1994, Peverell 2005). *A. cuspidata* has been identified by Stobutzki et al (2001) and Peverell (2005) as being bentho-pelagic (bottom dwelling travelling the water column) whilst the other pristid species are classified as being demersal (Compagno & Last 1999). All species of pristids in the GoC were also found to inhabit hard and soft substrates ranging from silty mud to coarse sand (Peverell 2005). Therefore the habitat utilisation by pristids in the GoC appears to be reasonably flexible ranging over diverse habitats and substrate types.

In this chapter pristid movement patterns and habitat preferences will be discussed in relation to information gained from tag and recapture, acoustic tracking and laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS) analysis of vertebra.

The specific aims of this chapter were:

4. To investigate the life history of *P. microdon* in the GoC using laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS)
5. To investigate the movement patterns and habitat utilisation of GoC pristids
6. To document the diet preferences of GoC pristids

4.2 Methods

4.2.1 Laser ablation

The LA-ICPMS equipment recorded the elapsed time in seconds of each spot analysis in the sequence; hence, increasing time reflects the distance travelled across the radius of the vertebrae. The time record in seconds can then be converted to distance in mm, and by reference to the growth-band determined age of the individual, can then be converted into an approximate age.

Overlaying the ablation time-line/distance onto the von Bertalanfy growth curves, derived from counts of vertebrae banding (see Chapter 3, section 3.3.2) for each individual sawfish, was used to estimate the age and life-history stage at which the various changes in Sr^{88}:Ca^{43} ratio occurred. An example of the result of this procedure is presented in Figure 29. therefore habitat preferences at diddifent stages of the animals life history could be identified.

Pristis zijsron are known to inhabit inshore coastal waters (Last & Stevens 1994) and were not recorded in estuarine or freshwater habitats during this study. The microelements Sr^{88} and Ca^{43} are known signatures for distinguishing between freshwater and marine waters (Campana & Tzeng 2000). LA-ICPMS of excised vertebrae where undertaken using a Hewlitt Packard Agilent 7500 ICP-MS and

EXCIMER UV laser ablation system. The size range of *P. microdon* (n=14) used in this study ranged from 89cm T_L (embryo), 83cm T_L (neonate), 150cm T_L (juvenile) to 582cm T_L (mature specimen). The *P. zijsron* samples (n=3) covered the juvenile (219.5 and 254cm T_L) and mature life stages (449cm T_L) of the species (Table 10).

The ratio of Sr^{88}: Ca^{43} concentrations were plotted against ablation time (seconds). Thin sectioned vertebra was mounted on analytical slides (dimensions 27.5 x 54mm) using clear casting resin (as per the aging technique for thin sectioned vertebrae in chapter 3). LA-ICPMS samples were mounted in a perspex ablation chamber for analysis. A NST 6-12 glass reference was ablated and analysed to check the calibration of the ICPMS before each new sample was added to the perspex chamber. Once calibrated the cross hair of the laser was placed on the notochordal remnant (focus) and the ICPMS was then operated in a continuous scan mode until the vertebra margin was reached. The laser pulse was operated at 20 milliseconds per isotopic mass and analysed sequentially.

The ablation spot size was 40 microns and was viewed using high quality video optics in transmitted light. Ablation was conducted under a 90% helium and 10% hydrogen atmosphere with the material mixed with argon prior to introduction into the plasma. Prior to each analysis a blank "dry run" was run to ensure there was no change in the composition of the transport gas. Post analysis photographs of the spot locations were recorded on a digital camera attached to a petrographic microscope; the track of sequential spot samples from the vertebra focus to the distal margin.

To allow comparisons between the species, the mean calcium to strontium ratio was taken as a moving average over a 10 second period for each individual vertebra. As such, the mean readings where then determined at 10, 55, 105 seconds etc……) (Table 10). As the ratios for embryonic sawfish where consistent from conception to birth, the mean ratio was determined for that time period. The mean values for each of the above time periods were then converted to a percentage of the embryonic ratios. Thus, a rise in the ratio resulted in percentages above 100 while a decrease resulted in percentages below 100. These mean percentage values where then analysed by a two way analysis of variance using SPSS® version 15 to determine if time or species or an interaction of the two influenced the mean calcium to strontium ratio.

The mean value of the combined time periods (ie. the counts for 10 seconds every 50 seconds which gave a mean ratio of 3.36 ± 0.04 Sr^{88}: Ca^{43} ,(n=32) for each of the *P. zijsron* samples was assumed to be representative of an animal predominantley inhabiting the marine environment. This mean was used as the "standard" for comparisons between salinity environments for *P. microdon*; low salinity versus marine or higher salinity.

4.2.2 Tag and recapture

A community awareness program to educate the public in sawfish conservation and to invite people to relay information back to the project was used in this study. Seminars were given at commercial fishermen's meetings, and sawfish identification, tag and release workshops were held for commercial fishers in Karumba and Weipa. Indigenous rangers were included on independent sawfish surveys. Other communication strategies included the circulation of posters (CD 1 Appendix 2) throughout Cape York and articles in local papers, and ABC radio interviews. In collaboration with Bill Sawynok (INFOFISH Services Tagging Coordinator) a sawfish guide to tag and release was placed on the INFOFISH web page (www.infofish.com.au). This page has a wide target audience of keen recreational fishers.

Hallprint type SSD-WT steel tipped dart tags were used to tag pristids in this study and details on the tagging methodology can be found in methods section of Chapter 3 (see CD2 Appendix 3) of this study. All pristid species were tagged on an opportunistic basis. The spatial coverage of tagged *P. microdon* was mainly limited to the Mitchell River (67%). Stream flow data obtained from QLD Climate Service of the Bureau of Meteorology for the Mitchell River was plotted against the corresponding tagging years to determine whether there is a pattern of habitat utilisation by *P. microdon* during flooding periods within the river (see chapter 2 Figure 6).

Pristid tag return information was collated in a Microsft Access® database before being graphically presented in Mapinfo®. The Mapinfo® mapping function was used to measure the distance between the plotted point of tag and release and point of recapture of each animal. The mapping function in the geographic information system had been

correctly registered therefore was dimensionally correct and gave the most accurate distance calculations on longitude and latitude.

4.2.3 Acoustic tagging

Funding was sought from the National Oceans Office (NOO) to undertake a pilot study into the short term movement patterns of either *P. microdon* or *P. zijsron* in the GoC. The area identified for the study was Port Musgrave at Mapoon, a remote Aboriginal Community on the western side of Cape York Peninsula. Mapoon Aboriginal Community is situated on the southern side of Port Musgrave located approximately 80km north of Weipa, latitude 12° 00' S longitude 141° 53' E (Figure 26).

Port Musgrave was chosen as the site for this study because of the logistical support provided by Mapoon Indigenous Fishing Enterprises and the known abundance of sawfish inhabiting the waters. Commercial fisher contacts obtained through the FRDC Project 99/125 - Tropical Resource Assessment Program Phase II (observer program) provided the project staff with anecdotal historical records of sawfish abundance in the region, including Weipa.

Port Musgrave is a relatively shallow embayment made up of vast soft mud flats and rocky headlands with mangroves dominating the shoreline. The Wenlock and the Ducie Rivers drain into Port Musgrave before flowing into the GoC. Water salinity levels in Port Musgrave are heavily influenced by the freshwater flows of both these river systems during the monsoonal wet season. The area is part of the operational area of the GoC barramundi commercial net fishery. Mapoon Aboriginal community operates two commercial fishing licences in the area and also fish traditionally. Recreational line fishers also frequent the area during the dry season months from May through to October.

4.2.3.1 Acoustic tracking and depth recording equipment

The tracking equipment was a Sonotronics CHP-87S tag and Sonotronics acoustic receiver (model USR-91) and hydrophone mounted on the side of a 3.5m punt. This equipment was chosen because it has been used successfully to track *C. leucas* in

freshwater and estuarine waters of the Brisbane River (R. Pillans University of QLD PhD student pers com 2004). The signal transmitted from the acoustic tag can be detected from a distance of 600 to 1000 m. Salinity, water depth, substrate profile and underwater obstacles and surface chop can interfere with the strength of the signal. The position of the sawfish was established by using a directional hydrophone which was kept in the water with the acoustic signal monitored on a continuous basis.

A Lotek LTD_10 TDR (time depth recorder) was programmed to record depth and temperature every 10 seconds. The TDR was attached to the acoustic tag, which was then attached to the animal via a corroding tag. A galvanic time-release corroding swivel was designed to release the tag after approximately 38 hours. This was dependent on salinity levels and a time-release trial was performed under marine conditions prior to attaching the tag to check the systems reliability. This tag corroded after 41 hours. Salinity levels in Port Musgrave however were a lot lower (average 24ppt) than those used during the time trial. For this reason a 24 hour swivel was used in replace of the 38 hour galvanic time release corroding swivel.

A small high-density float was attached to the TDR and acoustic tag to aid in the recovery of the tag (Figure 2). Water depth (m) was recorded as the distance from the water surface to the origin of the first dorsal fin (Figure 27).

4.2.3.2 Tagging protocol

A sawfish (*P. zijsron*) was captured by gill net on the foreshore at Port Musgrave; latitude 11 57’ 192”, longitude 141 54’ 168”. It was originally planned that two sawfish were to be acoustically tracked over the week, however only one animal was caught during the study. The sawfish was removed from the net using a net hook and the procedures set out by Peverell (2005b), (see CD 2 Appendix 3). Following removal from the net a fin clip was taken for future genetic analysis and total length (T_L) and lower jaw total length (L_{JTL}) were recorded. The acoustic tag and time depth recorder were attached using a galvanic 24 hour seaswater release (Figure 27).

4.2.3.3 Tracking protocol

Following tagging the animal was released and the tag signal checked. Throughout the course of the tracking period, we tried to maintain our position so that the sawfish was between the shoreline and the vessel. The position of the tagged sawfish was recorded using a Garmin 12 portable global positioning system. Waypoints were recorded on an opportunistic basis (but never more than 20 minutes apart) when the animal demonstrated periods of movement. Waypoints (latitude and longitude) were taken as close as possible to the animal (as determined by the strength of the signal) and in all instances were within 50 m of the actual position. Distance of the observing dinghy from the sawfish had no apparent influence on the animal's behaviour. Salinity and water temperature was recorded hourly using a WTW LF340 salinity/conductivity meter. The sawfish was monitored on a continuous basis until the time-release swivel dissolved freeing the acoustic and time depth recorder tag. Water temperature (°C) and salinity (ppt) was recorded a meter below the surface at the beginning and end of the tracking study and at 6 hourly intervals.

4.2.3.4 Analysis and presentation of tracking data

Sawfish tracking waypoints were imported into MapInfo® Software where they were overlayed on a geographic vector layer of Mapoon and Port Musgrave. The direction of the acoustic track was presented in the form of a route created by joining each successive waypoint with a directional arrow.

Distance (Dist) was calculated by summing the distance (m) between successive waypoints. Average rate (Av Rate) of foraging movement was calculated as the distance divided by the duration of tracking; ie, total distance travelled divided by the total elapsed time. Maximum rate of movement (Max Rate) was the maximum rate of displacement calculated between any two successive waypoints. Rate of movement was recorded in metres per minute.

4.2.3.5 Activity budget

An activity time budget was calculated using MS Excel® and presented graphically as a line chart and histogram where the x-axis represented elapsed time standardised for each plot; ie tidal cycle, distance moved and rate of movement. The data used to

calculate and interpret the sawfish activity budget included diurnal tide (m), route - distance travelled (m) and activity data ($m.s^{-1}$). Home range (km^2) was calculated using a modified version of the convex polygon method (Troy & Coulson 1993) whereby, the foraging polygon was created by joining the waypoints on the outer most margins of the route and the area calculated using the mapping function in Mapinfo®.

4.2.3.6 Depth data

Data from the TDR tag was downloaded using TAGTALK software provided by Lotek. Pressure data was then converted into depth (m). The distance from the origin of the first dorsal fin to the TDR was subtracted from the depth recorded by the TDR to give depth at first dorsal fin origin (Figure 27). A Kolmogorov-Smirnov two-sample test was conducted using Genstat® to test for differences in the depth profile between day and night tracking hours ($P<0.05$).

4.2.4 Diet

Specimens used in the investigation of pristid diet were obtained from commercial fishers on an opportunistic basis with samples supplied by the commercial inshore and offshore set fishers and recorded in field notes of DPI&F fisheries observers. The stomach contents from *P. microdon* (n=42), *P. clavata* (n=17), *P. zijsron* (n=18) and *A. cuspidata* (n=86) were collected in this study. Diet was established on the presence or absence of prey items in the stomach. In some instances the stomach contents of live animals were flushed using the deck hose into a prawn basket, measured and identified. Prey items were identified to the lowest possible taxonomic level. Where identification could not be made in the field and it was feasible samples were frozen and transported back to the lab and FAO identification guides were used. Prey items that could not be identified due to their state of digestion were classified from otoliths and skeletal matter. The remaining gut contents were identified as unknown.

Results of pristid diet are given as preliminary descriptions only. A more comprehensive study statistically quantifying pristid diet will need to be undertaken in the future. Dietary data is expressed in terms of number of prey items per stomach separated by pristid size class. Total length (T_L) measurements were taken of prey items

where possible. Information contained in this study is limited because of the low sample numbers; however it provides important information on species ecology and trophic level status.

4.3 Results

4.3.1 Laser Ablation

As noted in the methods section, the state-of –the-art equipment used in this Laser-ablation study allowed a sequential series of spot analysis to be taken at closely spaced radial intervals across the surface of the thin vertebrae section. The result is a nearly continuous time-line of element ratios as the vertebrae developed and the growth bands were laid-down (see also Chapter 3 section 3.2.3).

For the purposes of this assessment, the very early growth of these sawfish was assumed to be linear and "age-in-days" proportional over the period between birth and the first-year growth band. This simplifying assumption allows an estimate of the age in days at which element ratios change, and allows a standardised comparison to be made between the two species being studied.

The mean and standard deviation of the Sr^{88}:Ca^{43} ratio measured for 10 second periods at each incremental 50 second interval (corresponding to approximately 182 days of development/growth of the sawfish) from the laser ablation of the vertebrae of 14 *P. microdon* and 3 *P.zijsron* are presented in Table 10.

There was a significant effect shown in the analysis of the LA-ICPMS of vertebrae of *P. microdon* and *P. zijsron* distance along the vertebrae (time) ($F=3.611$, $d.f = 1*20$, $p<0.001$). Both species showed similar Sr^{88}:Ca^{43} ratios when in gestation but when pupped, each species showed a significantly different ratios at ablation times 155 to 550 seconds) (Figure 28). Post Hoc analysis by least significant difference found that the mean ratios from 255 to 505 secs where significantly different from those when the animals where pupped for *P. microdon* and for *P. zijsron*. This period corresponds with juvenile growth in both species (Figure 29).

The Sr^{88}:Ca^{43} ratio in *P. zijsron* increased consistently once the animals where pupped and reached a plateau at approximately 400 secs. In contrast the Sr^{88}:Ca^{43} ratio in *P. microdon* dropped significantly once the animals where pupped at a minimum ablation time of approximately 450 secs. After that time, the ratios consistently increased to mimic that seen in *P. zijsron* (Figure 28). The 95% confidence intervals for the mean Sr^{88}:Ca^{43} ratios for each species are non-overlapping indicating that statistically these are significantly different.

Table 10: LA-ICPMS analysis of mean Sr^{88}:Ca^{43} ratios taken over 10 second moving average for a 50 second period (n=85) in the vertebrae of *Pristis microdon* (n=14) and *Pristis zijsron* (n=3). Ablation time (seconds) is indicative of the animal's entire life history as the ablation is taken from the vertebra focus to the distal marging of the vertebra. For *P. microdon* the time period (ablated seconds) across the ventral surface of the sectioned veterbrae is representative of approximately 10 to 155 seconds, whilst sawfish growth up to 5 years of age is representative of approximately 155 to 605 seconds. *Pristis microdon* measuring 585cm T_L and estimated to be 28 years old is represented by an ablation time of 1655 seconds. Note E=embryo.

			LA_ICPMS time series (ablation seconds) of Mean Sr^{88}:Ca^{43} ratois															
Species	**T_L (cm)**	**Age**	**10**	**55**	**105**	**155**	**205**	**255**	**305**	**355**	**405**	**455**	**505**	**555**	**605**	**655**	**705**	**755**	**805**
P. microdon	83	0	2.47 (.076)	2.51 (.107)	2.66 (.085)	2.78 (.140)													
P. microdon	90	E	2.13 (.102)	2.12 (.097)	2.36 (.085)	2.54 (.118)													
P. microdon	101	0	2.72 (.231)	2.75 (.215)	2.77 (.237)	2.97 (.187)													
P. microdon	89	E	2.01 (.124)	2.04 (.137)	2.18 (.130)	2.34 (.112)	2.43 (.119)												
P. microdon	124	1	2.04 (.302)	1.91 (.308)	2.04 (.320)	2.21 (.351)	2.43 (.411)	2.31 (.428)	2.47 (.133)										
P. microdon	161	2	2.42 (.172)	2.57 (.186)	2.66 (.167)	2.73 (.139)	2.48 (.137)	2.43 (.134)	2.92 (.182)	2.5 (.155)									
P. microdon	149	2	2.50 (.102)	2.70 (.186)	2.75 (.173)	2.76 (.200)	2.71 (.210)	2.84 (.177)	2.99 (.185)	3.06 (.178)									
P. microdon	194	3	2.16 (.129)	2.22 (.107)	2.37 (.190)	2.22 (.159)	1.84 (.145)	1.86 (.144)	1.82 (.128)	1.83 (.112)	1.89 (.135)								
P. microdon	233	5	2.47 (.247)	2.50 (.253)	2.46 (.210)	2.42 (.161)	1.831 (.188)	1.83 (.116)	1.91 (.119)	1.87 (.125)	1.94 (.105)	2.02 (.109)	2.06 (.131)						
P. microdon	239	4	2.11 (.111)	2.23 (.178)	2.42 (.189)	2.45 (.135)	2.06 (.095)	1.84 (.107)	1.88 (.077)	1.93 (.096)	1.89 (.077)	2.01 (.089)	1.95 (.087)	2.10 (.176)					
P. microdon	276	5	2.31 (.102)	2.52 (.176)	2.53 (.216)	2.53 (.146)	2.12 (.134)	2.20 (.171)	2.14 (.165)	2.10 (.137)	2.17 (.109)	2.14 (.114)	2.03 (.128)	2.07 (.159)	2.87 (.174)				
P. microdon	229	4	1.90 (.082)	2.04 (.190)	2.06 (.182)	2.08 (.170)	1.67 (.140)	1.51 (.079)	1.39 (.089)	1.43 (.082)	1.39 (.105)	1.39 (.082)	1.52 (.077)	1.53 (.102)	1.77 (.140)				
P. microdon	230	4	2.4 (.109)	2.44 (.217)	2.50 (.254)	2.57 (.195)	2.07 (.144)	1.70 (.109)	1.88 (.133)	2.02 (.117)	1.95 (.118)	2.34 (.210)	3.05 (.282)	3.57 (.224)	2.73 (.119)				
P. microdon	585	28	2.77 (.119)	2.91 (.124)	2.88 (.137)	2.88 (.174)	2.35 (.173)	2.57 (.127)	2.56 (.135)	2.57 (.142)	2.54 (.163)	2.57 (.121)	2.59 (.137)	2.44 (.118)	2.68 (.144)	2.81 (.132)	3.06 (.134)	3.09 (.118)	3.16 (.147)
mean P. microdon			**2.31 (.265)**	**2.39 (.301)**	**2.47 (.260)**	**2.53 (.266)**	**2.18 (.324)**	**2.11 (.425)**	**2.20 (.520)**	**2.14 (.486)**	**1.97 (.345)**	**2.08 (.397)**	**2.23 (.538)**	**2.34 (.759)**	**2.51 (.504)**	**2.81**	**3.06**	**3.09**	**3.16**
P. zijsron	220	3	2.85 (.198)	2.85 (.214)	2.96 (.178)	2.81 (.283)	3.4 (.183)	3.37 (.142)	3.57 (.182)	3.80 (.200)	3.40 (.166)	3.77 (.232)							
P. zijsron	254	5	2.61 (.141)	2.73 (.214)	2.61 (.178)	3.18 (.283)	3.33 (.183)	2.81 (.142)	3.04 (.182)	3.30 (.200)	3.54 (.167)	3.24 (.232)	3.34 (.258)						
P. zijsron	450	16	2.94 (.172)	3.01 (.147)	3.14 (.362)	2.97 (.316)	3.58 (.255)	3.25 (.212)	3.50 (.309)	3.57 (.208)	3.49 (.273)	3.39 (.202)	3.20 (.247)	3.36 (.214)	3.24 (.272)	3.11 (.225)	3.42 (.278)	3.30 (.166)	3.58 (.151)
mean P. zijsron			**2.80 (.171)**	**2.86 (.143)**	**2.91 (.270)**	**2.30 (.186)**	**3.44 (.129)**	**3.14 (.292)**	**3.37 (.290)**	**3.56 (.254)**	**3.48 (.069)**	**3.46 (.273)**	**3.27 (.103)**	**3.36**	**3.24**	**3.11**	**3.42**	**3.30**	**3.58**
			LA_ICPMS time series (ablation seconds) of Mean Sr^{88}:Ca^{43} ratois															
Species	**T_L (cm)**	**Age**	**855**	**905**	**955**	**1005**	**1055**	**1105**	**1155**	**1205**	**1255**	**1305**	**1355**	**1405**	**1455**	**1505**	**1555**	**1605**	**1655**
P. microdon	585	28	3.55 (.194)	3.44 (.136)	3.77 (.169)	3.76 (.139)	3.86 (.138)	3.79 (.126)	3.86 (.125)	3.79 (.138)	3.73 (.111)	3.73 (.132)	3.88 (.123)	3.8 (.130)	3.85 (.136)	3.75 (.150)	3.7 (.128)	3.75 (.64)	3.64 (.132)
mean P. microdon			**3.55**	**3.44**	**3.77**	**3.76**	**3.86**	**3.79**	**3.86**	**3.79**	**3.73**	**3.73**	**3.88**	**3.80**	**3.85**	**3.75**	**3.70**	**3.75**	**3.64**
P. zijsron	220	3																	
P. zijsron	254	5																	
P. zijsron	450	16	3.69 (.180)	3.47 (.191)	3.45 (.189)														
mean P. zijsron			**3.69**	**3.47**	**3.45**														

4.3.2 Tag and recapture

The number of tagged and released pristids in this study was small, thus the results of this study only provide preliminary data on the movement and habitat utilisation of these species. A total of 67 *P. microdon*, 4 *P. clavata*, 3 *P. zijsron* and 58 *A. cuspidata* were tagged in the GoC set net fishery (Chapter 3 Table 8). *Pristis microdon* was the only species to be tagged and released by commercial inshore set net fishers exclusively at the beginning of the fishing season which corresponds with the wet season months The other pristid species were tagged periodically throughout the fishing season in both summer and winter months.

The results of two juvenile *P. microdon* tagged and recaptured in the Mitchell River demonstrate a pattern of upstream and down stream migration at different times of the year. Upstream movement of approximately 83km was recorded for tag number B11358 of 191cm T_L which had migrated from an estuarine habitat environment in May to a freshwater environment in April of the following year (0.45km per day^{-1}), (Figure 30). Downstream movement of approximately 100km was recorded for tag number B11182 of 153cm T_L which had migrated from a freshwater habitat environment in July to an estuarine habitat environment in February (0.45km per day^{-1}), (Figure 31). These sawfish had been at liberty for 187 and 224 days respectively.

Apart from seasonal migration upstream and downstream of rivers, *P. microdon* also exhibited inter-river migration from one estuarine habitat environment to another with an inshore coastal habitat component in between. This movement pattern was identified for tag number FR1075 of 247cm T_L. This animal was tagged and released in the upper estuarine section of the Bynoe River in May and had travelled approximately 220 km in 100 days to be recaptured in September in the upper estuarine section of the Leichhardt River (2.2km per day^{-1}), (Figure 32). This movement included a coastal movement of approximately 140km.

In contradiction to the *P. microdon* movement patterns exhibited above, observations of tag numbers B11180 (size unknown) from the Mitchell River (GoC) and FR1290 of 231cm T_L from the Normanby River (QLD east coast) exhibited a more restricted

pattern of movement. Tag number B11180 was recaptured approximately 1km from its tag release site in the lower estuarine section of the Mitchell River after being at liberty for 410days. Similarly, except tagged and released in a freshwater environment, is tag number FR1290 which was recaptured in exactly the same location after being at liberty for 232 days. The accuracy of tag FR1290 data is assured as the author tagged and recaptured this animal during routine netting surveys in the area. Both tagged animals had experienced a wet season during their time at liberty.

Tag and recapture data for *P. clavata* is limited to one juvenile animal released in May. Tag number B11191 of 91cm T_L was tagged and released and subsequently recaptured in an inshore coastal environment consisting of a soft fine mud substrate. It is possible that this animal may have a restricted pattern of movement having only moved 23km in 121days (0.19km per day^{-1}), (Figure 33).

The tag and recapture data for *A. cuspidata* demonstrates both an inshore (0 to 7nm) and offshore (7 to 25nm) pattern of habitat utilisation. The three *A. cuspidata* tag recaptures were 264cm, 258cm and 191cm T_L respectively. An *A. cuspidata* which was tagged and recaptured in the inshore set net fishery (tag number FR1210) was released in March and was at liberty for 21 days and had travelled approximately 61km (2.9km per day^{-1}) in a north easterly direction along the coastline (Figure 34).

Two *A. cuspidata,* tagged and recaptured in the offshore set net fishery, demonstrated a possible pattern of restricted site fidelity and movement (Figure 35). Tag number B11295 of 264cm T_L was released and recaptured by the same offshore gillnet fisherman in the same approximate area 575 days later. This animal was tagged towards the end of the dry season (August) and recaptured in the later part of the wet season (March). A pattern of movement between the inshore and offshore fishery was observed for tag number FR1255 of 258cm T_L. This specimen was tagged in February and had travelled approximately 11km in an easterly direction into the inshore fishery in 58 days (0.19km per day^{-1}).

4.3.3 Acoustic tracking

A female *P. zijsron* (355mm T_L) was captured in a 165.5mm monofilment gillnet in approximately 1.5 m of water and over a firm sandy substrate. The animal was tagged with an acoustic and time depth recorder tag (Figure 27) and released on the southern foreshore of Port Musgrave at 14:43 on the 1/5/04 and tracked continuously for a 27 hour period at which time the galvanic dissolving swivel broke and released the tag.

Following release the sawfish travelled in a north easterly direction along the sandy foreshore before rounding the sand spit on the southern bank of the entrance to Port Musgrave. Once in the embayment the animal travelled in a southerly direction parallel to and close to the shoreline in shallow water (Figure 36). In Port Musgrave the average water temperature was 31°C and salinity 24 ppt.

4.3.3.1 Depth

The sawfish remained in very shallow water (mean water depth = 0.69 m) (Figure 37. The maximum depth of the sawfish was 1.84 m while the minimum depth was 0.4 m. The minimum water depth recorded was limited by the length of line attaching the tag to the dorsal fin with a depth of 0.4 m being the depth at which the tag was on the surface (Figure 37). There was a significant difference between sawfish depth during day and night (Komogrov Smirnoff, p=0.011), with the sawfish in deeper water (mean = 0.84 m) during the day compared to night (mean = 0.48 m).

4.3.3.2 Activity budget

The direction and position of the foraging pathway are presented in Figure 38. In total the sawfish travelled 28 714 m with an overall speed of 18.6 m/min. The average speed was 28.4 (± 4.8) $m.min^{-1}$. The minimum and maximum speed recorded between 2 waypoints was 0.15 and 289 $m.min^{-1}$, respectively. The home range calculated over the 27 hours of continuous tracking was 14.4km^2 (Figure 38).

The tagged sawfish demonstrated rapid movement on two occasions, and both were in the early morning corresponding with the ebbing tide. During these two events the sawfish travelled a distance of 1921 and 868 metres respectively (Figure 39). This rapid

movement took place along the channel edge at low tide just after sunrise as represented by the blue arrows in Figure 36.

4.3.3.3 Observations

Sightings of the tag breaking the surface were made on six separate occasions totalling approximately 3.5 hours. During this time the water depth was less than 0.5 m. The sawfish was observed on five separate occasions and its behaviour was interpreted to be that of feeding with the rostrum breaching the surface in a thrashing movement. This behaviour was usually associated with baitfish breaking the surface followed by a sudden burst of movement creating large swirls and water displacement.

4.3.4 Diet

Empty stomachs dominated the total number of stomachs assessed for *P. microdon* (73%), *P. clavata* (59%), *P. zijsron* (65%) and *A. cuspidata* (56%). The diet of *P. microdon* and *P. clavata* consisted of both teleosts and Crustacea, whilst that for *P. zijsron* only consisted of teleost. *Pristis microdon* stomach contents were varied (see Figure 41) and included *Macrobrachium* spp. and *Penaeus* spp. (tiger prawn). *Penaeus merguiensis* (banana prawn) and inshore teleost species were found in the stomach of *P. clavata* (Table 11).

The greatest number of prey items was recorded for *P. microdon* and these included 2 species of Crustacea and 5 species of teleost, representing freshwater (Figure 40), estuarine and marine species (Table 11 and Figure 41). *Nibea squamosa* was represented in the diets of the three *Pristis* species but not in *A. cuspidata*. Of the prey items found in the stomachs of *A. cuspidata*, 99% were teleost with the remaining 1% being squid (*Photololoigo chinensis*). The teleost species composition of *A. cuspidata* stomachs was dominated by unidentifiable fish (84%) whilst the remaining contents consisted of those species commonly found in prawn trawl bycatch such as *Mullidae* spp., *Synodontidae* spp., and *Platycephalus* spp. (Figure 42).

Table 11: Inventory of prey items found in the stomach contents of Pristids from the Queensland Gulf of Carpentaria.

Species	T_L (cm)	Prey items									comments
	average (range) [n]	item 1	average # (max - min)	T_L (cm)	item 2	average # (max - min)	T_L (cm)	item 3	average # (max - min)	T_L (cm)	
Pristis microdon	184 (600 - 83) [30]	nothing									
	93 [1]	*Macrobrachium* spp.	1		Teleost	2					
	85	*Penaeus* spp. (tiger prawn)	1								
	336 (600 - 247) [3]	Teleost									
	241 [1]	*Ariidae* spp.	2	25							
	128 [1]	*Tandanus tandanus*	1	33							
	165 [1]	*Macrobrachium* spp.	3								
	180 [1]	*Macrobrachium* spp.	1								
	149 [1]	*Nibea squamosa*	1								
	253 [1]	*Nibea squamosa*	1	35							
	277 [1]	*Nibea squamosa*	1		*Polydactylus macrochir*	1		*Rhinomugil nasutus*	5		rostrum missing
Pristis clavata	153 (244 - 80) [11]	nothing									
	102 [1]	*Penaeus merguiensis*	1		*Leptobrama muelleri*	1	24				
	104 [1]	*Penaeus merguiensis*	2		*Mugilidae* spp.	1					
	107 [1]	*Clupeidae* spp.	2								
	101 [1]	*Nibea squamosa*	1								
	163 (220 - 106) [2]	*Mugilidae* spp.	1		*Penaeus* spp. (tiger prawn)						
Pristis zijsron	199 (449 - 93) [12]	nothing									
	482 [1]	*Eleutheronema tetradactylum*	1								
	103 [1]	*Engraulidae* spp.	1	12	*Ambassidae spp.*	1		*Nibea squamosa*	2	12.5	
	92 [1]	*Pomadasys kaakan*	1	19							
	82 [1]	*Nibea squamosa*	1	12.8	Teleost	2					
	166 [1]	*Nibea squamosa*	1	25							
	102 [1]	*Nibea squamosa*	1	9							
Anoxypristis cuspidata	130 (268 - 85) [14]	nothing									
(inshore)	88 [2]	Teleost	1								
Anoxypristis cuspidata	261 (329 - 163) [30]	nothing									
(offshore)	289 (329 - 230) [33]	Teleost	3 (1 - 8)								
	246 [1]	*Synodontidae* spp.	6								
	202[1]	Teleost	1		*Platycephalidae* spp.	1					
	282 [1]	*Chirocentrus dorab*	1		*Carangidae* spp.	4					
	(293 - 217) [2]	*Mullidae* spp.	3								
	306 [1]	*Mullidae* spp.	1		Teleost	2					
	305 [1]	Teleost	3		*Photololigi* spp.	1					

4.4 Discussion

The purpose of this chapter was to document habitat use and movement patterns in sawfish observed or captured in the GoC during this study. Although data limited, this study compliments previous studies into habitat use of *P. microdon* (Thorburn et al 2002, Thorburn et al 2004), but remains the first to investigate the other three species of pristids.

There have been relatively few studies of habitat use in the shark, skate and ray groups (Simpfendorfer & Heupel, 2004) and sawfish are no exception. As previously reported in Chapters 1 and 2 pristids have a circumglobal distribution in warm-temperate to tropical shallow, inshore continental waters, often in muddy enclosed bays, in estuaries, off river mouths, and off large continental islands, and in freshwater rivers and lakes (Compagno & Last, 1999). In a broad context this was found to be true for all pristid species in the GoC as insufficient data precluded more definitive analysis of micro habitat use in three of the four species. In this study it was demonstrated that in *P. microdon* inhabit habitats of variable salinity, including freshwater, estuarine and marine.

Laser ablation inductively couple plasma mass spectrometry suggested that at different life stages *P. microdon* occupy habitats of varying salinities (Figure 28Figure 29). This finding is not suprising as only juvenile specimens have been recorded in freshwater and it has been established that elasmobranch vertebrae are a "closed system" with respect to micro element deposition Sminkey & Musick (1995). Once incorporated into the cartilaginous tissue the trace element composition isn't lost due to resorption or remodelling. Thus changes in the micro-element ratio of Sr^{88}:Ca^{43} would be a record of the animal's ambient environment.

The Sr^{88}:Ca^{43} ratio between *P. microdon* and *P. zijsron* were significantly different for the period of juvenile growth (150 to 450 seconds ablation time), (Figure 28). Strontium ^{88} and Ca^{43} ratio was significantly higher in juvenile growth for *P. zijsron* than those of *P. microdon* for the same growth period. This suggests that during this phase in their lifecycle each species occupies a different habitat, of high and low salinity, respectively. It is likely that the juvenile life cycle of *P. zijsron* is spent in a

coastal more saline environment whilst *P. microdon* has a preference for a less saline environment, most likely freshwater habitats in rivers. This conclusion is supported by tagging information and survey/commercial catch data.

The habitat utilisation by juvenile *P. microdon* of less saline water appears to change as the animal gets larger. It appears from the LA_ICPMS data from 7 sub-adult individucals that there is a period of time when the sawfish is in an environment of fluctuating salinity (Figure 28). This period could be an estuarine phase to the sub adult sized animals of approximately 250cm T_L (3 to 4 years). At this size *P. microdon* would not be as vulnerable to predation compared to animals of smaller size classes. Thus the risk of leaving freshwater is not as great. This size class partitioning behaviour has been observed in *C. leucas* in a study off western Florida where larger sized juvenile animals were found more predominantly outside the estuarine zone and in coastal bays (Simpfendorfer et al 2004). Simpfendorfer (2004) also reported a similar habitat partitioning in *P. pectinata* with younger animals preferring the shelter of mangroves and shallow bays.

Analysis of Sr^{88}:Ca^{43} ratio in a single mature *P. microdon* also revealed a higher ratio with less fluctuations than that observed for both the mature and immature phases of growth for *P. zijsron* (Figure 28). As previously reported *P. zijsron* are known to inhabit inshore coastal waters during mature phases of their life cycle (Last & Stevens 1994). This suggests that the single *P. microdon* specimen in this study was in a more stable environment of higher salinities than the *P. zijsron* specimens. This environment is most likely found offshore and to be fully marine. More samples will be required to validate this conclusion.

Thorburn et al (2004) also hypothesised, from the capture of two mature specimens, that mature *P. microdon* disperse from the King Sound river systems into a coastal marine environment only to return to these river systems to breed and pup. Thorson (1982a) suggested the same life history pattern for *P. perotetti* and *P. pectinata* in the coastal waters of Central America.

Of the four GoC sawfish species studied as part of the tag and release program *P. microdon* was the only species to cross between fresh, estuarine and marine habitats.

These findings concur with the euryhaline classification of this species by Compagno & Cook (1995a) and those of Thorburn et al (2003 & 2004). In the current study a sub adult *P. microdon* migrated over 220km in 100 day, which indicates that this species does undertake substantial migratory movement utilising at different times freshwater, estuarine and marine habitats as indicated in the LA-ICPMS data.

Apart form moving long distances between rivers in what appears to be the sub adult phase of their life cycle, *P. microdon* have also been reported as spending considerable time in freshwater as juveniles (Tanaka 1990, Thorburn et al 2004). Seasonal upstream and downstream movement was observed in two tagged *P. microdon*. The specimen tagged in the wet season had moved upstream during the dry season and a specimen tagged in the dry season had moved downstream during the wet season. In both cases the animals had travelled distances of up to 100km. This pattern of movement in *P. microdon* might be in response to a predator prey relationship where these animals are following prey items such as freshwater catfish (*T. tandanus*), boney bream (*N. eribi*) and freshwater prawn (*M. rosenbergii*) downstream during their annual spawning migration.

The *P. microdon* tag and release information and the LA-ICPMS analysis indicate that this species has a very specific juvenile habitat requirement, one which could be considered a nursery ground. Thorburn et al (2004) suggest that the rivers which flow into King Sound, Western Australia may also act as nursery areas for *P. microdon* populations in that region. The balance of evidence from the current study of *P. microdon* would support this concept of freshwater rivers being the juvenile habitat and the estuarine/coastal and finally marine habitats as being adult habitat for this species.

Investigations into the diet of mature, sub adult and juvenile *P. microdon* adds credibility to the theory that this species does not complete its full life cycle in freshwater. The results of the stomach contents analysis demonstrate that this species has a preference for both marine and freshwater prey at different stages of their life history (Table 11). Juvenile *P. microdon* predominantly preys on the freshwater species whilst sub adult specimens prey predominantley on marine to estuarine teleost fishes. This finding supports the results from the microchemistry and the tagging

studies inferring that *P. microdon* are euryhaline and spend only part of their life history in freshwater. Again this is consistent with the observations of Thorburn et al (2003 and 2004), and Compagno & Cook (1995a).

The single tag return and gut contents analysis of *P clavata* supports both the distribution information documented in this study (see chapter 2 section 2.3.2) and the findings of Thorburn et al (2004) that *P. clavata* occupies prediminanelty a marine environment. The single tag return was in the inshore coastal marine habitat and the diet components found in the stomachs of *P. clavata* were of estuarine and marine origin. Hence there was no evidence to suggest that *P. clavata* in the GoC inhabit a freshwater environment. Although not recorded in the offshore set net fishery in the current study, *P. clavata* has been recorded as part of the bycatch in the NPF Fishery (Stobutzki et al 2002). The fact this species was not recorded in the offshore set net fishery is probably a factor of poor reporting and the rarity of the species.

Although no tag and recapture information is available for *P. zijsron* there is evidence through LA-ICPMS (as previously discussed), acoustic tracking and diet investigations to suggest that this species like *P. clavata* utilises shallow coastal habitat environments. The diet of *P. zijsron* consisted of prey items regularly caught in the inshore commercial set net fishery, namely jewel fish (*N. squamosa*), grunter (*P. kaakan*) and blue salmon (*E. tetradactylum*) (Gribble 2004a &b, Table 11). Feeding was observed on several occasions during the acoustic tracking period and random omnidirectional movement of the specimen was therefore interpreted as foraging in search of schools of baitfish located in shallow water. *Eleutheronem tetradactylum* were among the species in the stomachs of immature *P. zijsron* caught in Albatross Bay (L. Jnr. Squire Director CMA pers com 2004) an area of similar habitat to the area where the acoustic tracking study took place. Other *P. zijsron* coastal prey items identified in this study apart from *E. tetradactylum* include *Engrauliae spp*.and *Ambassidae spp*.

It appears the acoustically tracked specimen displayed no inhibitions in moving into shallow water despite its larger size. The sawfish did not travel long distances nor occupy an extended home range as has been documented for other large tropical

elsamobranchs (Holland et al 1999), neither did the specimen exhibit any preference for freshwater.

These results are very similar to those reported by Simpfendorfer (2004) for *P. pectinata*. In that study Simpfendorfer (2004) acoustically tracked five juvenile *P. pectinata* off the coast of Florida United States of America. In all cases each animal demonstrated a preference for shallow coastal habitat and possessed a high level of site fidelity. Simpfendorfer (2004) interpreted the use of shallow water habitat by juvenile *P. pectinata* as a behavioural trait designed to avoid predation. The preferred habitat utilised by juvenile *P. pectinata* (possibly on a continuous basis over a period of weeks) included shallow seagrass meadows, mangroves roots and man made structures in marinas. Although development in the GoC is minimal, natural habitat such as seagrass meadows and mangroves are relatively large (Danaher 1995, Roelofs et al 2005). A parallel can be drawn with the behaviour of *P. zijsron* and elements of the *P. pectinatta* study.

Anoxypristis cuspidata was the most widely distributed and abundant sawfish species recorded in the GoC (see chapter 2 section 2.3.2). The species utilises both inshore and offshore coastal waters as the tagging information and commercial catch records indicate.

Very little is known of the diet of *A. cuspidata* although it is thought the species primarily preys on cuttlefish and small fish (Compagno & Last 1999). In this study the diet of *A. cuspidata* consisted of marine teleost species with no freshwater species identified. Of the species which could be identified a number of species were those typically found in prawn trawl discards namely *Mullidae* spp., *Synodontidae* spp., *Platycephalus* spp., and *Photololoigo chinensis* (Stobutzki et al 2002). This diet suggests that this species maybe benthopelagic because both flathead (*Platycephalus* spp) (benthic species) and squid (*P. chinensis*) (mid water species) were present in the stomach. This suggests that *A. cuspidata* is perhaps non selective in its preference for prey items and may exhibits opportunistic feeding behaviour.

This chapter has provided detail on the habitat utilisation of GoC pristids. Although data limited it will provide resource managers with a better understanding of the habitat requirements needed to support GoC pristid populations. If protected area management is going to be considered as a possible management tool for mitigating the incidental capture of pristids in the area of operation of the inshore and offshore net fisheries, more studies are required to determine site fidelity within the micro habitats of this area. From this study it appears that pristids of all size classes utilise shallow coastal and in the case of juvenile *P. microdon* freshwater habitats.

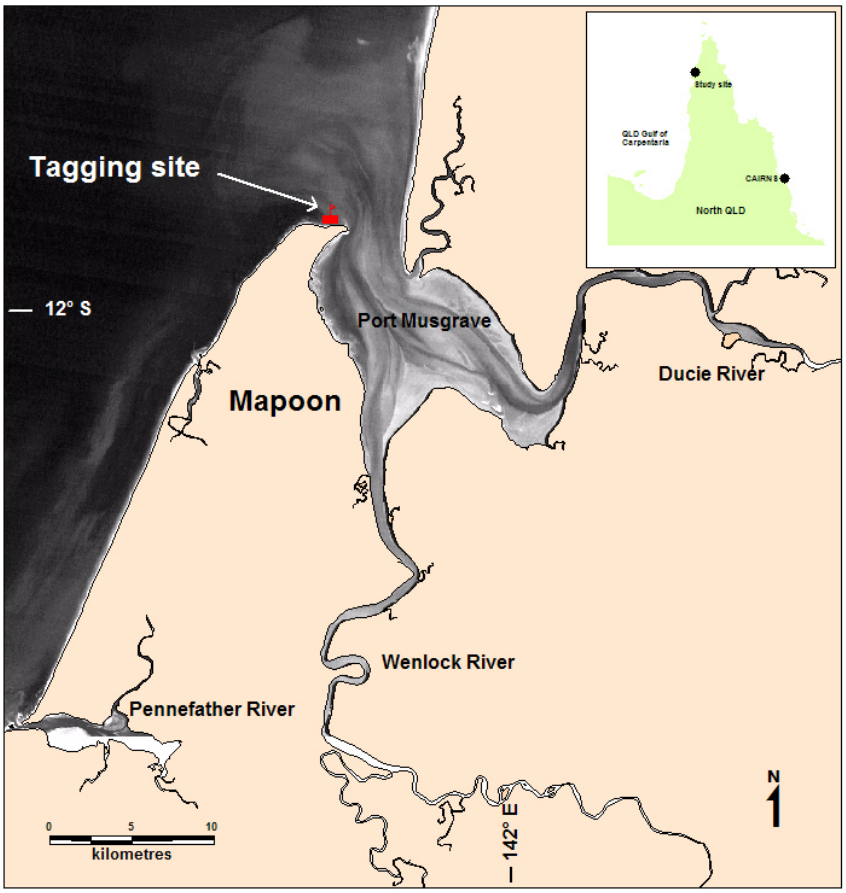

Figure 26: Sawfish acoustic tracking site location map for the Mapoon region north western Cape York Peninsula, Queensland. The water layer is presented as an aerial photograph with the darker patches indicative of deeper water.

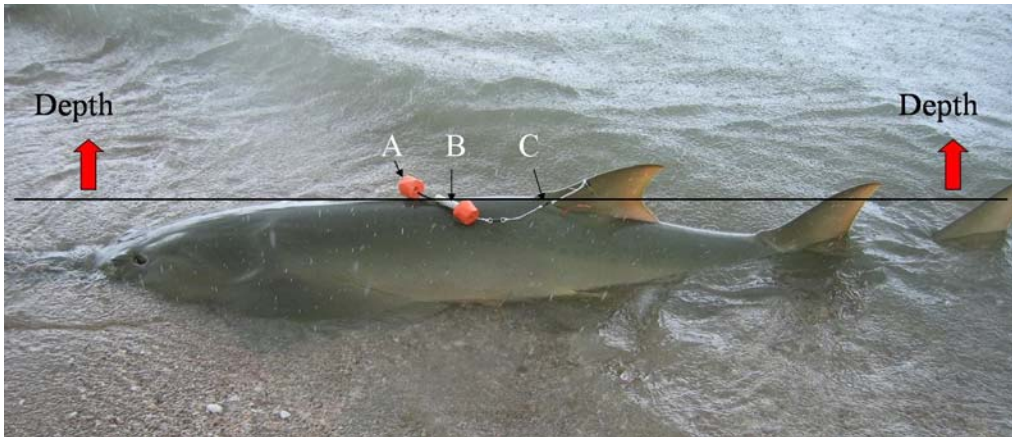

Figure 27: Position and size of acoustic tag and floats. A = LTD_10, B = acoustic tag, and C = galvanic time release. Horizontal line and arrows indicate where water depth was measured.

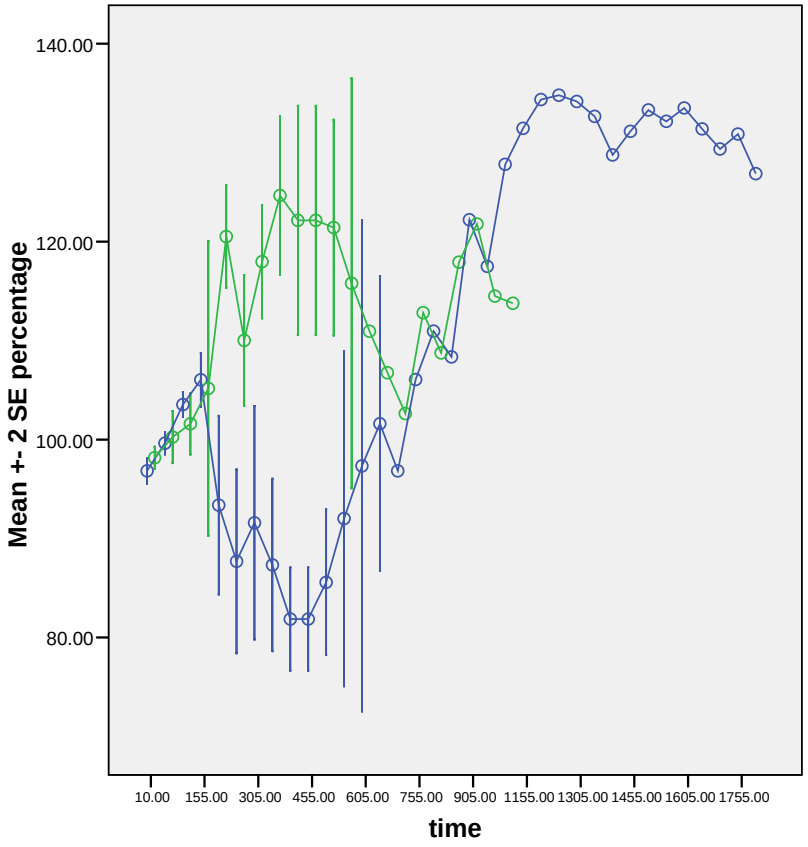

Figure 28: LA-ICPMS analysis of mean Sr^{88}:Ca^{43} ratios (0.05 confidence intervals) taken over a 10 second period in the vertebrae of *Pristis microdon* (n=14) and *Pristis zijsron* (n=3). The ablation time period 0 to 205 seconds represents embryoic development, 205 to 655 seconds represents juvenile growth (76 to 300cm T_L) and 655 to 1755 seconds is indicative of adulthood(>300cm).

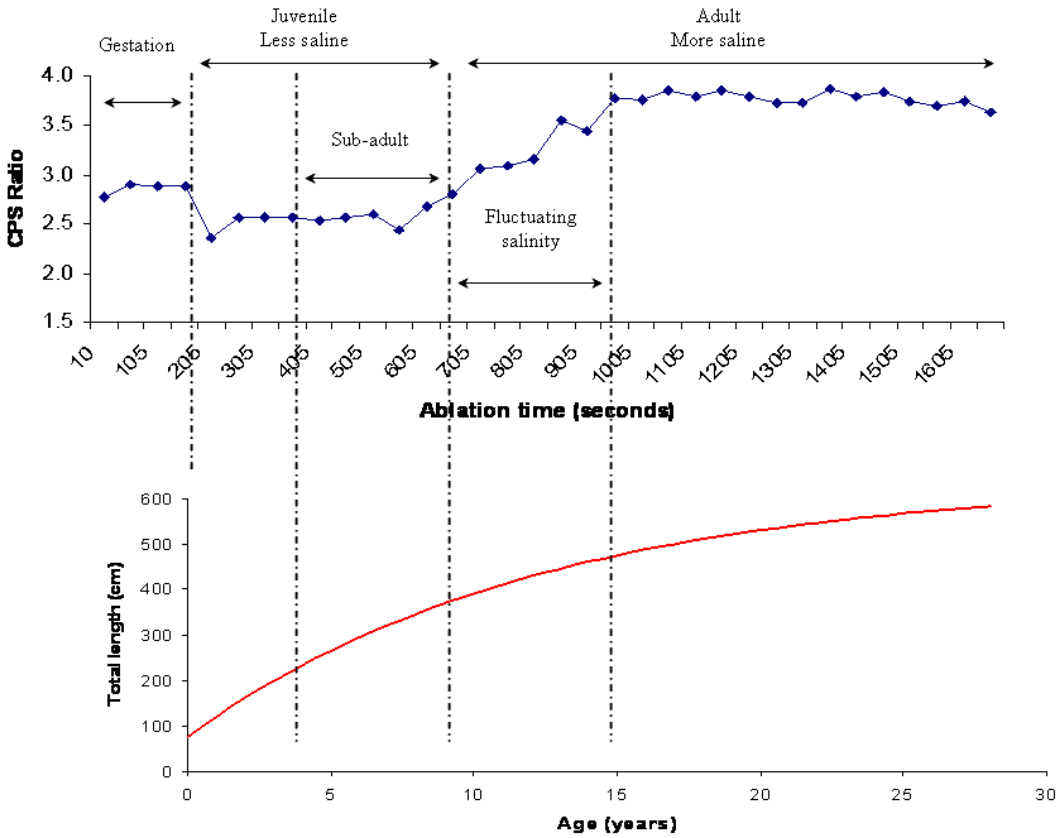

Figure 29: Diagram of overlay of a LA-ICPMS analysis of mean Sr^{88}:Ca^{43} ratios taken over a 50 second period in the vertebrae of a 585cm T_L *Pristis microdon* and the species von Bertalanffy growth curve. It appears *P. microdon* exhibits a preference change in environment at different stages of juvenile and adult growth

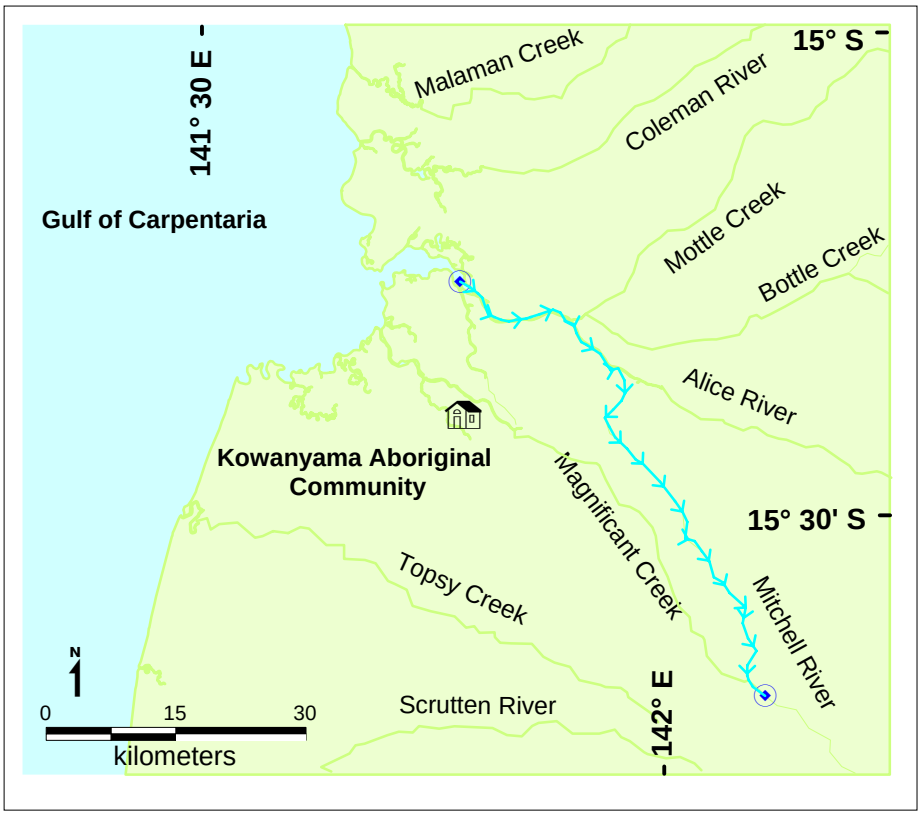

Figure 30: Estuarine to upstream freshwater movement of *Pristis microdon* tag number B11358. The animal was at liberty for 187 days and moved upstream 83km. The blue arrow track indicates where the sawfish was tagged, direction of movement and recapture site.

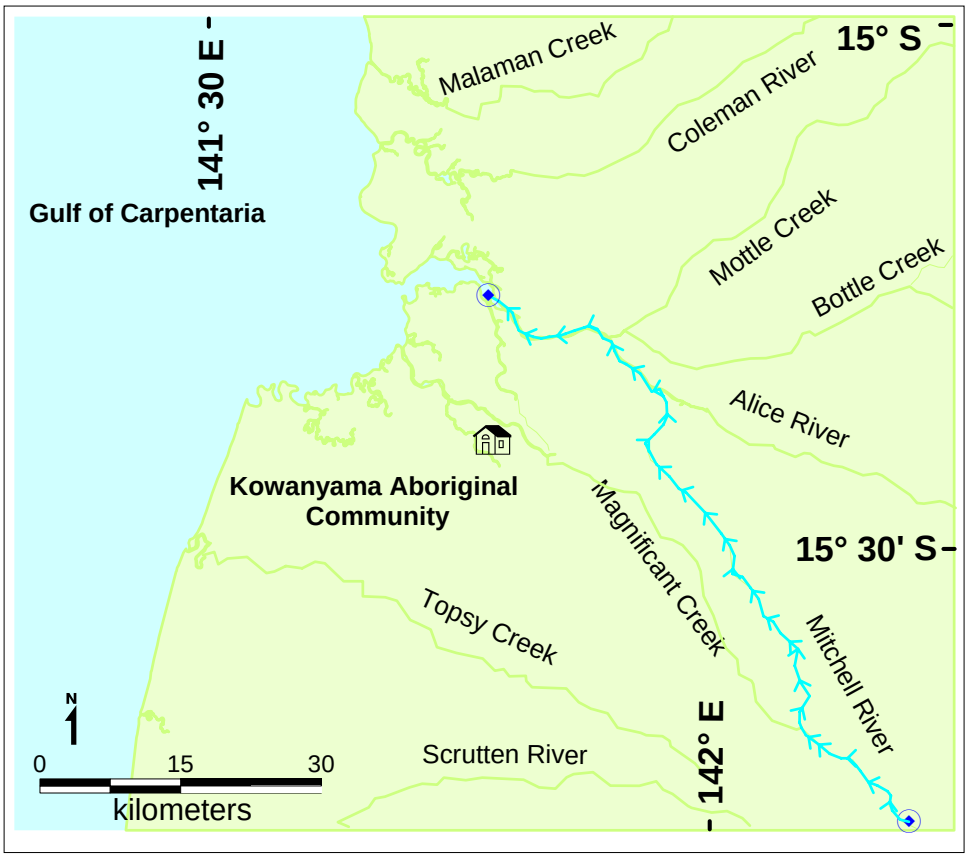

Figure 31: Upstream freshwater to estuarine habitat movement of *Pristis microdon* tag number B11182. The animal was at liberty for 224 days and moved downstream approximately 100km. The blue arrow track indicates where the sawfish was tagged, direction of movement and recapture site.

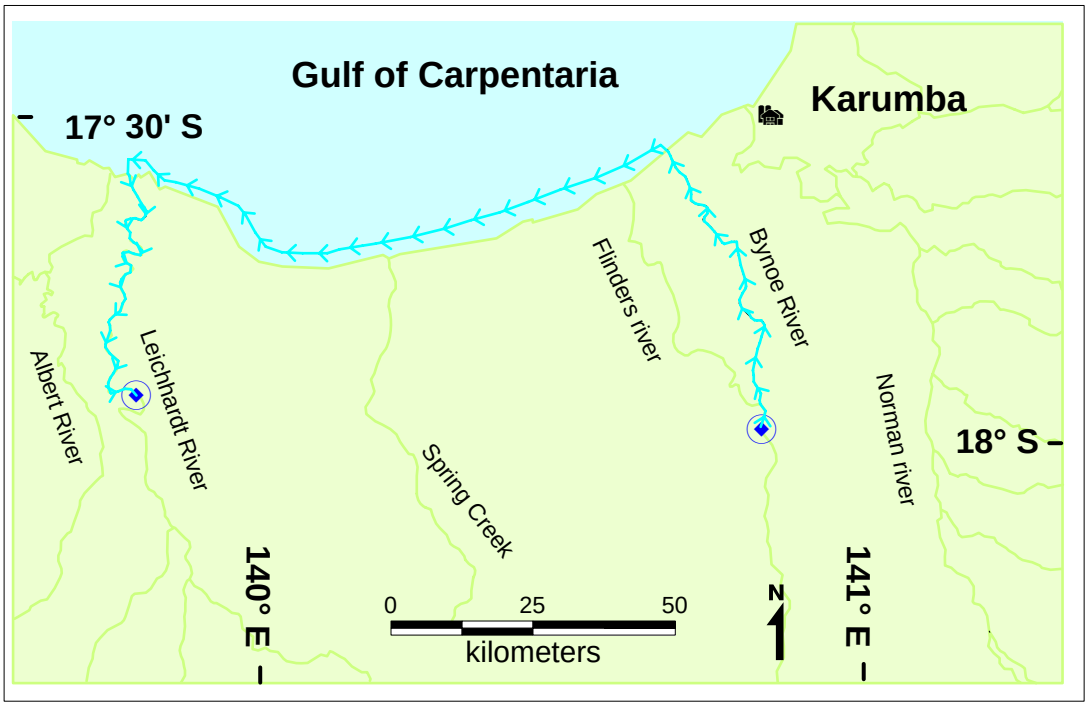

Figure 32: River to river movement of *Pristis microdon* tag number FR1075. The animal was at liberty for 100 days and moved in a westerly direction 220km. The blue arrow track indicates where the sawfish was tagged, direction of movement and recapture site.

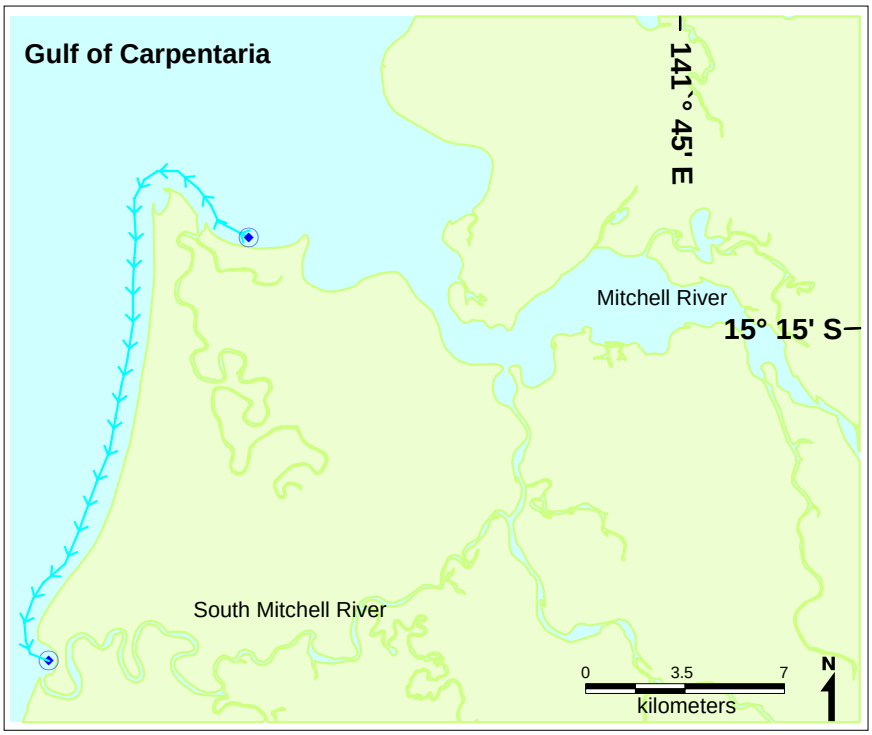

Figure 33: Inshore coastal movement of *Pristis clavata* tag number B11191. The animal was at liberty for 121 days and moved in a southerly direction 23km. The blue arrow track indicates where the sawfish was tagged, direction of movement and recapture site.

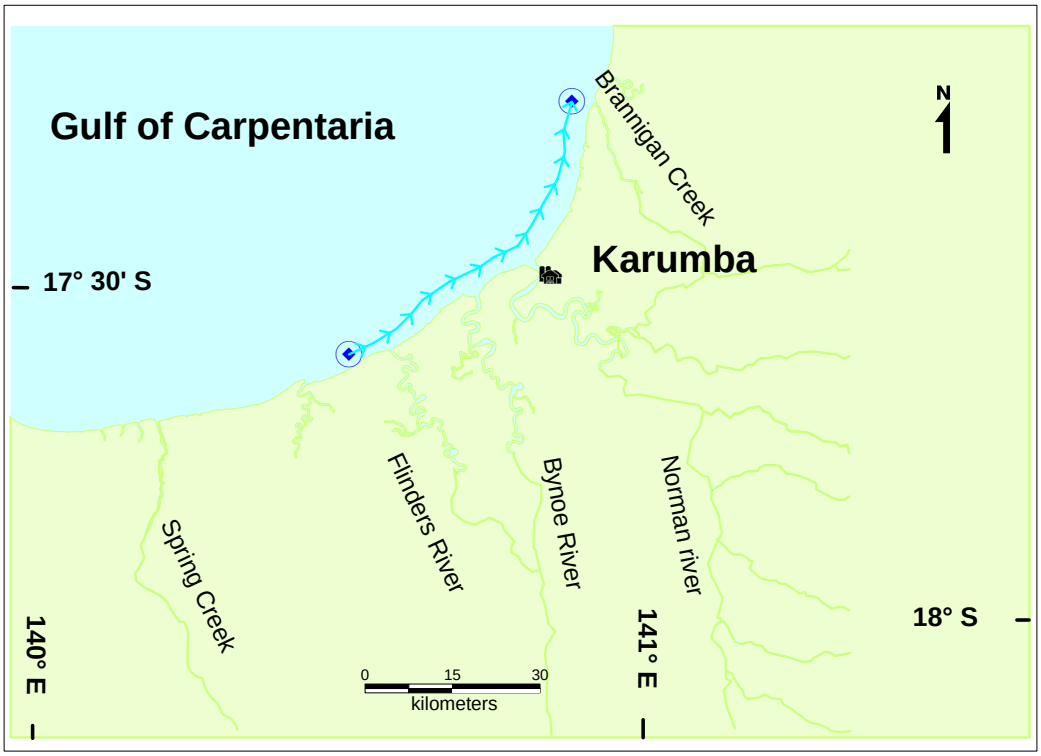

Figure 34: Inshore coastal tag return movements of *Anoxypristis cuspidata* tag number FR1210. The animal was at liberty for 21 days and moved approximately 61km. The blue arrow track indicates where the sawfish was tagged, direction of movement and recapture site.

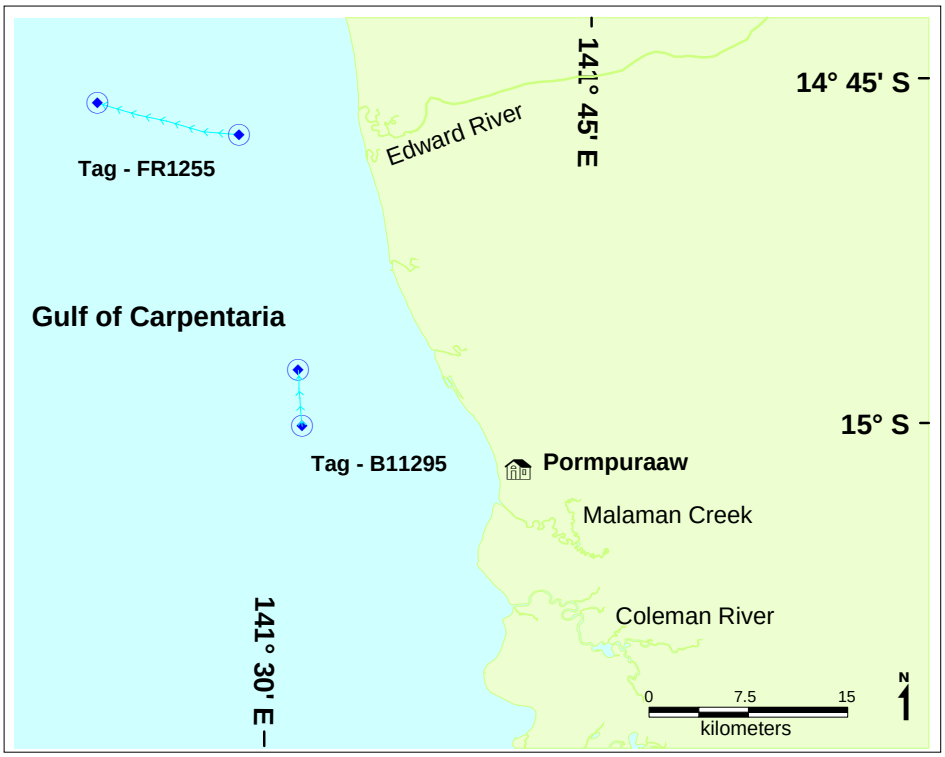

Figure 35: Inshore and offshore coastal tag return movements of *Anoxypristis cuspidata*. Tag number B11295 was at liberty for 575 days and moved approximately 5km. Tag number FR1255 was at liberty for 58 days and moved inshore approximately 11km.The blue arrow track indicates where the sawfish was tagged, direction of movement and recapture site.

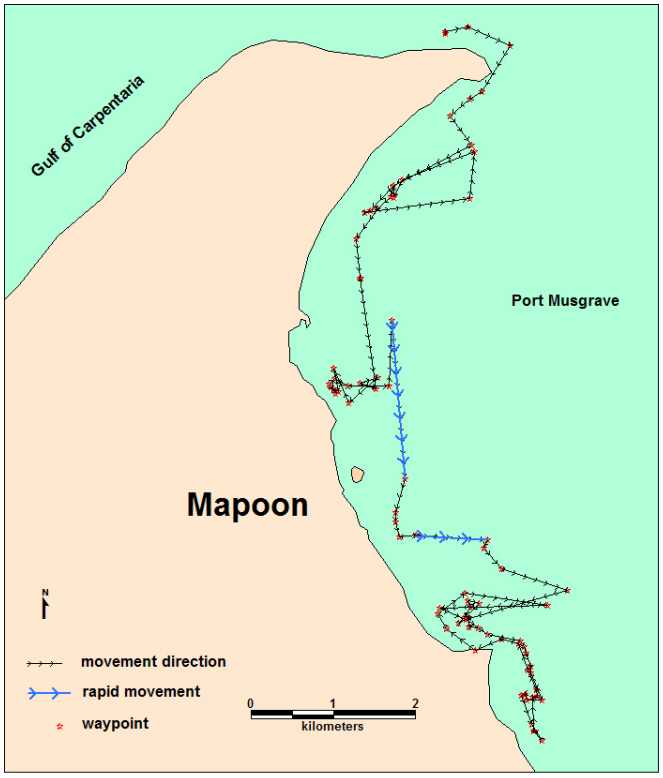

Figure 36: Twenty seven hour track of a *Pristis zijsron* tagged with a continuous pinging acoustic tag off Cullen Point, Port Musgrave

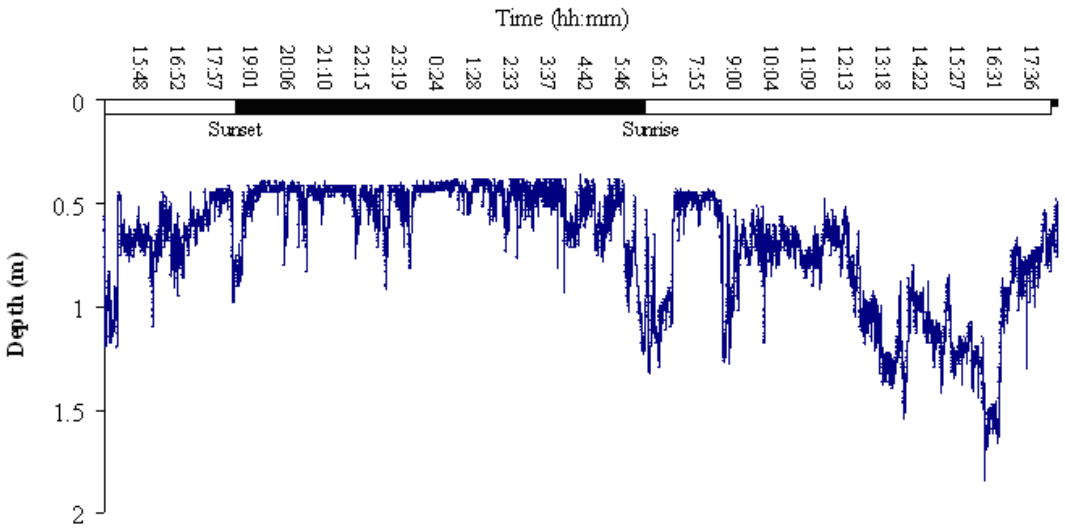

Figure 37: Data from the TDR recorded retrieved from *Pristis zijsron* after being continuously over 27 h, showing the depth profile over time

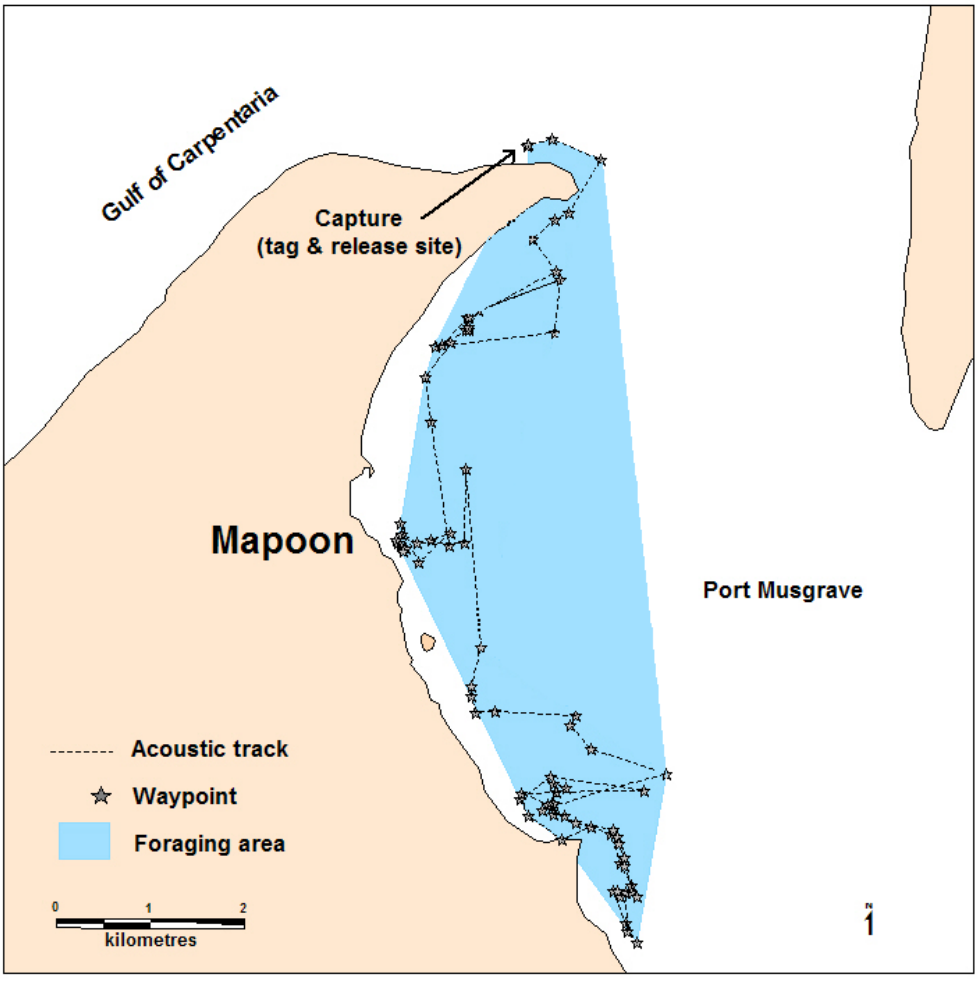

Figure 38: Home range calculated from the tracking route of *Pristis zijsron* monitored over a 27 hours period in waters off Cullen Point and Port Musgrave

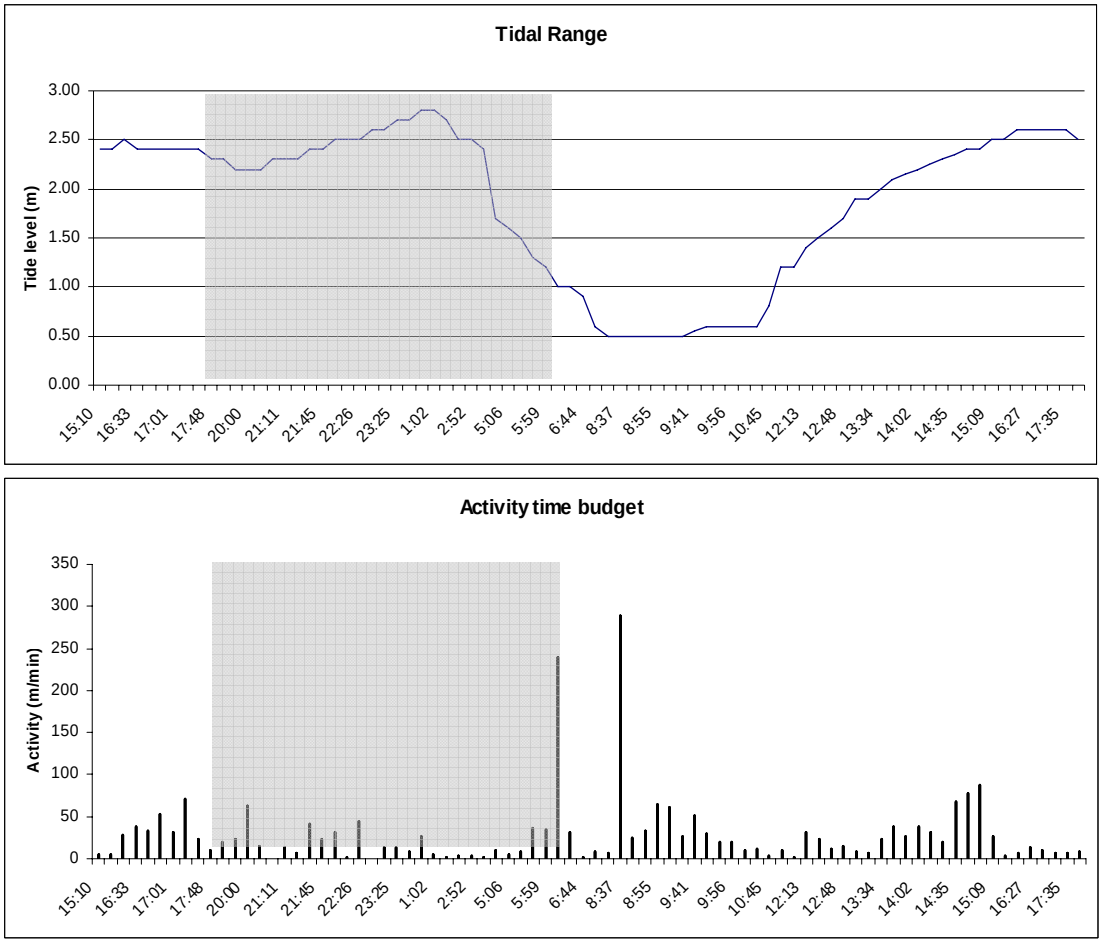

Figure 39: Time activity budget for acoustically tagged *Pristis zijsron* over a 27 hour period; top – tidal cycle and day night; activity measured in metres travelled per minute^{-1}

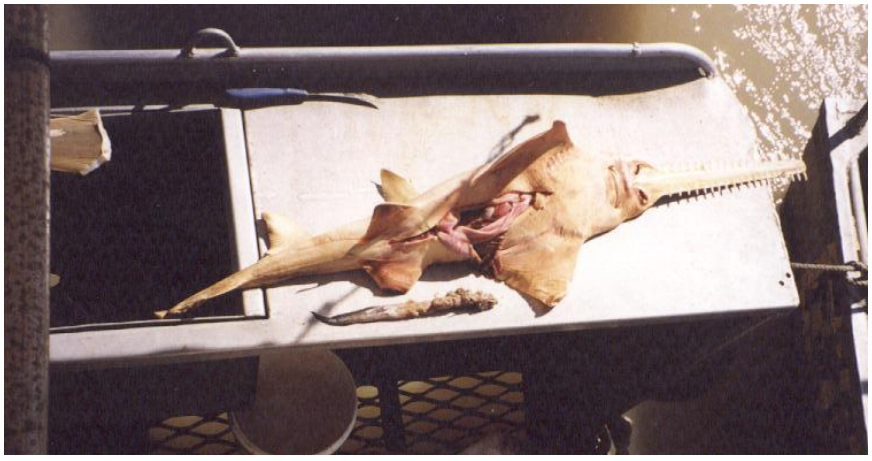

Figure 40: The stomach contents of a 128cm T_L *Pristis microdon*. The stomach contained a freshwater eel tailed catfish (*Tandanus tandanus*) of 33cm total length

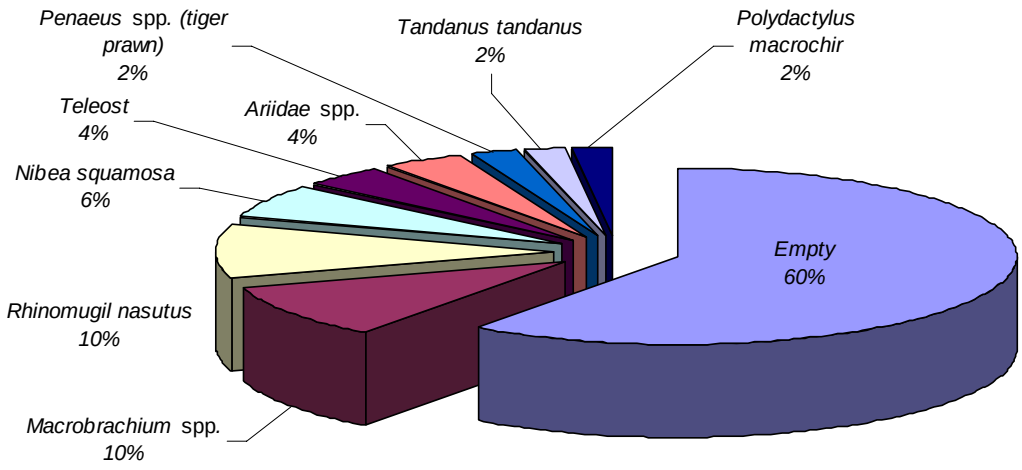

Figure 41: Stomach content analysis of 41 *Pristis microdon* captured in the inshore set net fishery of the Gulf of Carpentaria

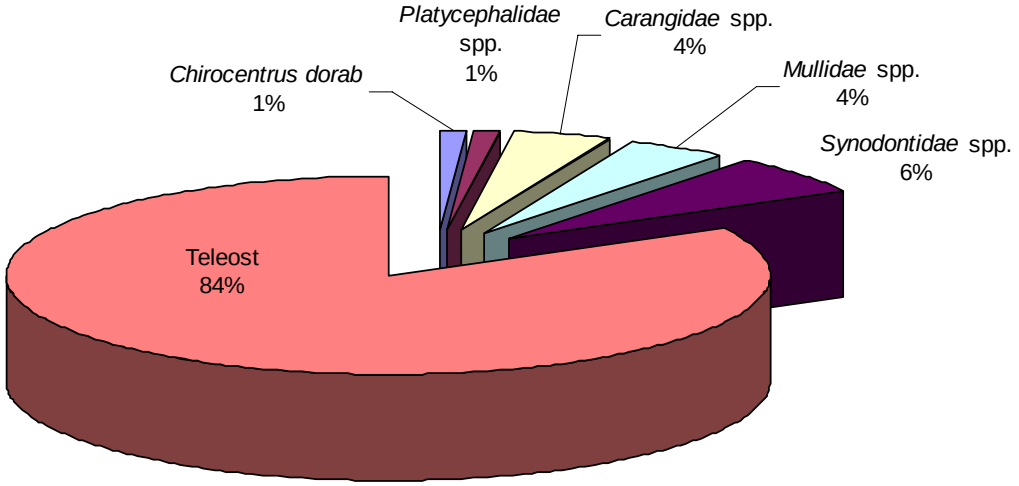

Figure 42: Species composition of the fish component of the stomach contents of 87 *Anoxypristis cuspidata* caught in the inshore and offshore set net fishery of the Gulf of Carpentaria

Chapter 5 General Discussion

5.1 Biological overview

In this study *P. microdon*, *P. clavata*, *P. zijsron* and *A. cuspidata* were identified as part of the incidental catch in the GoC inshore set net fishery. The abundance of all sawfish species in the set net fishery was extremely low and highly variable. It should be noted, however, that the GoC is probably among one of the last areas to support sawfish viable populations when compared to reports from other areas around the world, in particular South East Asia.

Of concern was the absence of mature sized *Pristis* from this study. There are two possible explanations for these findings; firstly, mature *pristis* have been fished down to very low numbers, or secondly, mature individuals of these species inhabit waters outside the area of operation of the GoC set net fisheries during the time of the fishing season. It appears from the data in the current study that the inshore fishery interacts more with *Pristis* species compared to the offshore fishery. This could also be attributed to poor reporting as Stobutzki et al (2002) recorded *Pristis* species in the bycatch of the NPF fishery which operates in similar waters to the offshore set net fishery. More studies are required to investigate these anomolies.

In this study *P. microdon* was the only species observed to move between freshwater and coastal marine habitats, with juveniles normally occurring in freshwater. This is a strategy that has been linked to avoiding predation from larger sharks in *P. perotetti* (Simpfendorfer 2004). The other pristid species appear to be predominantly found inshore along coastal foreshores. Size class partitioning was observed in *A. cuspidata* where larger mature animals inhabiting offshore waters and smaller juveniles inhabiting inshore waters.

Pristis microdon and *A. cuspidata* appear to have an annual reproductive cycle (see chapter 2) given the presence of large oocytes in the ovary in females that have just pupped; that is, they are ready to mate again. Pupping appears to occur in all pristid

species over the monsoonal wet season. This period coincides with the seasonal netting closure imposed on the inshore and offshore set net fisheries of the GoC. The closure was introduced in 1980 (Garret 1987) and additional spatial closures were introduced in 1999 (QFMA 1999). These management initiatives combined with the relatively low levels of coastal development and low levels of habitat degradation, have fortuitously provided a measure of protection for breeding pristids.

Chondrichthyan species that exhibit annual reproductive cycles have often been assumed to be resilient to harvest pressure, for example the productive *C. tilstoni* (Stevens & Wiley 1986) a target species within the GoC offshore set net fishery. However, *Pristis* have a relatively long generation time (i.e., an average of 8 years compared to 2 years for *C. tilstoni*) hence cannot achieve the same productivity as *C. tilstoni* because it is likely that they will be removed as juveniles by the inshore set net fishery. Furthermore, the reproductive strategy exhibited by *Pristis* is common among Chondricthyan species that have declined under fishing pressure, such as the grey nurse shark (DAFFA 2002b, Pollard et al 1996).

In common with all ovoviviparous and viviparous species it is likely that the number of pristid pups is dependent on the size of the female (Compagno & Last 1999). Given the very few observations of mature *pristis* size classes in this study and *A. cuspidata* were not observed at their normal maximum size, then the lack of large mature females could limit the ability of GoC pristid populations to rapidly increase. The populations would be relying on smaller females for reproduction, hence would produce less pups overall.

5.2 Conservation status and Management issues

Across the globe pristid populations have been markedly reduced by extensive fishing in coastal, estuaries and freshwater areas throughout their ranges (Simpfendorfer 2000). The current knowledge on Australian pristids is limited and it is alleged that like most elasmobranchs, *P. microdon*, *P. clavata*, *P. zijsron* and *A. cuspidata* are long lived, produce few offspring and mature late in life (Tanaka 1990, Compagno &

Last 1999, Stevens et al 2000, Poganoski et al 2002, Stobutzki et al 2002Cavanagh et al 2003), a life history strategy which makes them especially vulnerable to overexploitation (Stobutzki et al 2002). The lack of species-specific information creates difficulties for resource managers who are faced with developing management policies in the face of uncertainty and at times only after the animals have been fully exploited.

In the QLD GoC pristid populations have been conserved due to a number of factors including relatively minor coastal development, low levels of habitat degradation, and a multitude of spatial and temporal fishing closures, which help reduce interaction with commercial fisheries. Whether this level of protection is sufficient to sustain GoC sawfish populations is not known, and additional fishery management measures maybe required. This is especially the case for the recreational and indigenous fisheries given there are no management strategies in place to address the take of sawfish by these groups. In this study activities that are threatening the immediate survival of GoC sawfish populations, are commercial, Indigenous and recreational fishing. These activities should be the focus of future pristid management initiatives.

From the observations made during this study it is possible to suggest three approaches to increasing the protection of GoC pristids.

1. Spatial closures: any spatial closure should be designed to protect multiple species rather than individual species and should cover both freshwater and coast areas to provide protection for the various life history stages. There are spatial closures in place currently for a variety of habitats not necessarily for sawfish such as the closure of the south Mitchell river to all forms of non indigenous fishing. Expansion and optimisation of this system of spatial closures would be a positive initiative for the protection of pristid populations. An important element of such a spatial closure would be the control of development, particularly where such development would interrupt the normal water flow of the river systems. The best possible outcome would be gained if the commercial fishers and the community at large were involved in the planning process for the closures (see point 3 below).

2. Temporal or seasonal closures: the current seasonal closure to protect spawning barramundi over the monsoonal wet has the beneficial side effect of protecting the pupping of pristids during this period. In all the species observed during this study the data indicates that pupping occurs in inshore waters during the wet season (see Chapter 2). Optimising the timing and duration of the closure for vulnerable species other than barramundi would be another positive initiative for pristids. Again consultation with the community is essential.

3. Fisher education and public awareness: the data indicates that sawfish could be caught outside the closed season and that they exhibit migration along the coast which would mean that neither seasonal nor spatial closures would completely protect this portion of the pristid population. Given that a certain number will be caught in gill nets, ensuring live release of such incidental captures is the third positive imitative for pristid conservation. During this study pristid identification guides for commercial fishermen were developed and distributed, pristid identification and tagging workshops were run with commercial fishermen to explore and develop safe methods of live release and a handbook on the methods of safe release was produced (see CD 1 Appendix 2 and CD 2 Appendix 3). In addition to the commercial set net fishery safe handing and release document a modified version was created to address the incidental capture of pristids in the recreational fishery. This document is published on the INFOFISH web page. Pristid identification posters and media interviews were also used as a communication tool to increase public awareness of the project and raise the conservation profile of GoC pristids.

   Incorporating these resources into an education program for commercial, recreational and indigenous fishers should reduce the mortality of animals not protected by spatial or seasonal closures. This approach has had a positive impact on the public awareness of *P. perotetti* and *P. pectinata* in the United States (Seitz & Poulakis 2002).

Presently, the only legislative protection offered to GoC pristids comes in the form of fisheries management regulations specially formulated for the sustainability of target finfish resources. The current harvest of GoC pristids is unregulated and on the findings of this study, where low abundances of pristid species was observed in all three GoC regions, it is strongly remomended that their conservation status be reviewed and appropriate management steps be incorporated into legislation.

Conservation measures should not only focus on estuarine and marine habitats but incorporate a broad coverage including freshwater and associated terrestrial habitats. *Pristis microdon* (although only in its juvenile life cycle stage) was the only species to demonstrate a preference for freshwater habitat. This habitat in its nature is physically constraining and juvenile *P. microdon* populations are limited in their ability to evade problems such as pollutants, habitat modification or destruction, and incidental capture by recreational and indigenous fishers (Compagno & Cook 1995b). The current impact of these processes on juvenile *P. microdon* populations is unknown, however these threats have been recognised by Simpfendorfer (2002) and Seitz & Poulakis (2002) for *P. pectinata* populations, a Northern hemisphere sawfish species.

In this study it was found that the coastal inshore waters of the GoC were particularly important to juveniles of all four pristid species, making them all susceptible to coastal development, coastal pollution and inshore set net fishing. In terms of conservation the needs of these rare and in some cases endangered species must be factored into coastal development plans in the GoC. This concern is not simply for large scale public-works style developments but also for minor works such as weirs or barrages on streams and rivers.

Pristis microdon can easily be taken on lures and dead or live baits (Thorburn et al 2003). Juvenile *P. microdon* are also prone to capture by indigenous hunting methods such as seine and gill netting, line fishing, harpoons and fish traps. The effectiveness of both recreational and indigenous fishing methods are amplified manyfold when sawfish are restricted to drying waterholes (Thorburn et al 2003). The river flows of some GoC river systems have been modified through the introduction of weirs and road causeways. Even under normal flow these constructions could act as barriers

restricting the movement of juvenile *P. microdon,* under restricted flow in low rain fall years they would be a complete barrier.

An example of where a weir can have an impact on localised *P. microdon* populations is the fish kill reported above the Glenore weir in the Norman River, 2003 (M. Pearce QDPI & F Restocking Extension Officer, pers com 2004) (Figure 43). The Norman River is also known for supporting juvenile *P. microdon* (Thorburne et al 2003) so it is entirely probable that either the prey items would have been depleted or there was mortality of the juveniles aswell.

Figure 43: Glenore weir on the Norman River. This picture was taken during the dry season shortly after a major fish kill upstream of the weir, 2003

5.3 Future research and potential sources of data

In comparison to the research undertaken on teleost fishes, our current knowledge of chondricthyan fishes, in particular batoides is fragmentary and under reported (Oliver 1996). This is because many species are difficult and expensive to sample, exhibit seasonality, are highly mobile, and as a resource they have not been systematically exploited until recent times (Gruber & Stout 1983, Cailliet 1983a, Schwartz 1983, Walker 1998). The Family Pristidae fall into this category and the populations in the GoC are an example of where there appears to be reasonable numbers, but if left unmanaged, population declines may occur similar to those observed in other parts of the world (Compagno & Cook 1995a & 1995b, Cavenagh et al 2003, Thorson 1982b,

Simpfendorfer 2000). Many aspects of pristid physiology, ecology, life history, reproduction, habitat requirements, and other biological aspects require further attention.

The most direct impact on the sustainability of chondricthyan populations in recent times has been fishing mortality, both commercial & recreational. An overview of patterns and trends in world shark fisheries by Bonfil (1996) revealed significant data gaps in the areas of quantification of catch by gear and unreported catch from other fisheries, an amount estimated to be the same if not higher than the reported catch. This information normally comes in the form of commercial catch and effort logbook data, which is for the most part un-validated.

To overcome the problems associated with quality assurance over logbook records, fishery observer work has, and still is, being undertaken in the commercial set net fisheries of the GoC with varying degrees of coverage and efficiency. The QLD compulsory observer program in the Gulf offshore set net fishery is the only program dedicated to the monitoring of bycatch species. Information collected to date on sawfish has been extremely useful and highlights the benefits of such a program. In contrast the information supplied through voluntary observer programs has been relatively sparse and fragmentary. This is because the information collected is secondary to the study being undertaken, with work normally focussing on target species such as barramundi. To take advantage and maximise the benefits of other observer programs, sawfish need to be made a priority species. This is often difficult, especially when work is being undertaken on other more economically valued species.

Revamping existing observer programs, making sawfish a priority species and utilising the results from intensive research surveying (like Thorburn et al 2003) can address the lack of biological and life history information. Gene tagging methodology is attractive and might merit further investigation given mortality is kept to a minimum. Potentially gene tagging can provide information on populations and their movements (R. Buckworth Principal Fisheries Biologist NT Fisheries pers com 2003).

Addressing the need for information on sawfish habitat utilisation over its different life cycle stages will require independent sampling strategies. This study only provides a "snapshot" of movement and habitat preference for sawfish. Although successful the acoustic tracking of *P. zijsron* in this study only provided information on habitat utilisation and movement patterns of one animal over a short period. In the future, thought should be given to addressing how long-term data on the movement patterns and critical habitat requirements of sawfish populations can be obtained. Satellite-tracking technology adapted for marine application has been used in the movement and habitat utilisation study of other large elasmobranch species, namely the white shark (*Carcharodon carcharias*) and whale shark (*Rhychodon typus*). There is no reason given the sawfishes preference for shallow water that this technology cannot be employed in pristid research.

The use of arrays of acoustic listening stations to monitor movements of tagged sawfish in tropical estuaries would also be feasible given the inshore movement pattern of the sawfish. Listening stations (automated acoustic tag identification sites) record the presence of individual acoustic tags and can be anchored on the sea bottom in several locations to determine rates of movement and movement patterns within an estuary. Acoustic listening station arrays have been used to obtain critical information concerning the early life history and the importance of nursery areas to the survival of young sharks in Florida (Heupel & Simpfendorfer 2002) as well as to gather information on the movement and migration patterns of critically endangered grey nurse sharks (*Carcharias taurus*) within Australia (J. D. Stevens CSIRO Marine pers com 2004).

Recreational and indigenous fishers along with other activities where the incidental capture of sawfish occurs, such as the QLD shark control program should be investigated as other potential sources of information. Seitz and Poulakis (2002) have successfully solicited the help of different sectors of the community, government agencies and industry to establish an abundance and distribution pattern of *P. pectinata* in the waters of Florida, United States of America. In the current study information of extreme importance has been gleaned from the general public, sources

outside the commercial fishing sector and scientific realm. This demonstrates the importance of extension and education programs.

Tackling the data gaps identified within the recreational and indigenous line and net fishery will be more difficult to resolve than that for the commercial fishing sector. Intensive surveys working with indigenous communities looking for sawfish has proven successful and should be further investigated (FRDC Sustainability of Northern Australian Sharks & Rays – phase II). Some of the issues when dealing with indigenous communities include level of literacy and ability to identify species. These issues can be overcome through simple picture-based keys and field training.

In a study reported by Thorburn et al (2003) on northern freshwater sharks and rays, posters were used by the QLD survey team to encourage reporting by recreational fishers of sightings of sawfish and other elasmobranchs within freshwater systems. This initiative had varying degrees of success and since the completion of the project information has still been filtering back through INFOFISH Services, a National recreational tagging database service and the DPI&F call centre.

An opportunity to obtain valuable growth, genetic and dietary information is also possible through the limited take of sawfish by the Aquarium trade. Cook et al (1995) identified aquarium and museum collectors as being a potential key threatening process to the survival of pristids, although if this perceived threat is managed and approached sensibly it could yield some interesting biological information as reported in this study.

5.4 Constraints and caveats

Due to the rare or protected status of sawfish, and the lack of biological and life history information on the Pristidae Family, in many ways this study had to be a meta analysis of partial information available from a number of sources or techniques (Hunter & Schmidt 1990). Furthermore an important element of the project was the training of commercial fishermen in methods of live release of sawfish (Peverell

2005b), which had the side effect of reducing the number of specimens that was available for this project.

Thorson (1976, 1982a & 1982b) set the precedent for obtaining sawfish data from the commercial fishery and this technique was successfully used in this study. In addressing quality assurance issues relating to this form of data collection a number of training programs were initiated, species identification guides were produced and data collection kits (including cameras) were circulated. However the most important aspect of the data gathering methodology of this study was the strong day to day presence in the fishery through the fishery observer program.

By involving the commercial fishing sector it was possible to overcome the logistical constraints involved when sampling in remote areas. These constraints include, access, lack of technical back up and communication, physical danger and health. The GoC is monsoonal, the rivers and coastlines are mangrove-swamp lined, and apart from sharks, box jellyfish and crocodiles, there are a number of insect vectors of Denge fever, Japanese encephalitis and assorted tropical viruses. The sawfish themselves can be large (up to 730cm T_L), difficult to handle, and dangerous as they are equipped with heavily toothed rostrums (saws) and strong whipping tails. These features combined with the need to keep them alive at all costs because of their rare and protected status made working on the Pristidae group a challenge.

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CD-rom 1 – Appendix 1 and Appendix 2

Appendix 1

Journal Article : Distribution of sawfishes (Pristidae) in the Queensland Gulf of Carpentaria, Australia, with notes on sawfish ecology

Peverell, S.C. (2005). Distribution of sawfishes (Pristidae) in the Queensland Gulf of Carpentaria, Australia, with notes on sawfish ecology. Environmental Biology of Fishes 73: 391-402

Book Chapter: Description of Key Species Groups in the Northern Planning Area

Peverell, S.C., Gribble, N., and Larson, H. (2004) Sawfish. In: National Oceans Office. Description of Key Species Groups in the Northern Planning Area. National Oceans Office, Hobart, Australia 75-84pp.

Appendix 2

QDPI & F Information Series Report

Peverell, S.C. (2002) Queensland sawfish identification guide. The State of Queensland, Department of Primary Industries and Fisheries, QIO3038. 2pp

Peverell, S.C. (2005) Queensland sawfish release procedures guide for the GoC set net fishery. The State of Queensland, Department of Primary Industries and Fisheries, QIO3038. 11pp

National Oceans Office Technical Report

Peverell, S.C. and Pillans, R. (2004) Determining feasibility of acoustic tag attachment and documenting short-term movements in *Pristis zijsron* (Bleeker, 1851). Report to the National Oceans Office, Department of Primary Indusrties and Fisheries. 18pp.

LA-ICPMS raw data

CD-rom 2 – Appendix 3

Video - A guide to releaseing sawfish, Gulf of Carpentaria inshore and offshore set net fishery

Mpeg 1 – *Pristis zijsron* tag and release by DPI & F researchers

Mpeg 2 - *Anoxypristis cuspidata* tag and release in the offshore net reel fishery