Journal of the Royal Society of Western Australia, 94: 345–358, 2011

North-western Australia as a hotspot for endangered elasmobranchs with particular reference to sawfishes and the Northern River Shark

D L Morgan [1 3], J M Whitty [1], N M Phillips [1], D C Thorburn [1], J A Chaplin [1] & R McAuley [2]

[1] Freshwater Fish Group & Fish Health Unit, Centre for Fish & Fisheries Research, Murdoch University, South St, Murdoch, WA, 6150

[2] Western Australian Marine & Fisheries Research Laboratories, PO Box 20, North Beach, Western Australia 6920

[3] Corresponding author: ✉ D.Morgan@murdoch.edu.au

Manuscript received December 2010; accepted April 2011

Abstract

Recent targeted surveys, together with the collection of sawfish (Pristidae) rostra from the general public, have demonstrated that the Kimberley and northern Pilbara are important refuges for sawfish, with four of the world's seven species found here. These comprise all of Australia's known sawfish species, including the three species protected under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*, *i.e.* Freshwater Sawfish (*Pristis microdon*), Dwarf Sawfish (*Pristis clavata*) and Green Sawfish (*Pristis zijsron*). The Northern River Shark (*Glyphis garricki*), which was only described in 2008, has only recently been discovered in the Kimberley and is listed as *Endangered* under the EPBC Act. These species are listed as *Critically Endangered* on the IUCN Red List and collectively represent ~45% of Australia's elasmobranchs that are listed as *Vulnerable* or higher under the EPBC Act. There is, however, limited information on the spatial extent of these species throughout Western Australia, particularly as most sawfish surveys have targeted only a few specific areas over a vast coastline. We therefore encouraged public participation in providing *Pristis* rostra, taken from the fish as curios, in order to extend the known locations of the species and relate these to life history stages based on their size. Here we report on the published records and our unpublished catches (n = 376) across three *Pristis* spp., and collate this with data from donated rostra, 73% (n = 283) of which were considered usable, in that catch locations were reliable and they were from Western Australian waters. We provide information on sawfish distributions in Western Australia and identify areas that are important as pupping grounds, nursery areas or harbour mature individuals. We also collate known records of *G. garricki* and provide information on the ecology of this and the EPBC listed sawfish species.

Keywords: Pristids; *Pristis*; Kimberley; *Glyphis*; Western Australia

Introduction

There are currently 10 species of elasmobranchs that are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in Australian waters. These include one species that is *Critically Endangered*, two species that are listed as *Endangered*, six species that are listed as *Vulnerable* and one species as *Conservation Dependent* (www.environment.gov.au/epbc/). Seven of these 10 species have been positively identified from within Western Australian waters, including the *Endangered* Northern River Shark (*Glyphis garricki*) and six *Vulnerable* species, *i.e.* Grey Nurse Shark (*Carcharias taurus*), Great White Shark (*Carcharodon carcharias*), Dwarf Sawfish (*Pristis clavata*), Freshwater Sawfish (*Pristis microdon*), Green Sawfish (*Pristis zijsron*) and the Whale Shark (*Rhincodon typis*) (Morgan *et al*. 2004; Thorburn & Morgan 2004; Thorburn *et al*. 2007, 2008; Stevens *et al*. 2008; Last & Stevens 2009; Pillans *et al*. 2009; Whitty *et al*. 2009a, b). A further species, the Speartooth Shark (*Glyphis glyphis*), which is listed as *Critically Endangered* under the EPBC Act 1999, is known from near the Western Australian border in the Northern Territory (Pillans *et al*. 2009). Thus, the coastal waters of the Kimberley potentially contains Australia's two *Glyphis* spp., and are also a global hotspot for sawfishes (Pristidae), with four of the world's seven species of pristids found here; these four species comprise all of the known Australian sawfish species.

The pristids are a unique group of ray that are readily identified by the presence of an elongated and flattened rostra possessing enlarged tooth-like denticles known as rostral teeth (Last & Stevens 2009). Globally, all sawfishes have undergone major declines in both range and abundance, largely as a result of their rostral teeth being vulnerable to entanglement in fishing nets (*i.e.* by-catch), but also through loss of habitat and exploitation, as the rostra are often taken from the fish as curios. The population structures of many of the world's sawfish species are believed to be fragmented (*e.g.* Simpfendorfer 2000) and there is virtually no information on the sizes of the remaining populations. Four species of pristid, from two genera, are known to occur in Australian waters. In fact, Australia may contain the only remaining viable populations of some of these species, although it is believed that some species were once distributed more broadly in the Indo-West Pacific region. Each of the four species appears to be broadly distributed in northern Australia, but distributional descriptions are lacking in Western Australia and are based on limited and often localised surveys or from anecdotal reports. However, the northern Pilbara coast and west Kimberley are known to represent an important area for the four species, namely *P. microdon*, *P. clavata*, *P. zijsron* and the Narrow Sawfish (*Anoxypristis cuspidata*) (Morgan *et al.* 2004; Thorburn *et al.* 2007, 2008; Stevens *et al.* 2008; Last & Stevens 2009; Whitty *et al.* 2009a, b). Although the first three of these species are listed as *Vulnerable* under the EPBC Act, all are protected species within Western Australia under the *Fish Resource Management Act 1994* (FRMA Act), and *P. zijsron* was listed under *Schedule 1* of the *Wildlife Conservation Act 1950* in Western Australia in 2006. Additionally all are listed as *Critically Endangered* under the IUCN Red List, and are protected from international trade through *Appendix I* of the Convention on International Trade in Endangered Species (CITES). *Pristis microdon* is the only exception, as it is listed under *Appendix II*, allowing for aquarium trade for conservation purposes. *Glyphis garricki*, having only been discovered in Western Australia in 2002 (Morgan *et al.* 2004; Thorburn & Morgan 2004) and formally described in 2008 (Compagno *et al.* 2008), is also protected in Western Australia under the FRMA Act, and is listed as *Critically Endangered* by the IUCN Red List. Collectively, these species represent ~45% (56% if further evidence confirms the existence of *G. glyphis* in the Kimberley) of Australia's elasmobranchs that are listed as *Vulnerable* or higher under the EPBC Act.

It is only very recently that research has been conducted into the ecology of *Pristis* and *Glyphis* species in Western Australia, but it is mostly the result of very localised sampling in only a few selected areas. Recent research on *P. microdon* has largely been confined to the Fitzroy River and King Sound (Thorburn *et al.* 2003, 2004, 2007; Morgan *et al.* 2004; Thorburn & Morgan 2005a; Thorburn 2006; Whitty *et al.* 2008, 2009a, 2009b), while information on *P. clavata* is largely from collections in King Sound and the Fitzroy River estuary (Thorburn *et al.* 2008) or from Hall Point and Cape Keraudren (Stevens *et al.* 2008), and data on *P. zijsron* are limited to Cape Keraudren (Stevens *et al.* 2008). For *G. garricki,* data are drawn from limited captures in King Sound (Thorburn & Morgan 2004, 2005b; Thorburn 2006; Whitty *et al.* 2008) and that reported in Pillans *et al.* (2009) for the north-eastern Kimberley.

In order to strengthen information on these EPBC listed *Pristis* species, and as we were aware of many instances where rostra were removed from fish and kept as souvenirs, we enlisted the public to provide rostra for examination. The use of donated rostra from various people within different towns and communities of the region and from the recreational, indigenous and commercial fishing sectors is a valuable tool for examining species distributions in this remote part of Australia. Rostra have previously proved useful for the extraction of DNA (Phillips *et al.* 2009a, 2011). These rostra, which are taken as curios, are likely to provide valuable information on each species' spatial demographics that would otherwise take many years to document through targeted surveying in remote regions over a vast coastline. Utilising the relationship of rostrum length to total length and known size at sexual maturity for the species (*e.g.* Thorburn *et al.* 2007, 2008; Peverell 2008), this study aims to reconstruct spatial distributions of pristids of various life-history stages from rostra and localised ecological studies in Western Australia. It is hypothesised that the use of rostra from private collections will be a valuable tool to reconstruct species distributions and identify areas which may act as nurseries or provide habitat to mature individuals.

Methods

Data presented here are focussed on northern Western Australian (northern Pilbara and Kimberley) assemblages of the EBPC listed species of *Pristis* and the one species of *Glyphis*, but information from other regions (Peverell 2005, 2008; Pillans *et al.* 2009; Last & Stevens 2009) is used for comparative purposes and to address knowledge gaps. Regional information on these species was collated from both literature reviews (*e.g.* Thorburn *et al.* 2003, 2004, 2007, 2008; Morgan *et al.* 2004; Thorburn & Morgan 2004, 2005a; Phillips 2006; Phillips *et al.* 2008, 2009b, 2011; Stevens *et al.* 2008; Whitty *et al.* 2008, 2009a, b) and our unpublished data including recent surveys in the region, which has been ongoing since 2001. The fourth Australian species of sawfish, *A. cuspidata* has not been included in this review as (1) it is currently not listed under the EPBC Act and (2) we have virtually no ecological information on the species in the region.

The above studies in Western Australia are, however, generally from very localised sampling, with all but two largely concentrated within the Fitzroy River and parts of King Sound in the south-west of the Kimberley. The exceptions being the genetic studies by Phillips *et al.* (2011) which included samples from throughout Australia, and that by Stevens *et al.* (2008) which included very localised sampling in the Pilbara (Cape Keraudren) and western Kimberley (Hall Point). The above studies therefore, provide only limited information on the spatial distribution of the *Pristis* species in Western Australia.

Sawfish rostra have long been kept as curios in private collections. To overcome the limited spatial extent of targeted surveying for sawfishes, we invited the public to donate or lend rostra for morphological examination. Since 2001 we have examined 283 donated rostra from the three EPBC listed *Pristis* species (see Table 1), including some that were collected during WWII in the Fitzroy River and one held in the collections of the Australian Museum that dated back to 1885 (location unknown). Rostra were readily identified on the basis of a combination of the number of rostral teeth and the tooth morphology (see results and Phillips 2006; Thorburn *et al.* 2007; Last & Stevens 2009). This included 141 that were identified as belonging to *P. clavata*, 74 that were from *P. microdon* and 68 that were from *P. zijsron*. For 27 (~9%) of these, the original capture location was either unknown or not detailed enough to be of use for distributional data, but most were either supplied with a high degree of accuracy (*e.g.* to the nearest 1 km) or were from general locations, for example, King Sound, or

Roebuck Bay. A further 52 rostra were from outside of Western Australia (see Table 1). For the purpose of providing distributional data, only those rostra from Western Australia that had accompanying site capture information with a high degree of certainty were used for analyses.

Information on the distribution of sawfishes in Western Australia was thus obtained from the collation of the locations of the 204 rostra that were donated from private collections throughout the region and the targeted surveys during various studies. When considering that the approximate size at sexual maturity of the species is generally known, the size of these rostra also provided valuable information on the spatial extents of potential nursery areas as well as locations utilised by mature animals, which is a major knowledge gap for each of these species and complemented the site specific studies in Western Australia on each of these species. An additional 237 individuals of *P. microdon* have been captured and measured (and tagged) from the Fitzroy River and King Sound between 2002 and 2010, one was reported from Cape Keraudren and another from 80 Mile Beach (see Thorburn *et al*. 2007, Whitty *et al*. 2009a, Morgan & Whitty unpublished data). Chidlow (2007) reported on the capture of one *P. microdon* from Cape Naturaliste within the State's south-west, although this capture is believed to be an anomaly. Ishihara *et al*. (1991a) recorded 10 *P. clavata* in the Pentecost River system. Stevens *et al*. (2008) reported on nine *P. clavata* near Hall Point in the Kimberley, Thorburn *et al*. (2008) provide details on 44 *P. clavata* captured in King Sound (including tidal areas of the larger rivers) between 2002 and 2004, and we captured a further 55 *P. clavata* from King Sound and the Fitzroy River estuary (Morgan & Whitty unpublished data) between 2005 and 2010. We have 17 capture records of *P. zijsron* from Western Australia (McAuley unpublished data), and Stevens *et al*. (2008) report on 11 *P. zijsron* from the Cape Keraudren region.

Ignoring donated rostra with unreliable site localities or where capture information was unavailable or outside of Western Australia (see Table 1), our review is based on the following:

P. microdon: 55 donated rostra + 240 captures (n = 304)

P. clavata: 120 donated rostra + 118 captures (n = 238)

P. zijsron: 27 donated rostra + 28 captures (n = 54)

Measuring the length of each rostra, together with known size at sexual maturity from the various studies (*e.g.* Peverell 2005, 2008; Thorburn *et al*. 2007, 2008) and total length versus rostral length relationships, has allowed us to create distribution records of the species and assess the spatial extent of potential nurseries, adult habitats and pupping grounds for each species of *Pristis* throughout Western Australia. Species maps of these pristids as well as *G. garricki*, which are based on the studies by Thorburn & Morgan (2004), Whitty *et al*. (2008, 2009a) and Pillans *et al*. (2009), were created in MapInfo. For clarity, each individual rostra or capture is not necessarily presented on each map, for example, over 200 *P. clavata* were reported from King Sound, and over 200 *P. microdon* were reported from the Fitzroy River.

Morphological measurements included: total length (TL), total rostrum length (TRL; alternatively labelled rostrum length (RL) in some literature (*e.g.* Thorburn 2006; Thorburn *et al*. 2007, Whitty *et al*. 2008)), standard rostrum length (SRL) and weight (WT). TL is the distance from the tip of the rostrum to the tip of the caudal fin (Fig. 1). TRL is the distance from the tip of the rostrum to its base, where the rostrum flares to join the head. The relationship of TL and TRL were used to approximate total lengths from donated rostra. All length and weight measurements are reported in cm and kg, respectively.

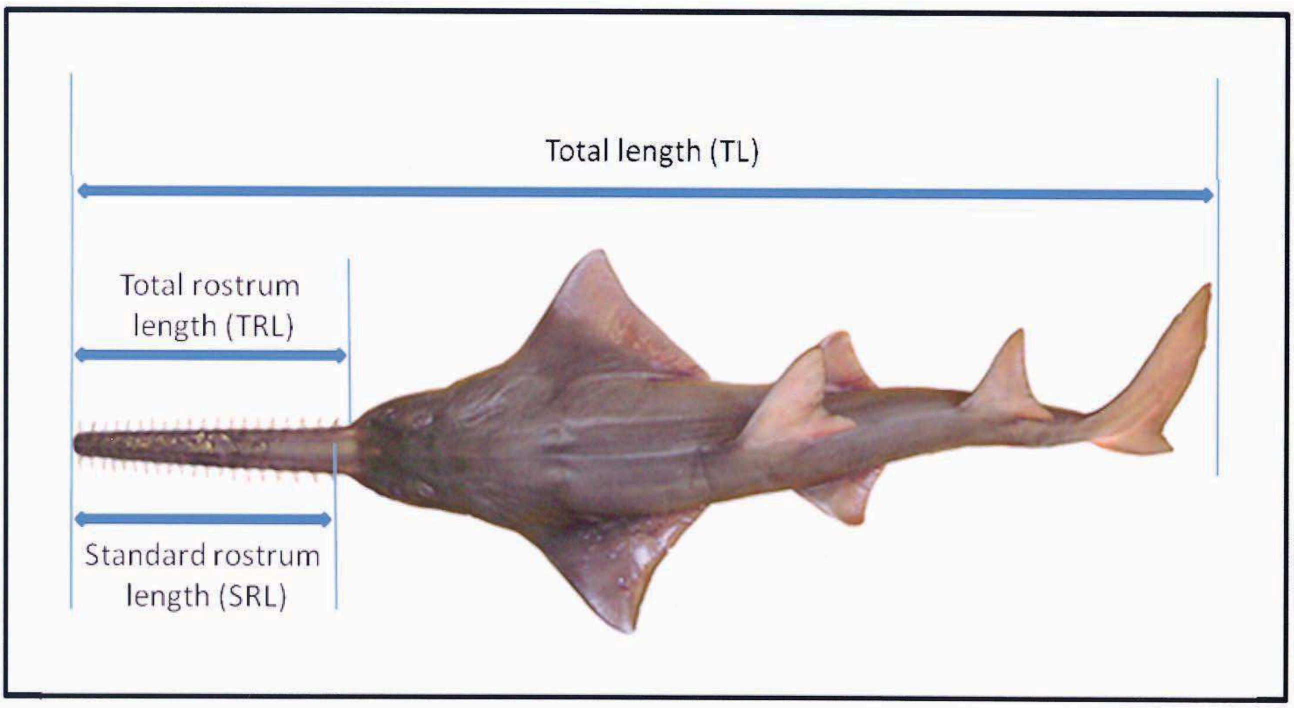

Figure 1. Morphological measurements derived from sawfish captured.

Results and Discussion

Donated rostra as a tool for enhancing research

To date, all targeted sawfish sampling in Western Australia has been restricted to a few specific locations and thus has been unable to provide an indication of their spatial extent in state waters. Rostra from private collections have allowed us to refine the distribution of *Pristis* spp. in Western Australia and have substantially added to scientific collections. For example, although we have records for 386 captures of the three *Pristis* spp. from targeted surveys, a further 283 rostra were donated from the public during this study (Table 1). While ~9% of these were from unspecified locations, and a further 18% were from outside of Western Australian waters; the remaining 205 rostra were useful for examining spatial patterns of the species (see Table 1, Figs 5–7). Donated rostra thus accounted for ~35% of all known records in Western Australia. Many of these rostra were from locations that we previously had no records of sawfish from. Importantly, donated rostra account for ~50% of all records of both *P. zijsron* and *P. clavata* in state waters. Together with known information on the relationship between fish length and rostra length and the length at maturity, we are also able to determine areas that are known adult habitats and juvenile habitats (see below). Based on the known approximate size of newborn pups and the predicted rostrum length from TRL/TL relationships, we are also able to determine potential pupping areas. Phillips *et al.* (2011) also demonstrated the value in assessing the population genetic structure and genetic diversity of sawfishes from rostra.

Table 1

Numbers of rostra donated and their original capture locations for *Pristis clavata, Pristis microdon* and *Pristis zijsron* during this study. Fitzroy River includes only rostra from non-tidal reaches. King Sound includes rostra from tidal waters of the Fitzroy and Robinson Rivers. See Figures 5, 6 and 7 for locations.

Site of rostra	*Pristis clavata* n = 141	*Pristis microdon* n = 74	*Pristis zijsron* n = 68
Fitzroy River		41	
King Sound	118	11	3
One Arm Point			1
Cape Leveque			1
Pender Bay			1
Beagle Bay			4
Willie Creek			1
Roebuck Bay	2	2	8
80 Mile Beach		1	1
Port Hedland			2
Whim Creek			2
Karratha			3
Exmouth			1
Coral Bay			1
Western Australia (location unknown)	7	9	11
Queensland	1	3	5
Northern Territory	13	4	17
New South Wales			6
Papua New Guinea		2	
Indonesia		1	

Morphology, distribution and ecology of *Pristis* spp. in north-western Australia

Freshwater Sawfish (Pristis microdon)

Morphology and recognition

Pristis microdon is a large-sized sawfish, and can be distinguished through the following morphological characteristics: first dorsal fin origin located anterior to the origin of its pelvic fins; base of first dorsal fin greater than that of the second; height of second dorsal fin slightly higher than that of the first; small ventral caudal fin lobe; no terminal notch on dorsal lobe (Taniuchi *et al.* 1991b; Compagno & Last 1999; Last & Stevens 2009); proximal teeth begin in close approximation at the base of the rostra, in Western Australia 17–23 left (Fig. 2) and 34–47 total (Fig. 3) rostral teeth (Thorburn 2006; Thorburn

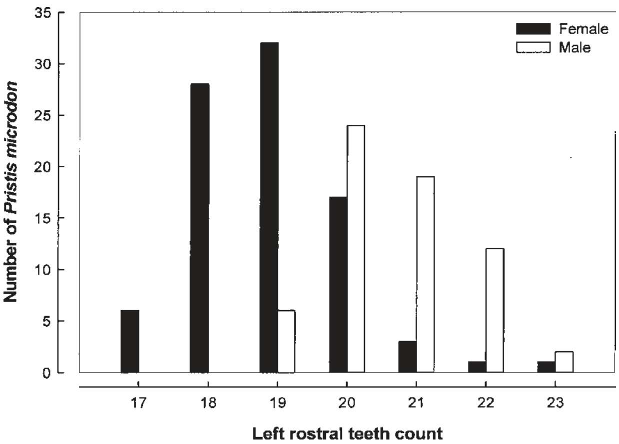

Figure 2. Left rostral teeth count of female and male *Pristis microdon* captured in Western Australia.

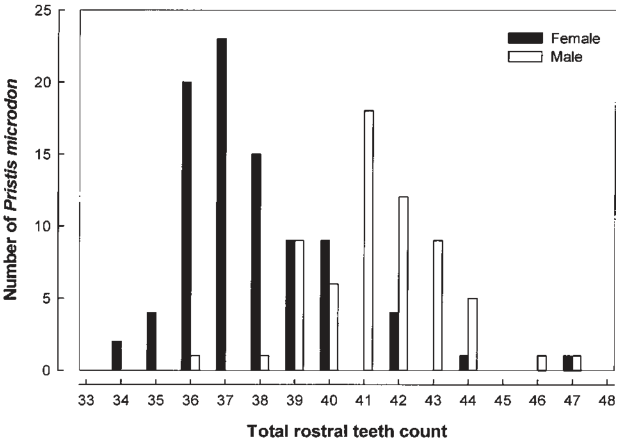

Figure 3. Total number of rostral teeth for female and male *Pristis microdon* captured in Western Australia.

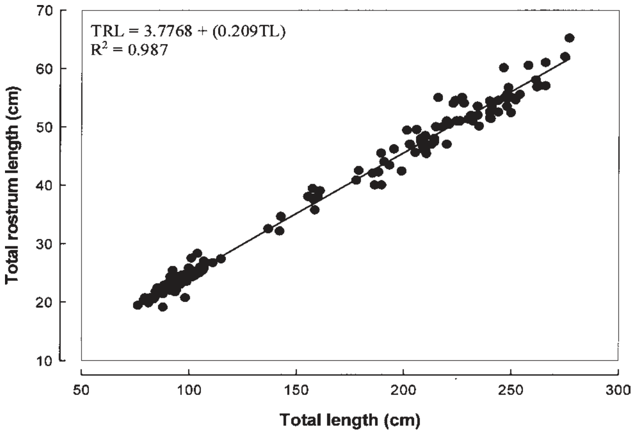

Figure 4. Relationship of total length (TL) to total rostrum length (TRL) of *Pristis microdon* captured in Western Australia.

et al. 2004, 2007, Whitty *et al.* 2008, 2009a); females with 17–23 left rostral teeth, usually ≤20, males with 19–23 rostral teeth (Fig. 2) (Whitty *et al.* 2009a) (also observed by Ishihara *et al.* (1991b) in *P. microdon* collected in other regions of northern Australia and Papua New Guinea); marginal grooves that go to the base of rostral teeth (Phillips 2006, Thorburn *et al.* 2007). Total rostrum length between 21 and 27.5% of TL (TRL = 3.7768 + (0.209TL) (based on *P. microdon* 76–277 cm TL (Fig. 4)). Taniuchi *et al.* (1991b) documented this range to be ~25% for *P. microdon* (99.2–108.4 cm TL) outside of Western Australia. Of the Australian specimens, the rostrum of *P. microdon* is most similar to *P. clavata*. These species can best be separated by position of the first dorsal fin and presence of a lower caudal lobe on *P. microdon*. Additionally, the degree in which the grooves on the posterior margin of the rostral teeth extend down the teeth to the junction with the rostrum blade is a useful tool to distinguish *P. clavata* from *P. microdon* (see Thorburn *et al.* 2007).

Life history

Born between 72 and 90 cm TL (Compagno & Last 1989; Peverell 2005; Thorburn *et al.* 2007; Peverell 2008; Whitty *et al.* 2009a), *P. microdon* are estimated to attain maximum lengths of 600–700 cm TL (Peverell 2008; Last & Stevens, 2009), with the largest recorded individual being 656 cm TL (Compagno & Last 1999). In Western Australia, the Fitzroy River appears to be the most important nursery area for this species, where male and female juveniles have been recorded at between 76.3–235 cm and 78.9–277 cm TL, respectively (Thorburn *et al.* 2003, 2007; Whitty *et al.* 2009a; this study).

Last and Stevens (2009) provide details on the global distribution of *P. microdon* and note the uncertainty of describing an accurate contemporary distribution due to localised extinctions; but do confirm their presence from several major river systems in Indonesia and New Guinea, and the species is also likely to occur in India and eastern Africa (Tanuichi *et al.* 2003; Skelton 2001). Rostra donated in this study further support their occurrence in New Guinea and Indonesia. Within Western Australia, *P. microdon* has been found from Cape Naturaliste (Chidlow 2007) in the south-west (a single specimen), to the Ord River (Gill *et al.* 2006) in the north. However, most have been recorded from the west Kimberley (Fig. 5), specifically the Fitzroy River, which is arguably one of the most important nursery areas known (Thorburn *et al.* 2003, 2004, 2007; Morgan *et al.* 2004; Thorburn & Morgan 2005a; Whitty *et al.* 2008, 2009a) (Fig. 5). Within the freshwaters of the Fitzroy River, all *P. microdon* are thought to be immature, with few immature fish located elsewhere in Western Australia (Fig. 5). The only confirmed records of immature *P. microdon* from Western Australia outside of the Fitzroy River and the other major tributaries of the King Sound are from donated rostra, and include Willie Creek north of Broome (n = 1), and in Roebuck Bay (n = 2) near Broome, although Thorburn *et al.* (2003) and Gill *et al.* (2006) provide anecdotal evidence that they are in the Ord River (Fig. 5). Males and females of *P. microdon* mature at ~300 cm TL, although males potentially mature at a slightly smaller size (Compagno & Last 1998; Thorburn *et al.* 2007; Peverell 2008; Whitty *et al.* 2008). Distribution of mature individuals (see below) known from captures and donated rostra (*i.e.* at >300 cm TL, their rostrum length would be >65 cm (Fig. 4)), in Western Australia have only been recorded from Cape Naturaliste (not illustrated) (Chidlow 2007), Cape Keraudren, 80 Mile Beach, Roebuck Bay (near Broome) and King Sound (Fig. 5). Dispersal in females is thought to be philopatric (see Phillips *et al.* 2009b, 2011), where the females may return to their natal river to pup. It is plausible that each of those larger females found along 80 Mile Beach and in Roebuck Bay (see Fig. 6), may move to the mouth of the Fitzroy River to pup.

Using vertebral analysis, Thorburn *et al.* (2007) estimated *P. microdon* in Western Australia of 100 cm, 140–160 cm, 180–220 cm, and 230–280 cm TL to be around one, two, three and four years of age, respectively. Also using vertebral analysis, Peverell (2008) produced similar age estimates, finding that Queensland *P. microdon* ranging between 83–101 cm, 119–140 cm, 143–180 cm, 170–219 cm, 229–253 cm and 234–277 cm TL were in their 1st, 2nd, 3rd, 4th and 5th year of life, respectively. Peverell (2008) also found a 582 cm TL female to be 28 years of age. Peverell (2008) calculated a k-value of 0.08 year^{-1} (L_∞ = 638 cm TL, t_0 = -1.55 years), estimating growth within the first year to be 52 cm, and growth in the fifth year to be 17 cm.

Limited information suggests that *P. microdon* pup annually with litters of 6–12 pups (Peverell 2008). While it is unknown where breeding occurs in Western Australia, the presence of small juveniles with umbilical scars indicates that at least one of the pupping grounds is in close approximation to the river mouth area of the Fitzroy River. From catches in the Fitzroy River, pupping is likely to occur in the wet season (January to April) (Whitty *et al.* 2008, 2009a). Size and duration of the wet season are likely to be positively correlated with survival of 0+ *P. microdon,* as a prolonged and/or very wet season would increase their ability to access more stable upstream pools and thereby decrease the risk of predation from large bodied predators (*e.g.* Bull Shark (*Carcharhinus leucas*) and Estuarine Crocodile (*Crocodylus porosus*)) (Thorburn *et al.* 2007, Whitty *et al.* 2008, 2009a). Juveniles have been recorded in pools of the Fitzroy River that are well in excess of 300 km from the alleged pupping sites in the river mouth (Morgan *et al.* 2004).

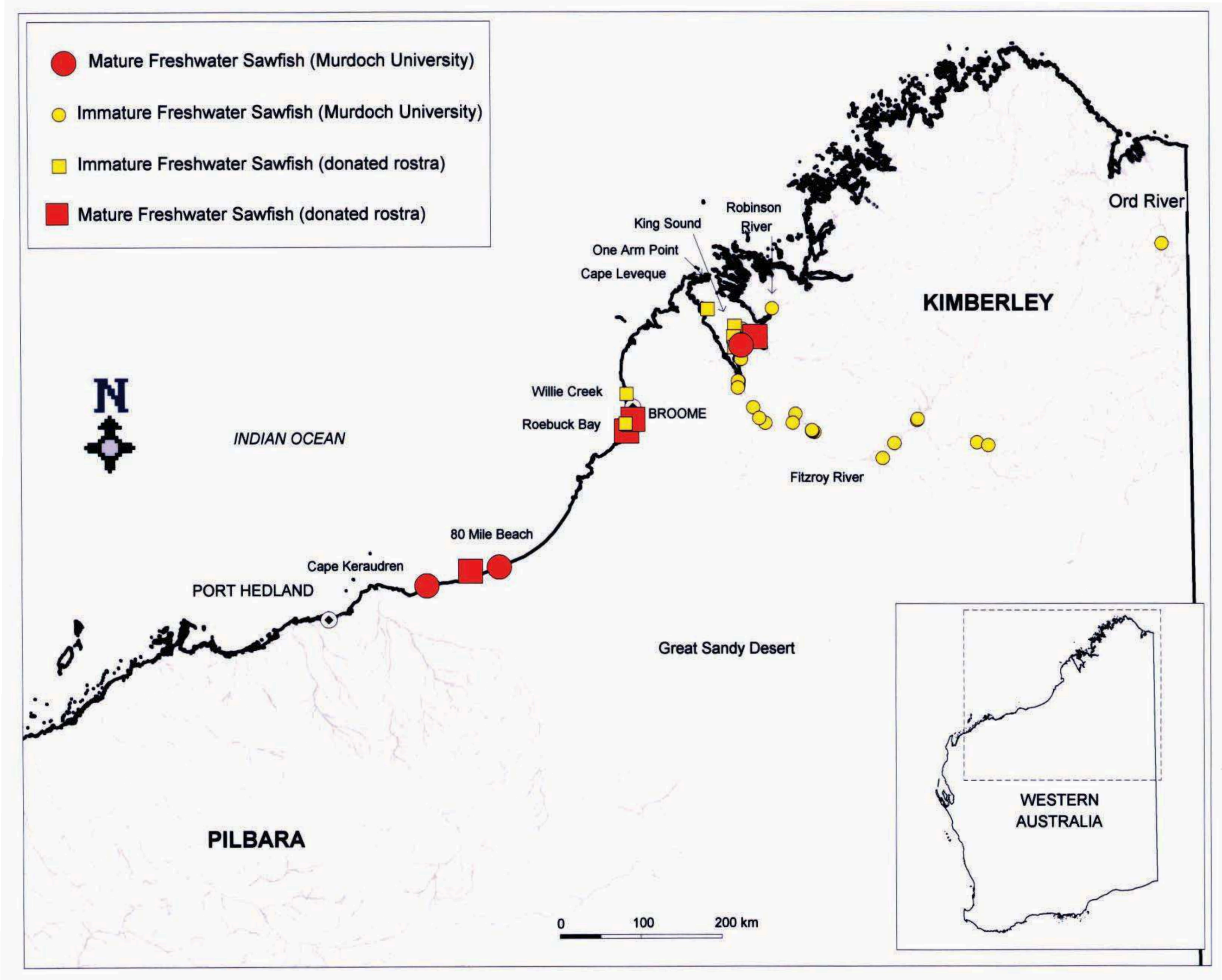

Figure 5. Catches of *Pristis microdon* in the northern Pilbara and Kimberley region of Western Australia, indicating maturity status (from Murdoch University and donated rostra). N.B. Chidlow (2007) reports on the capture of a mature male near Cape Naturaliste in south-western Australia. Data from Morgan *et al*. (2004), Thorburn *et al*. (2004, 2007), Gill *et al*. (2006), Whitty *et al*. (2008, 2009a, b), Phillips *et al*. (2008) and this study.

Dwarf Sawfish (Pristis clavata)

Morphology and recognition

Pristis clavata can be distinguished by the following morphological characteristics: origin of first dorsal fin in line or just posterior with that of the pelvic fin (Ishihara *et al*. 1991a; Compagno & Last 1999; Last & Stevens 2009); second dorsal fin only slightly lesser in size than the first (Ishihara *et al*. 1991a); no ventral caudal lobe (Compagno & Last 1999; Last & Stevens 2009); proximal rostral teeth begin near base of rostrum (Compagno & Last 1999); in Western Australia 19–22 left rostral teeth, 38–45 total rostral teeth, no significant difference between male and female teeth counts (Thorburn 2006; Thorburn *et al*. 2008); marginal grooves on rostral teeth that generally do not extend to the tooth base in juveniles and most adults (Phillips 2006; Thorburn 2006; Thorburn *et al*. 2007, 2008). In Western Australia, TRL has been recorded to range between 19.0–21.2% of the TL for *P. clavata* ranging from 80.2–140.2 cm TL (Ishihara *et al*. 1991a). Thorburn *et al*. (2008) recorded TRL to average 20.1% (± 0.001 SE) of TL in *P. clavata* ranging from 80–250 cm TL (TRL = 0.6142 $TL^{0.8475}$). This range may increase with the addition of smaller individuals (*i.e.* neonates) when considering that the holotype of the species (61.9 cm TL), had a TRL of ~25% of TL (Garmon 1906).

Life history

Pristis clavata is pupped at between ~60 and 81 cm TL and estimated to reach at least 310 cm TL (Peverell 2008; Last & Stevens 2009), making it the smallest of Australia's *Pristis* spp.

Last and Stevens (2009) suggest that *P. clavata* is restricted to northern Australia from Cairns to 80 Mile Beach, and that it is now rare in Queensland, however Peverell (2008) suggests that within Queensland, the species is restricted to the Gulf of Carpentaria. In Western Australia the majority of capture locations and donated rostra for *P. clavata* are from the King Sound and the lower reaches (tidally influenced) of its tributaries, *i.e.* Fitzroy River, May River and Robinson River, as well as from near Walcott Inlet in the Kimberley as well as Cape Keraudren and 80 Mile Beach in the northern Pilbara/

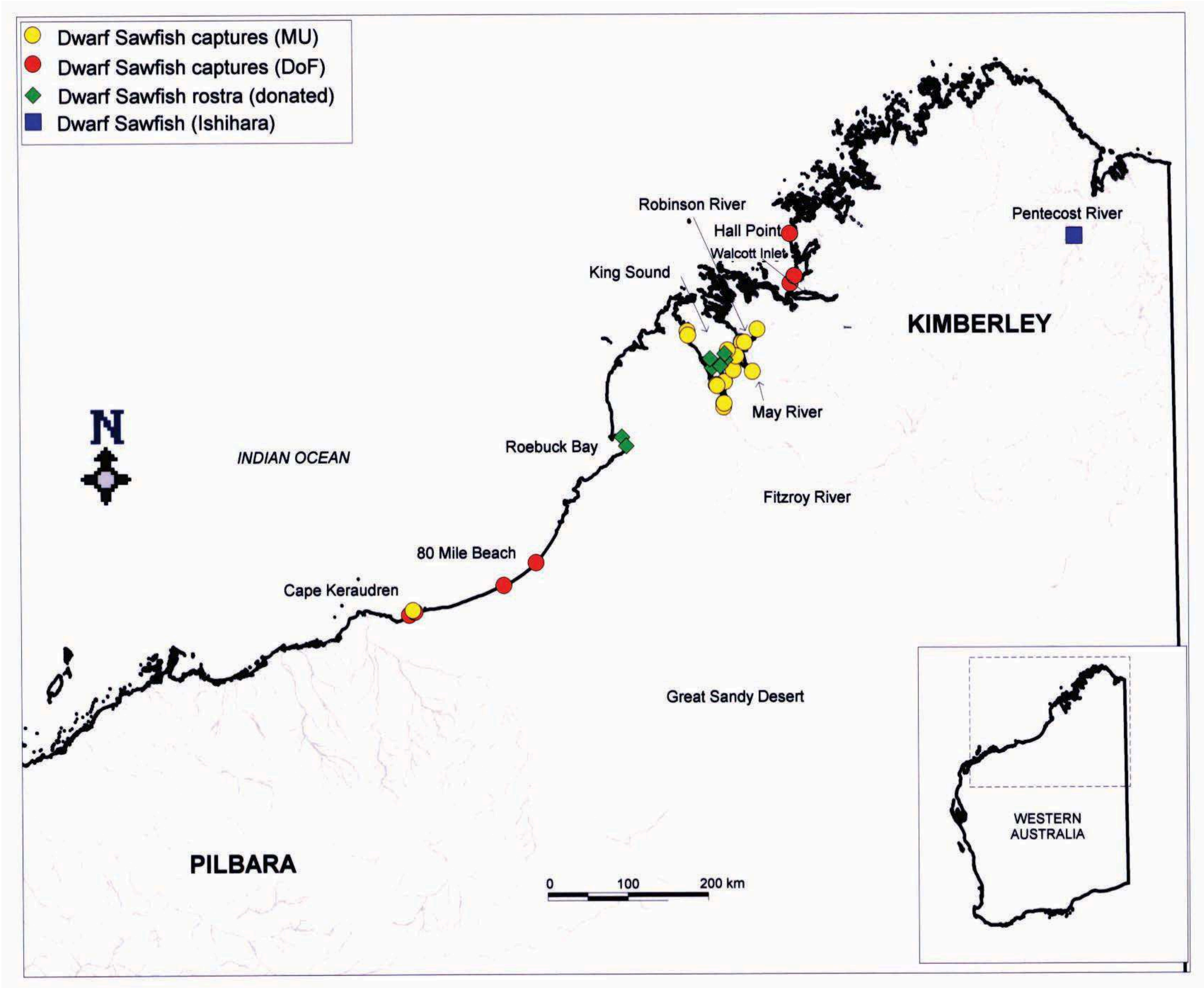

Figure 6. Capture locations of *Pristis clavata* in Western Australia (data derived from CFFR, Murdoch University (MU), Department of Fisheries (DoF), Stevens *et al*. (2008), Ishihara *et al*. (1991a) and rostra donated to this study). N.B. Donated rostra from King Sound are represented on the map by only a few samples, and are actually considerable in number (>100). DoF includes data presented in Stevens *et al*. (2008).

southern Kimberley (Table 1, Fig. 6) (this study; Thorburn *et al*. 2003, 2008; Stevens *et al*. 2008). Ishihara *et al*. (1991a) recorded *P. clavata* in the Pentecost River system. While the majority of captures are from shallow, tidally influenced systems, some captures from considerably deeper water (trawls) have been reported (Stephenson & Chidlow 2003).

Pristis clavata has been estimated to reach maturity at around 255–260 cm TL (Last & Stevens 2009). This is supported by the observations of male *P. clavata* in King Sound measuring 194, 219 (this study) and 233 (Thorburn *et al*. 2008) cm TL to have semi-calcified claspers, while males measuring 295 and 306 cm TL had fully calcified and elongated claspers (Peverell 2005). Age of female maturity is uncertain. Capture sites for rostra donated during this study were very localised, with a total of 109 from the King Sound and three from Roebuck Bay (Table 1, Fig. 6). In terms of mature fish, based on a length at maturity of ~240 cm, which corresponds to a total rostrum length of ~45 cm, mature individuals have been recorded from Hall Point in the north to Cape Keraudren in the south. The vast majority of catches and donated rostra have, however, been from the King Sound (Fig. 6). The smallest individuals recorded have been caught at the Fitzroy River mouth (n = 5, TRL <21 cm, TL <100 cm), while a further four donated rostra <21 cm in length came from the King Sound. A further three small individuals (TRL <25 cm) from 80 Mile Beach were recorded by the Department of Fisheries, Government of Western Australia.

Using vertebral ring counts (n = 5), and assuming annuli correspond to one years growth, Thorburn *et al.* (2008) estimated *P. clavata* of 90 cm TL in the King Sound to be of one year of age, of 110–120 cm TL to be of two years of age and that of 160 cm TL to be of three years of age. These estimations were in close congruence with that of Peverell (2008) for Gulf of Carpentaria fish.

Information about the population structure of *P. clavata* in Australian waters is limited to Phillips *et al.* (2011) and was based upon nucleotide sequence variation from a portion of the control region in the mitochondrial genome, suggesting that *P. clavata* may be genetically

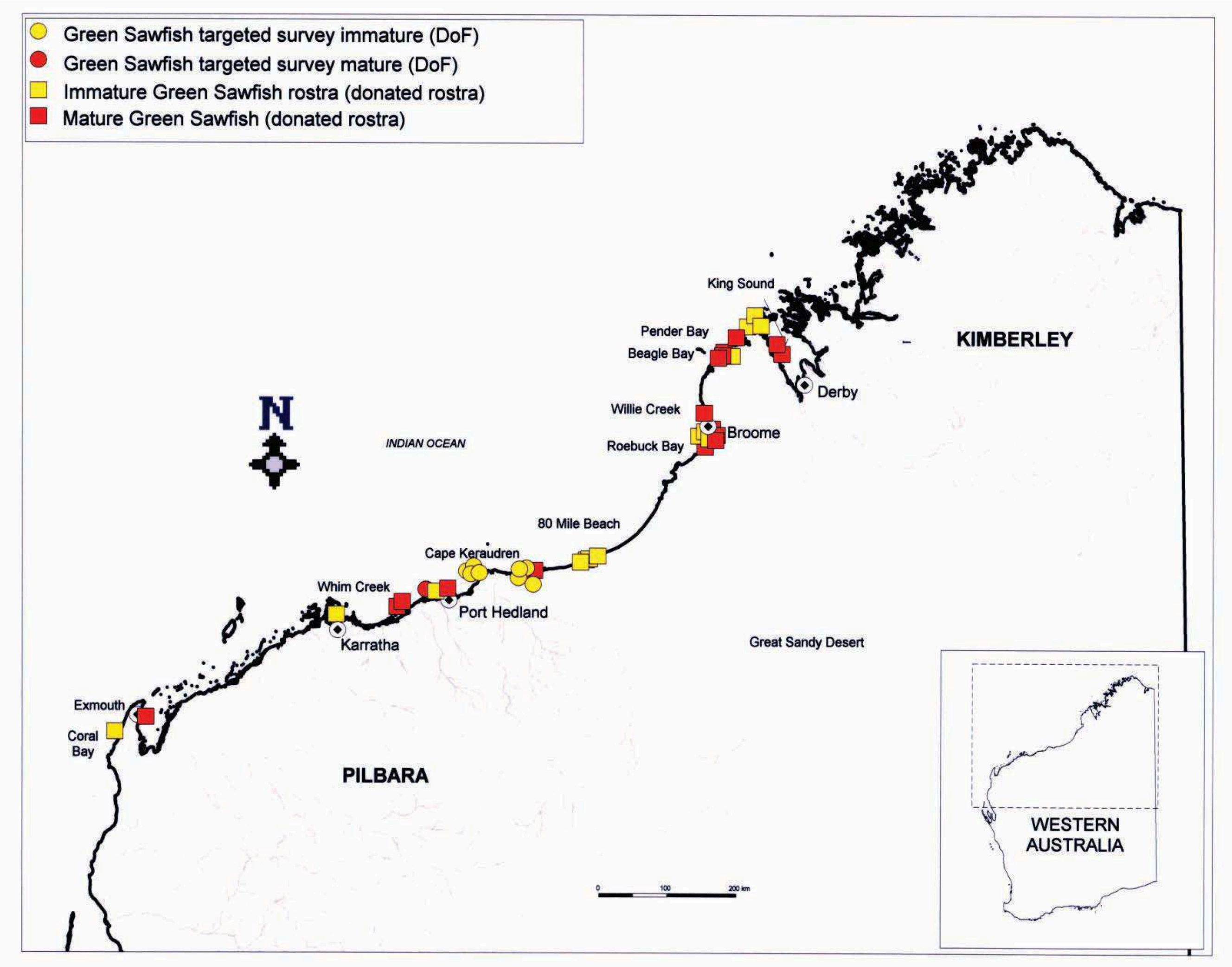

Figure 7. Locations of *Pristis zijsron* in Western Australian waters (data derived from CFFR, Murdoch University, Department of Fisheries (DoF), Stevens *et al*. (2008) and donated rostra from this study).

subdivided between the west coast of Australia and the Gulf of Carpentaria, although this comparison was not statistically significant (see Phillips *et al.* 2011). As assemblages of *P. microdon* and *P. zijsron* from the west coast and the Gulf of Carpentaria were found to be genetically distinct, *P. clavata* is probably also differentiated between these regions (Phillips *et al.* 2011).

Green Sawfish (Pristis zijsron)

Morphology and recognition

Pristis zijsron can be distinguished through the following morphological characteristics: origin of first dorsal fin in line or just posterior with that of the pelvic fin (Compagno & Last 1999); dorsal fins large and similar in width and height; ventral lobe of caudal fin minimal, less than half the length of the dorsal lobe (Last & Stevens 2009); no subterminal notch (Compagno & Last 1999); proximal rostral teeth begin near base of rostrum; 23–34 pairs of rostral teeth (Compagno & Last 1999; Last & Stevens 2009); relatively (*c.f.* other Australian sawfishes) extreme tapering of tooth interspaces with proximity to the tip of the rostra (posteriormost tooth gap 2–7 times that of the anteriormost gap) (Compagno & Last 1999; Last & Stevens 2009); groove on posterior margin of rostral teeth prominent in adults, but lacking in juveniles (Compagno & Last 1999). TRL is 24–30.6% of TL based on nine *P. zijsron* sourced from throughout the Indian Ocean, and ranging between 71 cm and 342 cm TL (TRL = 0.2825 TL – 3.7389) (Faria 2007). *Pristis zijsron* is most easily distinguished from the other sawfishes by a greater TRL:TL ratio and by the relatively extreme tapering of tooth interspace with progression towards the distal end of the rostra.

Life history

Last and Stevens (2009) state that *P. zijsron* is widely distributed in the Indian Ocean *e.g*. South Africa, India, Indonesia and Australia. They indicate that the Australian distribution extends from Sydney north and west to Coral Bay (near Exmouth) in Western Australia, with a single record off South Australia; however a decline in southward range on the east Australian coast is alleged to have occurred, to the point that it is now presumed extinct in New South Wales waters. In Western Australia there have been limited studies on the species, but from donated rostra, *P. zijsron* has been recorded from Coral Bay and the Exmouth Gulf to the

Western Australia/Northern Territory border. However, the majority of capture locations are between Karratha and One Arm Point (Fig. 7), with very few specimens (n = 3) recorded in King Sound, which is in stark contrast to *P. microdon* and *P. clavata*. Most captures of the species have been from near-shore waters, however, interactions have been reported from the Pilbara Fish Trawl Fishery, which operates in depths between 30 and 200 m (Stephenson & Chidlow 2003). Unlike *P. microdon*, *P. zijsron* does not move into freshwaters and its life-cycle is completed in the marine environment. Based on data obtained from donated rostra, mature *P. zijsron* (>300 cm TL, having a TRL>81 cm) in Western Australia are widespread and are currently known from Exmouth Gulf, Whim Creek, Port Hedland, 80 Mile Beach, Roebuck Bay, Willie Creek, Beagle Bay, Pender Bay, King Sound (including Goodenough Bay) (Table 1, Fig. 7). A further two individuals (>400 cm TL) were recorded by Stephenson and Chidlow (2003) in offshore waters of the Pilbara. The largest *P. zijsron* in our records was from Beagle Bay, which had a rostrum length of 165.5 cm, which would equate to a fish of ~600 cm in TL (Fig. 7). The smallest recorded *P. zijsron* in our collections originated at: Roebuck Bay (TRL = 16 cm and 22 cm), Karratha (TRL = 22.3 cm), Cape Leveque (TRL = 26.2 cm), One Arm Point (TRL = 27.3 cm), 80 Mile Beach (TRL = 30 cm), Cape Keraudren (TRL = 31 cm), Port Hedland (TRL = 32.0 cm) and Coral Bay (TRL = 32.2 cm) (Fig. 7), and are presumed to be new recruits. Additionally, Stevens *et al*. (2008) recorded a number of small juveniles near Cape Keraudren (at the southern end of 80 Mile Beach), which ranged in total length from 100 to 212 cm, with four <120 cm TL. These small individuals at 100, 107 (n = 2) and 111 cm TL would have had rostrum lengths of <30 cm. Conservatively assuming 0+ *P. zijsron* are <130 cm TL, these captures suggest pupping occurs from at least Coral Bay in the south to at least One Arm Point in the north of Western Australia; however, there are limited data for the north Kimberley coast and they are likely to be more prevalent between Karratha and the Exmouth Gulf (Fig. 7).

Vertebral analysis for aging demonstrated that *P. zijsron* of 83–102 cm (n = 8), 128 cm (n = 1), 157–166 cm (n = 2), 220 cm (n = 1), 254–257 cm (n = 2), 380 cm (n = 1), 438 cm (n = 1), 449 cm (n = 1), and 482 cm (n = 1) TL are likely to belong to the 0+, 1+, 2+, 3+, 5+, 8+, 10+, 16+ and 18+ age classes, respectively (Peverell 2008). *Pristis zijsron* attains a total length of at least 540 cm (Peverell 2005, 2008), with reports as large as 760 cm TL (Last & Stevens 2009).

In Queensland, *P. zijsron* pups in January (wet season) (Peverell 2005). Litter size is approximately 12 (Last & Stevens 2009). Male and female *P. zijsron* mature around 300 cm TL (~9 years of age) (Last & Stevens 2009). This was supported with the observation of a pregnant 458 cm TL female (Compagno & Last 1999) as well as a mature 380 cm TL female in Queensland (Peverell 2005).

The population structure of *P. zijsron* was assessed using nucleotide sequence variation in a portion of the mitochondrial control region, which is maternally inherited (Phillips *et al*. 2009b, 2011). The assessment demonstrated that this species is genetically sub-divided across northern Australia, with significant structure found between the west coast and the Gulf of Carpentaria (Phillips *et al*. 2009b, 2011).

Distribution and ecology of *Glyphis* spp. in north-western Australia

The two Australian species of *Glyphis* were only formally described in 2008 (see Compagno *et al*. 2008), and a review of these species was compiled by Pillans *et al*. (2009). Only one species, *G. garricki,* is confirmed from Western Australia, however, it is possible that *G. glyphis* occurs in at least the east Kimberley.

Northern River Shark (Glyphis garricki)

Morphology and recognition

Glyphis garricki is a medium-large carcharinid (whaler shark), that can be distinguished through the following morphological characteristics: greyish dorsal and white ventral colorations; border of the ventral and dorsal surfaces, referred to as the watermark boundary or waterline (Compagno *et al*. 2008), exists approximately an eye diameter below the orbit (Compagno *et al*. 2008); no discernible black demarcations, with exception of minor dusky tip on the terminal caudal lobe and faint black coloration on apex of terminal margin and ventral caudal lobe (Compagno *et al*. 2008); head fairly elongated, sloping and rounded (Compagno *et al*. 2008); small eyes, ranging from between 0.77% and 1.03% of the TL (Thorburn & Morgan 2004, Thorburn 2006) or 0.83–1.09 cm in length (Compagno *et al*. 2008); first dorsal fin triangular in shape (Thorburn 2006; Compagno *et al*. 2008); second dorsal fin 58–66% the height of the first (Thorburn & Morgan 2004; Compagno *et al*. 2008); pectoral fins large and slightly curved with narrow bases (Thorburn 2006; Compagno *et al*. 2008); anal fin is only slightly smaller (72–84%) in size compared to second dorsal, with the fin origin marginally posterior to that of second dorsal fin (Thorburn 2006; Compagno *et al*. 2008), lacks a notch observed in other similar species like *C. leucas* and Pigeye Shark (*Carcharhinus ambionensis*) (Field *et al*. 2008); asymmetric caudal fin, with a narrow and longer dorsal caudal lobe (*c.f.* ventral caudal lobe); subterminal notch present (Thorburn 2006; Compagno *et al*. 2008); no pre, inter or postdorsal ridge (Thorburn 2006); longitudinal pre-caudal pit (Compagno *et al*. 2008); upper jaw tooth count of 31–34; lower jaw tooth count of 30–35 (Last & Stevens 2009); upper teeth broadly triangular, lower teeth slender, slightly curved back with spear-like tips (Thorburn 2006; Compagno *et al*. 2008). Most similar in appearance to *G. glyphis*, but can be visually distinguished by the location of the waterline, which crosses just below the orbit in *G. glyphis*. *Glyphis garricki* is often confused with *C. leucas* and *C. ambionensis*, but can be differentiated from these species by its large second dorsal fin, and longitudinal triangular precaudal pit (*c.f.* crescentic precaudal pit) (Compagno & Niem 1998; Compagno *et al*. 2008).

Life history

Pupped at 50–60 cm, *G. garricki* are estimated to reach up to 300 cm TL (Stevens *et al*. 2005; Last & Stevens 2009). The largest recorded capture of *G. garricki* in Australian waters is a 251 cm TL female, but in Western Australia the largest male and female recorded is 142 cm TL (18.64 kg) and 135 cm TL (16.83 kg), respectively (Thorburn & Morgan 2004; Thorburn 2006).

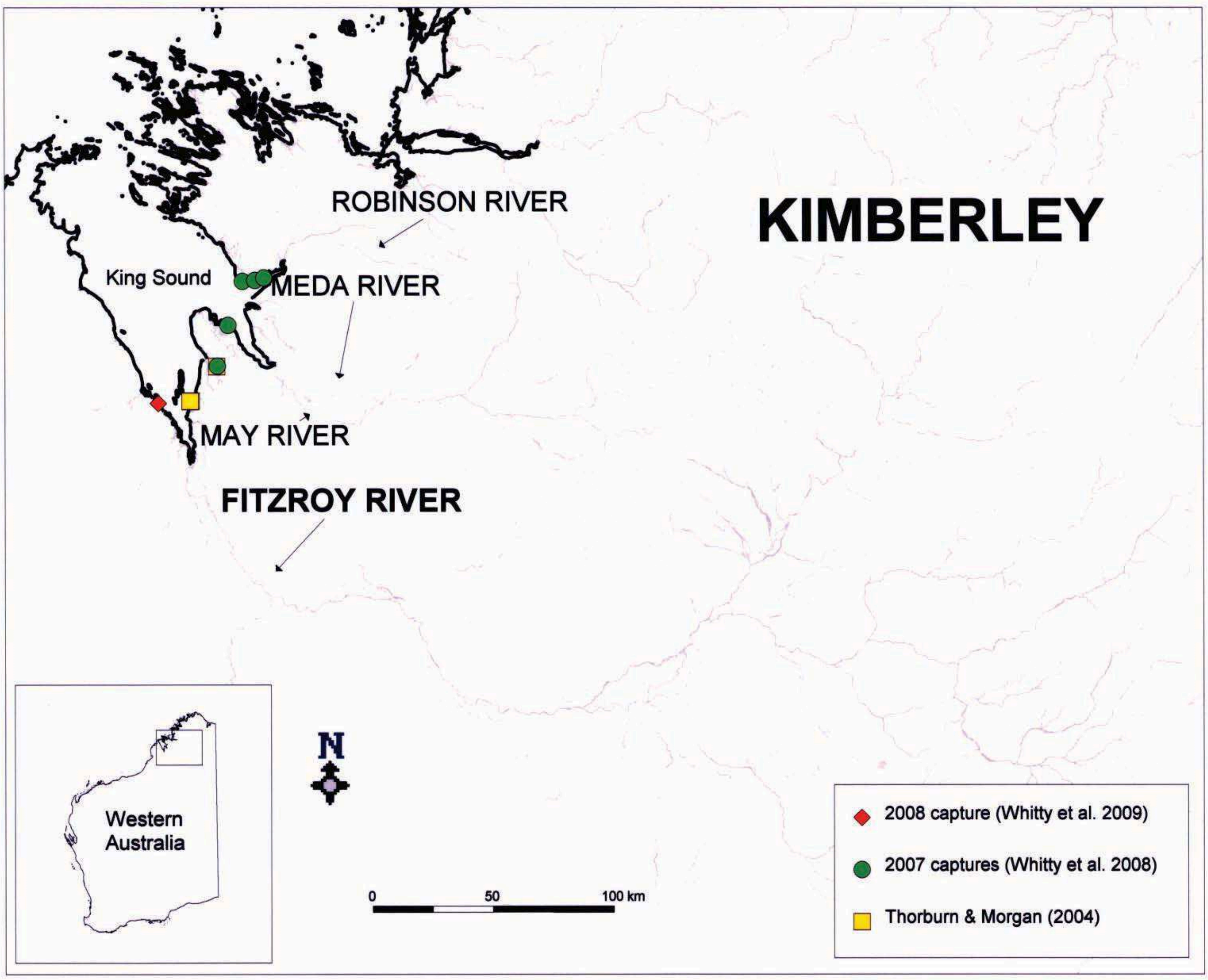

Figure 8. Known capture locations of *Glyphis garricki* in the west Kimberley (from Thorburn & Morgan 2004; Whitty *et al*. (2008, 2009a)). See Pillans *et al*. (2009) for the distribution of the species in the east Kimberley.

Vertebral counts of 137–151 (precaudal = 73–83) in Australian waters (Compagno *et al*. 2008; Last & Stevens 2009); 140–151 (avg =146 (+1.53 SE) in the King Sound (Thorburn & Morgan 2004). Fusion of vertebrae was documented in three *G. garricki* (99 cm TL male, 142 cm TL male, 135 cm TL female) captured in the King Sound in 2002 and 2003 (Thorburn & Morgan 2004; Thorburn 2006). Thorburn and Morgan (2004) hypothesised this possibly was due to inbreeding associated with a small genetically effective population size, but not necessarily a small census size.

In Western Australia the majority of capture locations for *G. garricki* are in the King Sound in the west Kimberley (Fig. 8) (see Morgan *et al*. 2004; Thorburn & Morgan 2004, 2005b; Whitty *et al*. 2008, 2009a), however, recent collections have also occurred in the Ord River mouth and Joseph Bonaparte Gulf (Last & Stevens 2009; Pillans *et al*. 2009). Most collections in Western Australia have occurred in turbid, macrotidal mangrove systems of the King Sound in salinities >20 ppt over sandy or silty substrates. Also known from a few locations in the Northern Territory (Field *et al*. 2008; Pillans *et al*. 2009). Pillans *et al*. (2009) provided records of 32 individual *G. garricki* from marine, estuarine and freshwater habitats in Western Australia and the Northern Territory, including 13 from the King Sound (Thorburn & Morgan 2004) and a further 11 from the north-eastern Kimberley in the King River (n = 3), Joseph Bonaparte Gulf (n = 6), and the Ord River (n = 2). A further 12 individuals have since been recorded in King Sound (this study) and thus ~82% of all known captures of this rare species in Australia are from Western Australia, and 50% are from King Sound.

Little is known about the age and growth of *G. garricki*. Initial aging work by Tanaka (1991) estimated a 131 cm TL female in the Northern Territory to be four years of age. Using this information with an estimated pupping size of 50–60 cm TL, growth in the first four years was estimated to average 19 cm year^{-1} (Stevens *et al*. 2005).

Litter size has been shown to be approximately nine (Stevens *et al*. 2005; Pillans *et al*. 2009). Stevens *et al*. (2005) estimated maturity to occur between 170 and 200 cm TL, based on the assumption that *G. garricki* has a similar growth rate to *C. leucas*. In King Sound, males of 99.4 (Thorburn & Morgan 2004) and 109 cm TL (Whitty *et al*.

2009) were found to have semi-calcified claspers (*i.e.* were maturing), whereas a 136.5 cm TL (Whitty *et al.* 2009a) and a 141.8 cm TL male (Thorburn & Morgan 2004; Thorburn 2006) were found to be mature, suggesting the estimate from Stevens *et al.* (2005) was high, or at least not accurate for males in the west Kimberley. Female maturity likely occurs at a size <177 cm TL as one female of this size was recorded to contain nine embryos (Last & Stevens 2009). Females between 147 and 157 cm TL (n = 4) were found to be immature (Stevens *et al.* 2005), supporting the view that maturity occurs above this size.

The only genetic study for *G. garricki* is that by Wynen *et al.* (2009). This was essentially performed to determine the extent and nature of genetic differences between the different *Glyphis* spp. Virtually nothing is known about the population structure of *G. garricki* in Australian waters. Wynen *et al.* (2009) assessed whether variation in a 500 bp fragment of the mitochondrial control region was sufficient to detect genetic differentiation within *Glyphis* species across northern Australia, however, no genetic variation was found in *G. garricki* despite samples from Western Australia and the Northern Territory (Wynen *et al.* 2009). It was concluded that more variable markers, such as microsatellite loci, would be necessary to investigate the population genetics of this species (Wynen *et al.* 2009), although the sample size used in this assessment was very small (n = 2; see Wynen *et al.* 2009).

General threats to the species

Peverell (2008) proposed that the Gulf of Carpentaria offers refuges for sawfishes on the basis that it is relatively undisturbed in terms of coastal development with low levels of habitat degradation and a multitude of spatial and temporal fishing closures. This could also be applied to the northern Pilbara and most of the Kimberley which is sparsely populated and relatively pristine, and where commercial fisheries are at a relatively low level with considerable restrictions. Furthermore Phillips *et al.* (2011) suggest that both *P. clavata* and *P. zijsron* have genetically 'healthy' populations on the west coast while genetic diversity of these species is reduced in the Gulf of Carpentaria. The threats to these species are, however, varied, and while they are highly susceptible to entanglement in fishing nets, their fins are greatly valued in the international fin trade as are their rostra, which are often taken as souvenirs (Bigelow & Schroeder 1953; Camhi *et al.* 1998; Seitz & Poulakis 2006). However, all Australian *Pristis* spp. are now protected in Australian waters and there are no direct fisheries for this group, although by-catch of *Pristis* spp. does occur in several fisheries (Stephenson & Chidlow 2003; McAuley *et al.* 2005; Peverell 2005; Field *et al.* 2008). Stevens *et al.* (2005) reported the gill net fisheries to have the highest percent of *Pristis* by-catch (80.2%), followed by trawling (16.6%), line (9.2%) and recreational gears (0.3%). In Western Australia, a range of 0.7–1.1 t (live weight) of *P. microdon* was estimated to be captured in the northern regions of the Kimberley Gillnet and Barramundi Managed Fishery (KGBMF; excluding the Broome and Eighty Mile Beach area) in 2000–2004 (McAuley *et al.* 2005). Their distribution in the Ord system has been impacted by the regulation of the system (Doupé *et al.* 2005) and in the Fitzroy River by the Camballin Barrage (Morgan *et al.* 2005). For *P. clavata* it was estimated that in 2000–2004, tonnage of *P. clavata* captured ranged from 2.6–6.5 t (live weight) in the Broome and Eighty Mile Beach Area, and ranged from 6.6–11.1 t (live weight) in the more northern regions of the Kimberley Gillnet and Barramundi Managed Fishery (McAuley *et al.* 2005). In 2000–2004, tonnage of *P. zijsron* captured was estimated to range between 5.3 and 9.6 t (live weight) in the Broome and Eighty Mile Beach Area (McAuley *et al.* 2005) and 4 t in the Pilbara Fish Trawl Fishery in 2001 which operates in ~50–200 m depth (Stephenson & Chidlow 2003). The high number of rostra obtained during this study (283) suggests that there is also an unsubstantiated harvest in the various fishing sectors in northern Western Australia. *Glyphis garricki* are potentially impacted on by a very low level of commercial gill-netting, but no information exists on this.

Conclusions

For the pristids, the species catch data together with data obtained from the donated rostra and the relationship of TL to TRL for each species, were valuable in constructing the most comprehensive distribution maps of these species in Western Australia. These data were also valuable in identifying the regions where mature fish were present, as well as identifying potential nursery areas of the different species (*e.g.* Figures 5 and 7). The use of donated rostra has reduced biases on distributions that were generated from targeted surveys in limited areas.

Results from this study indicate that newborn pups of *P. microdon* are restricted to the mouths and freshwaters of the major catchments within the King Sound. No other rivers sampled in Western Australia have been found to host juvenile *P. microdon*. In contrast, newborn pups of *P. clavata* are only known from the mouth of the Fitzroy River (tidal waters), King Sound and 80 Mile Beach. With regard to *P. zijsron,* pupping locations appear far more widespread and pups have been found at a number of coastal locations between Karratha and Cape Leveque. In general the proposed nurseries are all shallow, near-shore habitats often in close proximity to river mouths. Using these habitat types as nursery areas would likely decrease the risk of predation by larger marine predators (Heupel *et al.* 2007). The records of numerous juvenile *P. microdon, P. clavata* and *G. garricki* within the Fitzroy River and/or King Sound, suggests that this area is important for the maintenance of these species in Western Australia. The Fitzroy River itself is arguably one of the most important *P. microdon* nurseries throughout their known range. Additionally, using rivers as nurseries would limit the interaction of pups with near-shore gill net fisheries. The Fitzroy River offers highly seasonal and predictable flow regimes giving continuity of habitats throughout the seasons, unlike many rivers of the Pilbara where rainfall and river discharge are sporadic (Morgan & Gill 2004). Immensity of river discharge and increases in stage height during the wet season in the Fitzroy, likely adds to the success of the species in the river, due to the intrinsic relationship between the size of the wet season and recruitment/ survivorship of freshwater and estuarine fishes (Mills &

Mann 1985; Drinkwater & Frank 1994) including *P. microdon*. Additionally the intricate and abundant tidal mangrove systems, river estuaries, and rivers of King Sound provide ideal nursery areas for *P. clavata* and *G. garricki* (N.B. *G. garricki* neonates and juveniles are occasionally found in freshwater (Taniuchi *et al.* 1991a; Pillans *et al*. 2009), but they have not been recorded in freshwater in Western Australia).

Similar to the range of 0+ *P. zijsron*, mature *P. zijsron* are known from Whim Creek to King Sound. On the other hand, mature *P. microdon* appear to be less widespread, being known from 80 Mile Beach (Cape Keraudren) to King Sound. Mature *P. clavata* are similarly distributed to *P. zijsron*, being found from Hall Point to Cape Keraudren, albeit in low numbers. The majority of known records of mature *P. clavata*, based largely on rostral collections, have originated from King Sound. The tidal mangrove systems of King Sound are important nurseries for *P. clavata* and also *G. garricki*, with the mouths of tidal creeks in King Sound being the only known habitats for *G. garricki* in the west Kimberley, where 50% of all Australian records of the species have come from.

The increase in development of the Kimberley and subsequent human population growth will inevitably lead to a decline in the viability of these species, particularly if migration paths are reduced (*e.g.* by barriers in the Fitzroy River as has occurred in the Ord River (see Doupé *et al*. 2005)) or by an increase in interactions with recreational and commercial fishers. There are knowledge gaps in terms of the distribution and target surveys are required between King Sound and the Ord River.

Acknowledgements: Thanks to Murdoch University, the Department of the Environment, Water, Heritage and the Arts, Western Australian NRM, Natural Heritage Trust, Threatened Species Network, Kimberley Land Council, Yiriman Project, Yiriman Rangers, Nyikina-Mangala Rangers, Mitre 10 Derby, Woodside Energy, Colin Simpfendorfer, Stirling Peverell, Stephen Beatty, Travis Fazeldean, Jim and Geraldine Kelly, Brendan Ebner and the recreational and commercial fishing community, and importantly, the people of the Kimberley and Pilbara for providing rostra. Thanks also to those organisations that provided rostra including the Western Australian Museum, Cairns Marine, Northern Territory Department of Fisheires, Museum and Art Galleries of the Northern Territory and Australian Museum. The research was conducted with a Murdoch University Human Ethics Permit (#2008/018).

References

Bigelow H B & Schroeder W C 1953 Sawfishes, guitarfishes, skates and rays. In: Parr E & Olsen Y H (Eds) Fishes of the Western North Atlantic. Memoirs of the Sears Memorial Foundation for Marine Research. Yale University, New Haven, Connecticut 11–514.

Camhi M., Fowler S, Musick J, Bräutigan A & Fordhan S 1998 Sharks and their relatives. Ecology and Conservation. Occasional Paper of the IUCN Species Survival Commission 20: 1–39.

Chidlow J A 2007 First record of the freshwater sawfish, *Pristis microdon*, from southwestern Australian waters. Records of the Western Australian Museum 23: 307–308.

Compagno L J V & Niem V H 1998 Carcharhinidae, Requiem Sharks. In: Carpenter K E and Niem V H (Eds) FAO Species Identification Guide for Fisheries Purposes. The Living Marine Resources of the Western Central Pacific. Vol. 2. Cephalopods, Crustaceans, Holothurians and Sharks. FAO, Rome, 1312–1360.

Compagno L J V & Last P R 1999 Order Pristiphormes, Pristidae, Sawfishes. In: Carpenter K E & Niem V H (Eds) FAO Species Identification Guide for Fishery Purposes.The Living Marine Resources of the Western Central Pacific. Volume 3. Batoid Fishes, Chimaeras and Bony Fishes Part 1 (Elopidae to Linophrynidae). FAO, Rome, 1410–1417.

Compagno L J V, White W T & Last P R 2008 *Glyphis garricki* sp. nov., a new species of river shark (Carcharhiniformes: Carcharhinidae) from northern Australia and Papua New Guinea, with a redescription of *Glyphis glyphis* (Müller & Henle, 1839). In: Last P R, White W T & Pogonoski J J (Eds) Descriptions of New Australian Chondrichthyans. CSIRO Marine and Atmospheric Research, Hobart, Tasmania, 203–225.

Doupé R G, Morgan D L & Gill H S 2005 Prospects for a restorative fishery enhancement of Lake Kununurra: a high-level tropical impoundment on the Ord River, Western Australia. Pacific Conservation Biology 11: 136–146.

Drinkwater K F & Frank K T 1994 Effects of river regulation and diversion on marine fish and invertebrates. Aquatic Conservation: Marine and Freshwater Ecosystems 4(2): 135–151.

Faria V V 2007 Taxonomic review, phylogeny, and geographical population structure of the sawfishes (Chondrichthyes, Pristiformes). PhD Thesis, Iowa State University, Ames, Iowa.

Field I C, Carters R, Buckworth R C, Meekan M G & Bradshaw C J A 2008 Distribution and abundance of *Glyphis* and sawfishes in northern Australia and their potential interactions with commercial fisheries. Final report to the Department of the Environment, Water, Heritage and the Arts. 39 pp.

Gill H S, Morgan D L, Doupé R G & Rowland A J 2006 The fishes of Lake Kununurra, a highly regulated section of the Ord River in northern Australia. Records of the Western Australian Museum 23: 1–6.

Heupel, M R, Carlson, J K & Simpfendorfer, C A 2007 Shark nursery areas: concepts, definition, characterization and assumptions. Marine Ecology Progress Series 337: 287–297.

Ishihara H, Taniuchi T, Mitsuhiko S & Last P R 1991a Record of *Pristis clavata* Garman from the Pentecost River, Western Australia, with brief notes on its osmoregulation and comments on the systematics of Pristidae. In: Shimizu M & Taniuchi T (Eds) Studies on Elasmobranchs Collected From Seven River Systems in Northern Australia and Papua New Guinea. The University Museum, University of Tokyo, Tokyo, Nature and Culture 3: 43–53.

Ishihara H, Taniuchi T & Shimizu M 1991b Sexual dimorphism in number of rostral teeth in the sawfish, *Pristis microdon* collected from Australia and Papua New Guinea. In: Shimizu M & Taniuchi T (Eds) Studies on Elasmobranchs Collected From Seven River Systems in Northern Australia and Papua New Guinea. The University Museum, University of Tokyo, Tokyo, Nature and Culture 3: 83–89.

Last P R & Stevens J D 2009 Sharks and Rays of Australia. Second Edition. CSIRO Publishing, Melbourne.

McAuley R, Lenanton R, Chidlow J, Allison R & Heist E 2005 Biology and stock assessment of the thickskin (sandbar) shark, *Carcharhinus plumeus*, in Western Australia and further refinement of the dusky shark, *Carcharhinus obscures*, stock assessment. Final FRDC Perport – Project 2000/134. Fisheries Research Report No. 151, Department of Fisheries, Western Australia, 132 p.

Mills C A & Mann R H K 1985 Environmental-induced fluctuations in year-class strength and their implications for management. Journal of Fish Biology 27: 209–226.

Morgan D L, Allen M G, Bedford P & Horstman M 2004 Fish fauna of the Fitzroy River in the Kimberley region of Western Australia – including the Bunuba, Gooniyandi, Ngarinyin, Nyikina and Walmajarri Aboriginal names. Records of the Western Australian Museum 22: 147–161.

Morgan D L & Gill H S 2004 Fish fauna in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia – evidence for three subprovinces. Zootaxa 636: 1–43.

Morgan D, Thorburn D, Fenton J, Wallace-smith H & Goodson S 2005 Influence of the Camballin Barrage on fish communities in the Fitzroy River, Western Australia. Murdoch University/Kimberley Land Council/Department of Environment report to Land and Water Australia.

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

Peverell S C 2008 Sawfish (Pristidae) of the Gulf of Carpentaria, Queensland Australia. MSc Thesis, James Cook University, Townsville, Queensland.

Phillips N M 2006 Development of genetic and morphological methods for the study of sawfish (Pristidae) populations via analysis of old rostra. Honours Thesis, Murdoch University, Perth, Western Australia.

Phillips N, Chaplin J, Morgan D & Peverell S 2009a Extraction and amplification of DNA from the dried rostra of sawfishes (Pristidae) for applications in conservation genetics. Pacific Conservation Biology 15: 128–134.

Phillips N M, Chaplin J A, Morgan D L, Peverell S C & Thorburn D C 2008 Genetic diversity and population structure of the Freshwater Sawfish (*Pristis microdon*) in Australian waters. In J M Whitty, N M Phillips, D L Morgan, J A Chaplin, D C Thorburn & S C Peverell (Eds). Habitat associations of Freshwater Sawfish (*Pristis microdon*) and Northern River Shark (*Glyphis* sp. C): including genetic analysis of *P. microdon* across northern Australia. Centre for Fish & Fisheries Research (Murdoch University) report to the Department of the Environment, Water, Heritage and the Arts, Australian Government.

Phillips N M, Chaplin J A, Morgan D L & Peverell S C 2009b Preliminary results of a microsatellite and mitochondrial DNA assessment of the genetic diversity and population structure of, respectively, the freshwater sawfish, *Pristis microdon*, and the green sawfish, *Pristis zijsron*, in Australian waters. In N M Phillips, J M Whitty, D L Morgan, J A Chaplin, D C Thorburn & S C Peverell (Eds) Freshwater Sawfish, *Pristis microdon*, movements and population demographics in the Fitzroy River, Western Australia and genetic analysis of *P. microdon* and *Pristis zijsron*. Murdoch University report to the Department of the Environment, Water, Heritage, and the Arts, Australian Government.

Phillips N M, Chaplin J A, Morgan D L & Peverell S C 2011 Population genetic structure and genetic diversity of three critically endangered *Pristis* sawfishes in northern Australian waters. Marine Biology 158: 903–915.

Pillans R D, Stevens J D, Kyne P M & Salini J 2009 Observations on the distribution, biology, short-term movements and habitat requirements of river sharks *Glyphis* spp. in northern Australia. Endangered Species Research 2009: 1–12.

Seitz J C & Poulakis G R 2006 Anthropogenic effects on the smalltooth sawfish (*Pristis pectinata*) in the United States. Marine Pollution Bulletin 52: 1533–1540.

Simpfendorfer C A 2000 Predicting population recovery rates for endangered western Atlantic sawfishes using demographic analysis. Environmental Biology of Fishes 58: 371–377.

Skelton P 2001 A complete guide to the freshwater fishes of southern Africa. Struik Publishers, Cape Town.

Stephenson P & Chidlow J 2003 Bycatch in the Pilbara Trawl Fishery. WA Marine Research Laboratories, Department of Fisheries, Government of Western Australia report to Natural Heritage Trust.

Stevens J D, McAuley R B, Simpfendorfer C A & Pillans R D 2008 Spatial distribution and habitat utilisation of sawfish (Pristis spp) in relation to fishing in northern Australia. A report to the Department of the Environment, Water, Heritage and the Arts.

Stevens J D, Pillans R D and Salini J 2005 Conservation assessment of *Glyphis* sp. A (Speartooth Shark), *Glyphis* sp. C (Northern River Shark), *Pristis microdon* (Freshwater Sawfish) and *Pristis zijsron* (Green Sawfish). Final report to the Department of Environment and Heritage, Australian Government. 84 pp.

Tanaka S 1991 Age estimation of Freshwater Sawfish and sharks in northern Australia and Papua New Guinea. In: Shimizu M & Taniuchi T (Eds) Studies on Elasmobranchs Collected From Seven River Systems in Northern Australia and Papua New Guinea. The University Museum, University of Tokyo, Tokyo, Nature and Culture 3: 71–82.

Taniuchi T, Ishihara H, Tanaka S, Hyodo S, Murakami M and Seret B 2003 Occurrence of two species of elasmobranchs, *Carcharhinus leucas* and *Pristis microdon*, in Betsiboka River, west Madagascar. Cybium 27: 237–241.

Taniuchi T, Kan T T, Tanaka S & Otake T 1991a Collection and measurement data and diagnostic characters of elasmobranchs collected from three river systems in Papua New Guinea. In: Shimizu M & Taniuchi T (Eds) Studies on Elasmobranchs Collected From Seven River Systems in Northern Australia and Papua New Guinea. The University Museum, University of Tokyo, Tokyo, Nature and Culture 3: 27–41.

Taniuchi T, Shimizu M, Sano M, Baba O & Last P R 1991b Descriptions of freshwater elasmobranchs collected from three rivers in Northern Australia. In: Shimizu M, Taniuchi T (Eds) Studies on Elasmobranchs Collected From Seven River Systems in Northern Australia and Papua New Guinea. The University Museum, University of Tokyo, Tokyo, Nature and Culture 3: 11–26.

Thorburn D C 2006 Biology, ecology and trophic interactions of elasmobranchs and other fishes in riverine waters of northern Australia. PhD Thesis, Murdoch University, Perth, Western Australia.

Thorburn D C & Morgan D L 2004 The northern river shark *Glyphis* sp. C (Carcharhinidae) discovered in Western Australia. Zootaxa 685: 1–8.

Thorburn D C & Morgan D L 2005b Threatened fishes of the world: *Glyphis* sp. C (Carcharhinidae). Environmental Biology of Fishes 73: 140.

Thorburn D C & Morgan D L 2005a Threatened fishes of the world: *Pristis microdon* Latham 1794 (Pristidae). Environmental Biology of Fishes 72: 465–466.

Thorburn D, Morgan D, Gill H, Johnson M, Wallace-Smith H, Vigilante T, Croft I & Fenton J 2004 Biology and cultural significance of the freshwater sawfish (*Pristis microdon*) in the Fitzroy River Kimberley, Western Australia. Report to the Threatened Species Network.

Thorburn D C, Morgan D L, Rowland A J & Gill H S 2007 Freshwater Sawfish *Pristis microdon* Latham, 1794 (Chondrichthyes : Pristidae) in the Kimberley region of Western Australia. Zootaxa 1471: 27–41.

Thorburn D C, Morgan D L, Rowland A J, Gill H S & Paling E 2008 Life history notes of the critically endangered dwarf sawfish, *Pristis clavata*, Garman 1906 from the Kimberley region of Western Australia. Environmental Biology of Fish 83: 139–145.

Thorburn D C, Peverell S, Stevens J D, Last P R and Rowland A J 2003 Status of freshwater and estuarine elasmobranchs in northern Australia. Final Report to Natural Heritage Trust.

Whitty J M, Morgan D L, Peverell S C, Thorburn D C & Beatty S J 2009b Ontogenetic depth partitioning by juvenile freshwater sawfish (*Pristis microdon*: Pristidae) in a riverine environment. Marine and Freshwater Research 60: 306–316.

Whitty J M, Morgan D L, Thorburn D C, Fazeldean T & Peverell S C 2008 Tracking the movements of Freshwater Sawfish (*Pristis microdon*) and Northern River Sharks (*Glyphis* sp. C) in the Fitzroy River. In: Whitty J M, Phillips N M, Morgan D

L, Chaplin J A, Thorburn D C & Peverell S C (Eds). Habitat associations of Freshwater Sawfish (*Pristis microdon*) and Northern River Shark (*Glyphis* sp. C): including genetic analysis of *P. microdon* across northern Australia. Centre for Fish & Fisheries Research (Murdoch University) report to the Department of the Environment, Water, Heritage and the Arts, Australian Government.

Whitty J M, Morgan D L & Thorburn D C 2009a Movements and interannual variation in the morphology and demographics of Freshwater Sawfish (*Pristis microdon*) in the Fitzroy River. In: Phillips N M, Whitty J M, Morgan D L, Chaplin J A, Thorburn D C & Peverell S C (Eds). Freshwater Sawfish (*Pristis microdon*) movements and population demographics in the Fitzroy River, Western Australia and genetic analysis of *P. microdon* and *Pristis zijsron*. Centre for Fish & Fisheries Research (Murdoch University) report to the Department of the Environment, Water, Heritage and the Arts, Australian Government.

Wynen L, Larson H, Thorburn D, Peverell S, Morgan D, Field I & Gibb K 2009 Mitochondrial DNA supports the identification of two endangered river sharks (*Glyphis glyhpis* and *Glyphis garricki*) across northern Australia. Marine and Freshwater Research 60: 554–562.