Spatial distribution and habitat utilisation of sawfish (*Pristis* spp) in relation to fishing in northern Australia.

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1. INTRODUCTION

1.1 Background

Up to seven species of sawfish (Family Pristidae) belonging to two genera (*Anoxpristis* and *Pristis*) occur around the world. Both genera, and four species, occur in Australia (Last and Stevens 1994). Further taxonomic research is required to resolve nomenclatural issues and provide definitive identifications of some species. The narrow sawfish (*Anoxypristis cuspidata*), dwarf sawfish (*Pristis clavata*), freshwater sawfish (*Pristis microdon*) and green sawfish (*Pristis zijsron*) occur mainly in inshore coastal waters and riverine environments of tropical northern Australia.

Because of their rostra, sawfish are particularly vulnerable to capture in all forms of net fishing gear. Their large size (up to 7 m) and power can pose a real threat to fishers, which means that live release has been rarely practised in the past. Sawfish fins are particularly valuable in the international fin trade and the flesh is also of good quality so there is usually a major incentive for targeting them or retaining them when taken as bycatch. Together with their generally low biological productivity (Peverell 2005), environmental degradation of their habitats has meant that most populations of sawfish around the world have either been extirpated over much of their original distribution or at least suffered major declines in abundance as well as reductions in their range (Cook *et al.* 2006). Australia, in particular areas of the Kimberley and Pilbara regions of north western Australia, probably represent some of the last relatively healthy populations of sawfish in the world. However, even in this region sawfish numbers might have been reduced by commercial and recreational fishing. Stobutzki *et al.* (2000) assessed sawfish as the species at greatest risk of unsustainable fishing in northern Australia. Recognising this, two species (*P. microdon* and *P. zijsron*) are listed as Vulnerable on the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and most sawfish species are given some level of protection in all northern States and the Territory (Pogonoski *et al.* 2002). All sawfish are listed as Totally Protected under the Western Australian Fish Resources Management Act (FRMA). They are all listed as Critically Endangered on the IUCN (World Conservation Union) Red List and are also listed on Appendix 1 of CITES, with the exception of *P. microdon* that is listed on Appendix 11. These instruments provide some protection from international trade. The biology and ecology of sawfish in Australia have received little attention until recently when increased funding opportunities resulting from their elevated conservation status focused attention on them (Thorburn *et al.* 2003, 2007).

1.2 Need

Pristis microdon and *P. zijsron* are listed on the Commonwealth EPBC Act and there is growing concern over the status of populations of all sawfish species in Australia. Available data shows a rapid decline in sawfish numbers and a severe range retraction along the east coast. Entanglement in commercial fishing nets is the main threat to sawfish populations. Reducing capture rates of sawfish in commercial gear depends on knowing where and when they encounter nets. However, information about sawfish habitat requirements and movements is lacking. There is a need to obtain data on the long-term habitat utilisation and fine-scale movement patterns of sawfish in Australia by employing a combination of satellite tags and active acoustic tracking. Preliminary data collected by the present applicants suggests that satellite tags will be an effective means of monitoring sawfish movements. Accurate long-term positional information can be obtained if satellite tags are used successfully on *Pristis*, and complementary data from manual acoustic tracking provides data on fine-scale vertical and horizontal movements and habitat utilisation. Data on long term movement patterns and habitat utilisation will allow for a better assessment of the interactions with coastal fishing gear and for the development of advice on mitigation methods, including the required spatial scale of management/conservation measures.

1.3 Objectives

- To use satellite Smart Position and Temperature (SPOT) tags on *Pristis microdon* (or other *Pristis* spp) for collecting long-term spatial data to examine interactions with coastal net fisheries.

- To use active acoustic tracking to determine fine-scale movement patterns, depth behaviour and habitat utilisation of *Pristis microdon* (or other *Pristis* spp).

- To utilise data on habitat requirements and long-term movement patterns to recommend management strategies and policies that would reduce the impact of commercial fishing on sawfish populations in northern Australia.

2. METHODS

2.1 Fieldtrips

Fieldwork for this DEWHA funded project was carried out from 10-22 April 2008 at Cape Keraudren (150 km NE of Port Hedland) in the east Pilbara region of Western Australia. Cape Keraudren is situated at the southern end of 80 Mile Beach and comprises both ocean beach habitat as well as muddy, mangrove lined bays fed by a number of tidal creeks. The Pardoo Roadhouse was used as the base for operations and fishing, tagging and tracking was carried out either from an aluminium dinghy or from the beach.

Two previous sawfish fieldtrips to the Kimberley region of northwestern Australia (environs of Hall Point and Eagle Point 15° 40’ S, 124° 23’ E to 16° 14’ S, 124° 23’ E) were carried out 8-21 August 2005 and 8-20 August 2006. This remote area has a semi-diurnal tidal variation which can exceed 10 meters, submerging the shoreline mangroves at high tide and exposing a kilometre of muddy or sandy shore at low tide. These two trips were carried out from the RV Naturaliste and were funded mainly by

Fisheries WA with contributions from CSIRO Marine and Atmospheric Research (CMAR) and the Mote Marine laboratory, Florida. Fishing, tagging and tracking was carried out from aluminium dinghies. Results from these two fieldtrips, although not part of the DEWHA grant, are included in this report for completeness.

2.2 Fishing

Fishing was carried out using monofilament gillnets (35-100 m length, 2 m drop, 17.7 cm stretched mesh) set from an aluminium dinghy and anchored at both ends. Sets were short (about 1 h) and the net was monitored for captures and cleared when fish were observed hitting the net to minimise mortalities to sawfish and any bycatch species. Nets were set on the flats or off beaches either on the rising or falling tide to catch sawfish entering or leaving the mangroves. The date, time, depth and location of all sets were recorded. Sawfish were left in the water and secured to the boat by tying ropes around the rostrum and tail. Sex was determined from the presence or absence of claspers, and five measurements of length (to the nearest 0.5 cm) were taken with a flexible fiberglass tape measure: saw length (SL), precaudal length (PCL), fork length (FL), total length (TL) and stretched total length (STL). At Cape Keraudren some sets were made from the beach around high tide. The net was deployed on the beach when the water had receded, it was covered by the flood tide and then recovered on the following ebb tide. A few longline sets were made in the Kimberley; longlines comprised ca. 500 m of mainline with 50 hooks (snood length ca. 2 m, hook size 11/0 and 12/0 broadbill) baited with sea mullet (*Mugil cephalus*).

2.3 Bycatch

Bycatch was comprised mainly of carcharhinid sharks (mainly *Carcharhinus limbatus, C. tilstoni, C. amblyrhynchoides, C. cautus*). Sharks were released alive where possible and tagged with Jumbo Rototags (Daltons, UK) in the first dorsal fin. Any dead sharks were processed for biological information (genetics, vertebrae for ageing, reproductive condition and stomach contents).

2.4 Acoustic tagging

Acoustic tags were attached externally either by tying them with a short length of monofilament to a metal pin cattle ear Jumbo Rototag (Daltons, UK) inserted through the first or second dorsal fin, or with dissolving sutures, one end through the leading edge of the first dorsal fin and the other through the dorsal musculature. Sawfish were tracked using acoustic telemetry equipment comprising either a Vemco VR-60 or VR-100 receiver, a V-10 or VH110 hydrophone and either Vemco V22TP-01, V16P-5HR transmitters with a depth sensor, or Vemco V16-5H and V16-1H transmitter with no depth sensor. These tags continuously transmit their individual identification code. Tracking was carried out from aluminium boats (4- 5m length). The directional hydrophone was mounted on a pole and rotated manually to maximise signal strength. The tags had a range of about 1.0 km and a battery life of approximately 14 days. Depth from the tag together with position from a Garmin GPS 12 was assumed to be the position of the shark and was recorded manually every 15-30 minutes. Tracking was continuous apart from periods when it was necessary to change personnel or leave the sawfish because of adverse tidal or weather conditions. After these periods the shark was relocated by systematically searching the area of last contact.

Sawfish tracks were plotted on digitised maps using a Geographic Information System (ArcView 3.3).

2.5 Satellite tagging

The satellite tags used were Wildlife Computers (Redmond, USA) smart position or temperature transmitting tag (SPOT5). These provide ARGOS locations together with water temperature reported as time-at-temperature histograms in user defined bins. Tags were attached by two 5 mm diameter bolts which passed through the first dorsal fin and were secured on the other side by two washers and nuts. Tags were secured so that the antenna extended out of the water when the fin broke the surface. Transmissions were detected and processed by the ARGOS data collection and location system. The accuracy of ARGOS position estimates is coded by location class (LC) 3, 2, 1, 0, A or B, with LC3 being the most reliable and estimated to be within 150 m of true. The other numeric LC codes decline in reliability and can be within several kilometres of true.

We also used one pop-up satellite archival tag (PAT 4.0, Wildlife Computers) that archived data on depth, temperature and light levels and transmitted summarised data (depth-temperature profile, time-at-depth and time-at-temperature histograms and light curves) through service ARGOS on release from the fish. If the tag is recovered the raw archived data can be retrieved. We programmed the tag to archive data at 60 s intervals into 6 h bins with a release times of 50 days. The tag was attached using a length of nylon-coated stainless leader wire to a stainless steel Floy tag-head inserted in the dorsal musculature level with the first dorsal fin.

3. RESULTS

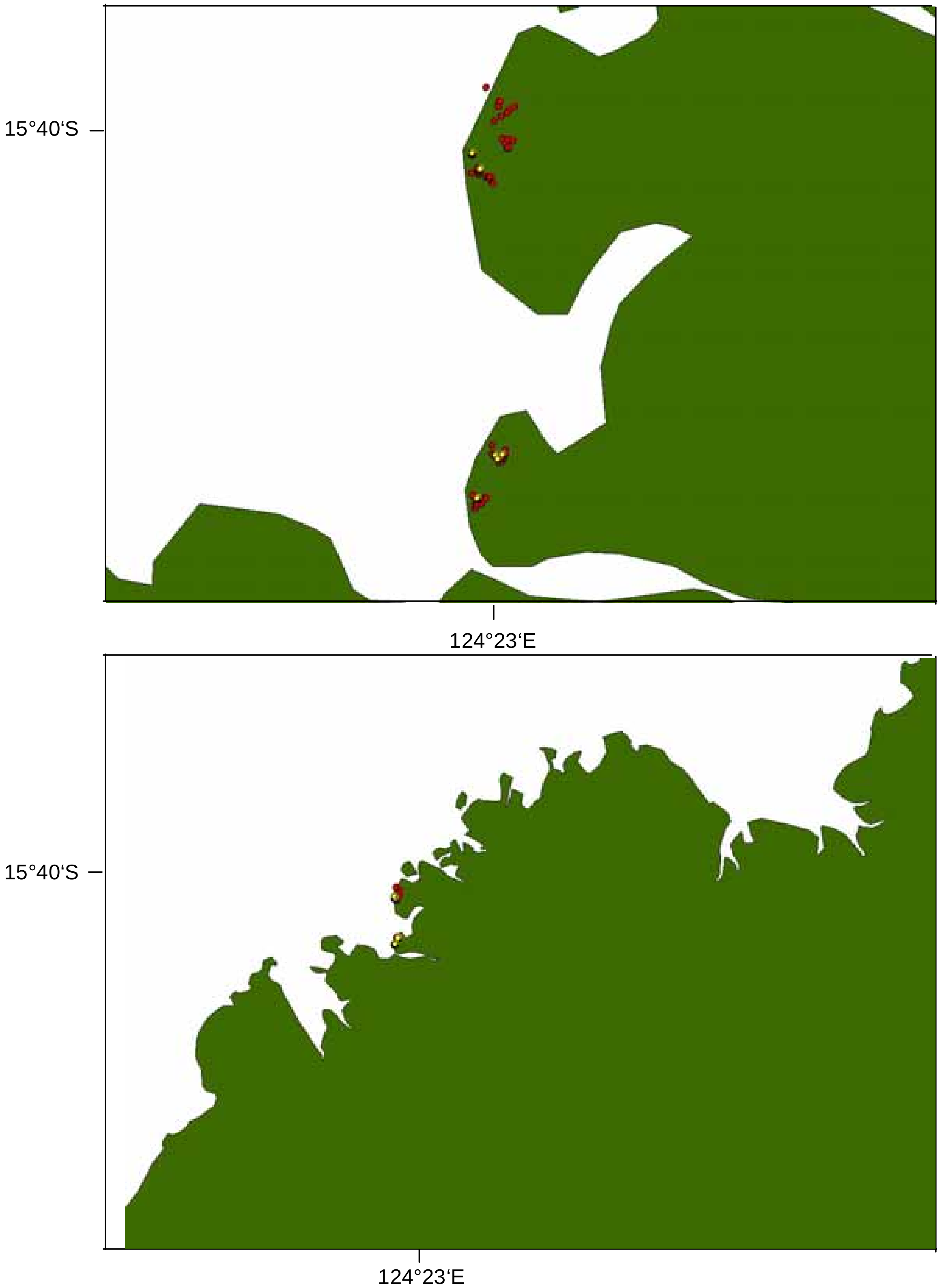
3.1 Sawfish catch data

In 2005, 58 gillnets were set for a total net metre hours of 373,358.46, resulting in the capture of five *P. clavata* (Catch Per Unit Effort (CPUE) 0.000013392). In 2006, 40 gill nets were set for a total net metre hours of 7,355.83, resulting in the capture of three *P. clavata* (CPUE 0.00040784).

Table 1. Sawfish captured on the three field trips, but not tracked

Date	**Species**	**TL (cm)**	**Sex**	**Location**	**Tag (fin or dart)**	
18.8.05	*P. clavata*	284	M	16 09S, 124 26E	7731 (fin)	
18.8.05	*P. clavata*	300	M	16 09S, 124 26E	7560 (fin)	
18.8.05	*P. clavata*	212	M	16 09S, 124 26E	7582 (fin)	
12.4.08	*P. zijsron*	107	M	19 58S, 119 48E	5027 (fin)	
12.4.08	*P. zijsron*	107	F	19 58S, 119 48E	5695 (dart)	
12.4.08	*P. zijsron*	111	M	19 58S, 119 48E	5698 (dart)	
12.4.08	*P. zijsron*	141	M	19 58S, 119 48E	5697 (dart)	
12.4.08	*P. zijsron*	156	M	19 58S, 119 48E	5696 (dart)	
13.4.08	*P. zijsron*	100	M	19 58S, 119 48E	5672 (dart)	
13.4.08	*P. zijsron*	176	M	19 58S, 119 48E	9927 (dart)	
13.4.08	*P. clavata*	220	F	19 58S, 119 48E	9911 (dart)	
13.4.08	*P. zijsron*	193	F	19 58S, 119 48E	9924 (dart)	
16.4.08	*P. zijsron*	212	M	19 58S, 119 48E	5880 (fin)	
16.4.08	*P. zijsron*	212	M	19 58S, 119 48E	9942 (fin)	

Figure 1. Locations of gill net sets (red circles) and *P. clavata* capture locations (yellow circles)



3.2 Acoustic tagging

During the three fieldtrips between August 2005 and April 2008, acoustic tags were deployed on six sawfish, details of which are given in Table 2.

Table 2. Sawfish acoustic tagging details

Date	Species	TL (cm)	Sex	Location	Sawfish ID
12.8.05	*P. clavata*	273	F	15° 40'S, 124° 23'E	HP05
18.8.05	*P. clavata*	290	M	16° 09'S, 124° 26'E	EP05
11.8.06	*P. clavata*	205	F	16° 09'S, 124° 26'E	1356
14.8.06	*P. clavata*	250	M	16° 14'S, 124° 23'E	1357
17.8.06	*P. clavata*	230	F	15° 40'S, 124° 23'E	1035
14.4.08	*P. zijsron*	260	M	20°.09'S, 119° 45'E	1034G

Between 2005 and 2008, six sawfish (five *P. clavata* and one *P. zijsron*) were actively tracked in shallow coastal waters using small boats. Individual sawfish were tracked for up to 70 h within periods of from 1-6 days and moved total distances of up to 30 km in that time (Table 3). The tracks of the five *P. clavata* showed very similar movement patterns (Figs. 2-6). All three *P. clavata* in 2006 spent at least 50% of the time in waters less than 2 m deep (Figure 7). Use of deeper waters occurred mostly when the sawfish were resting at high tides in the inundated mangroves, or while crossing deeper waters while leaving the mangroves during falling tides.

All five *P. clavata* moved the fastest during falling and rising tides with little or no movement at high and low tides (Figure 8). For approximately 100 minutes on either side of high tide, individuals rested in inundated mangrove forests. As the tide fell, *P. clavata* moved out of the mangroves and remained in depths of 0-2 m mostly on muddy banks or sand patches. Individuals moved distances of 1-10 km during each tidal cycle before returning to the mangrove forest on the next high tide (Table 4). High tide resting locations for individuals were often less than 100 m from the previous high tide resting site (Table 4). By moving quietly using the dinghy's oars rather than the motor, it was often possible to get within visual distance of a tracked *P. clavata* and observe it resting on the bottom. On only one occasion was a *P. clavata* observed apparently actively feeding as evidenced from the disturbance on the bottom and the escape reactions of a school of mullet (*Valamugil buchanani*) jumping out of the water around it. There was little evidence of a diel movement pattern with average daytime swimming speeds ranging from 0.2-1.0 km/h and average nightime speeds ranging from 0-1.6 km/h (Table 5).

The one *P. zijsron* was tracked intermittently for a total of 25 h 55 m over a period of four days. After tagging in Firewood Creek, it moved out with the ebb tide and travelled some 4.5 km across the bay. It then, like *P. clavata*, showed more restricted movements towards the shore on the rising tide and away from the shore on the falling tide, remaining in water mostly less than 1.5 m deep. As the tides moved towards springs and the mangroves became inundated, it entered the mangroves approaching high tide, leaving them again on the falling tide.

Table 3. *Pristis clavata* manual track times, distance moved and average speed

Sawfish ID	Start date	Consecutive time tracked	Cumulative distance moved (km)	km/h
HP05	12.8.05	52h 40m	15.4	0.29
HP05	15.8.05	2h 46m	0.6	0.20
HP05	16.8.05	15h 4m	2.5	0.17
EP05	18.8.05	22h 17m	10.7	0.48
EP05	19.8.05	18h 44m	8.4	0.45
1356	11.8.06	44h 7m	25.4	0.58
1356	16.8.06	2h 45m	4.3	1.56
1357	14.8.06	31h 45m	24.2	0.76
1035	17.8.06	20h 0m	8.1	0.41
1034G	14.4.08	7h 22m		
1034G	15.4.08	5h 45m		
1034G	15.4.08	5h 45m		
1034G	16.4.08	3h 35m		
1034G	16.4.08	3h 3m		
1034G	17.4.08	0h 25m		

Table 4. Distance moved during multiple full tidal cycles by manually tracked *P. clavata*.

ID	Distance at high tide from first high tide location (km)	Distance at high tide from previous high tide location (km)	Total distance moved between high tide locations (km)
1356	0.056	0.056	7.616
	0.057	0.105	7.077
	0.024	0.032	6.368
1357	1.203	1.203	5.299
	2.222	1.081	10.481
1035	0.107	0.107	1.998
HP05	2.869	2.869	4.075
	2.882	0.014	3.608
	2.855	0.027	2.168
EP05	0.236	0.236	6.140
	0.161	0.076	4.595
	0.131	0.073	6.258

Table 5. Day versus night movement comparison

ID	Date	Km moved day	Km moved night	Km moved total	Day time tracked (H:m)	Night time tracked (H:m)	Total time tracked (H:m)	Avg km/h day	Avg km/h night	Total km/h
1356	8/11/06		7.68			12:37			0.61	
	8/12/06	5.87	7.17		11:15	12:15		0.52	0.59	
	8/13/06	4.70			7:15			0.65		
	8/16/06		4.29			2:45			1.56	
	Total	10.57	19.15	29.72			46:07			0.64
1357	8/14/06		8.99			11:00			0.82	
	8/15/06	4.84	10.393		11:07	8:50		0.43	1.18	
	Total	4.84	19.38	24.21			30:57			0.78
1035	8/17/06	0.87	1.19		1:05	11:55		0.80	0.11	
	8/18/06	6.05			6:12			0.98		
	Total	6.92	1.19	8.10			19:12			0.42
HP05	8/12/05		2.72			11:02			0.25	
	8/13/05	3.60	3.89		11:29	12:09		0.31	0.01	
	8/14/05	2.03	3.19		11:07	5:54		0.18	0.54	
	8/15/05	0.55	0.57		2:46	0:28		0.20	1.22	
	8/16/05	0.17	0.15		0:56	0:46		0.18	0.19	
	Total	6.35	10.525	16.87			70:26			0.30
EP05	8/18/05		5.70			11:55			0.48	
	8/19/05	5.05	4.00		10:04	8:37		0.50	0.46	
	8/20/05	4.39			9:57			0.44		
	Total	9.44	9.69	19.14			40:33			0.47

Figure 2. Track of HP05 (a 273 cm STL female *P. clavata*). (Dashed line = day, solid line = night, ■ = high tide, ●= low tide, Δ= rising tide, ○ = falling tide)

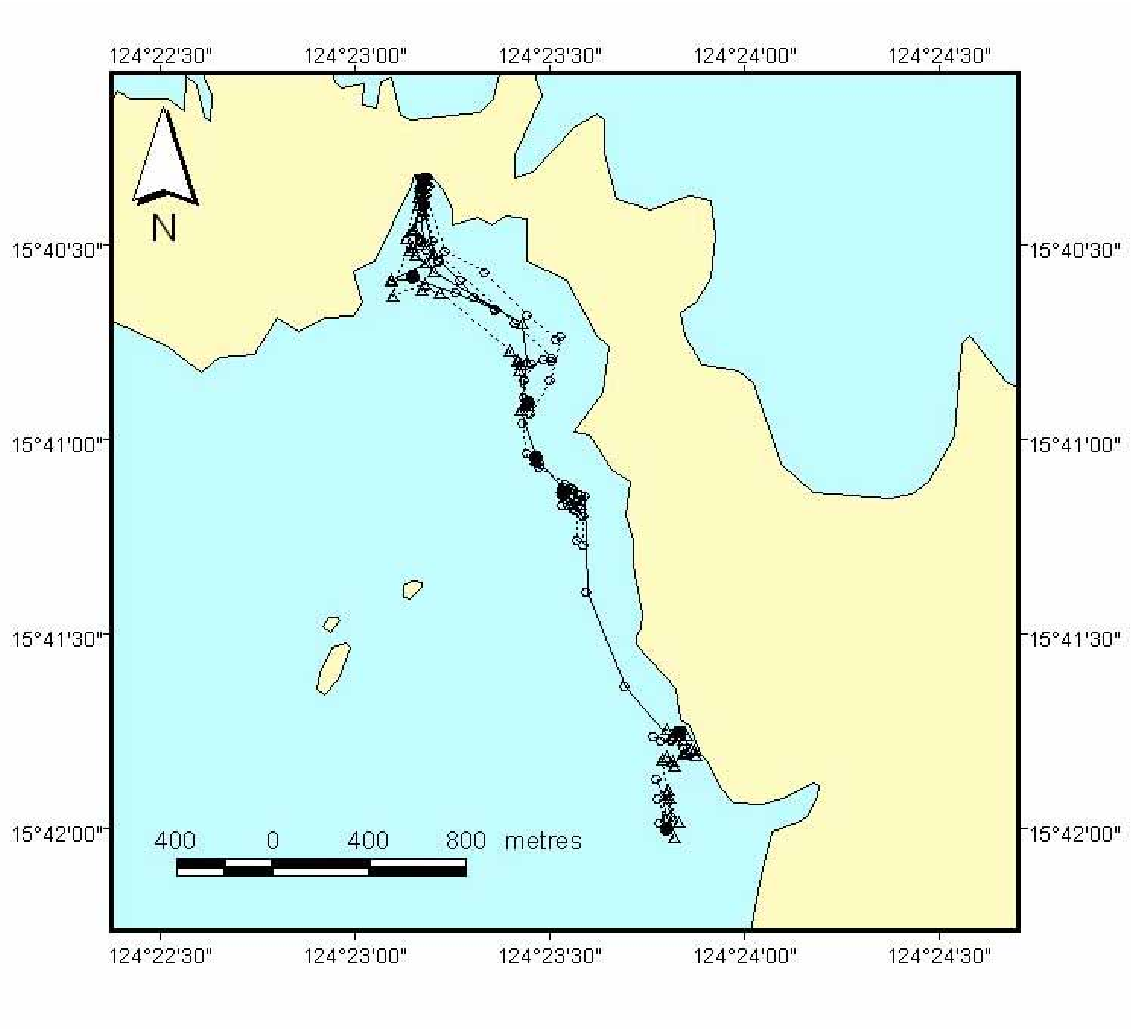


Figure 3. Track of EP05 (a 290 cm STL male *P. clavata*). (Dashed line = day, solid line = night, ■ = high tide, ●= low tide, ∆= rising tide, ○ = falling tide)

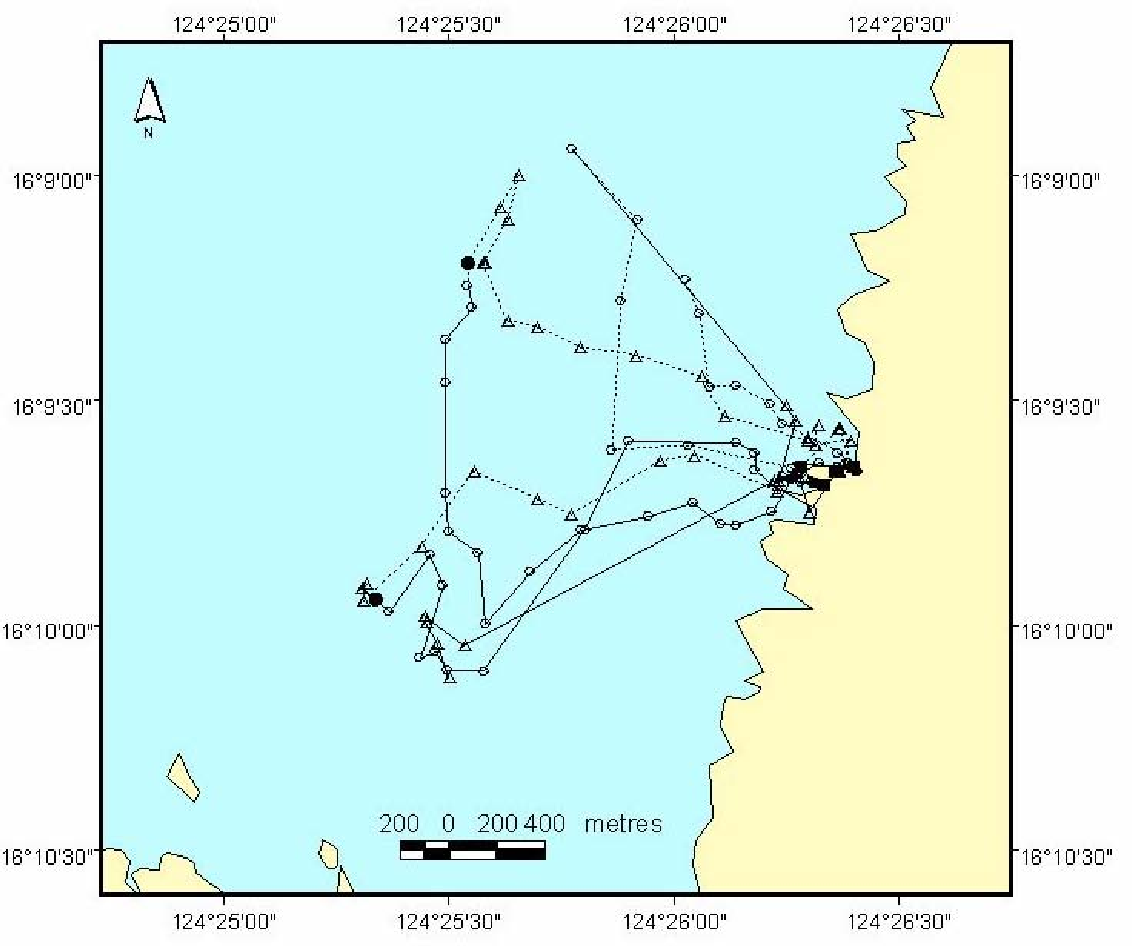


Figure 4. Track of 1356 (a 205 cm STL female *P. clavata*). (Dashed line = day, solid line = night, ■ = high tide, ●= low tide, ∆= rising tide, ○ = falling tide)

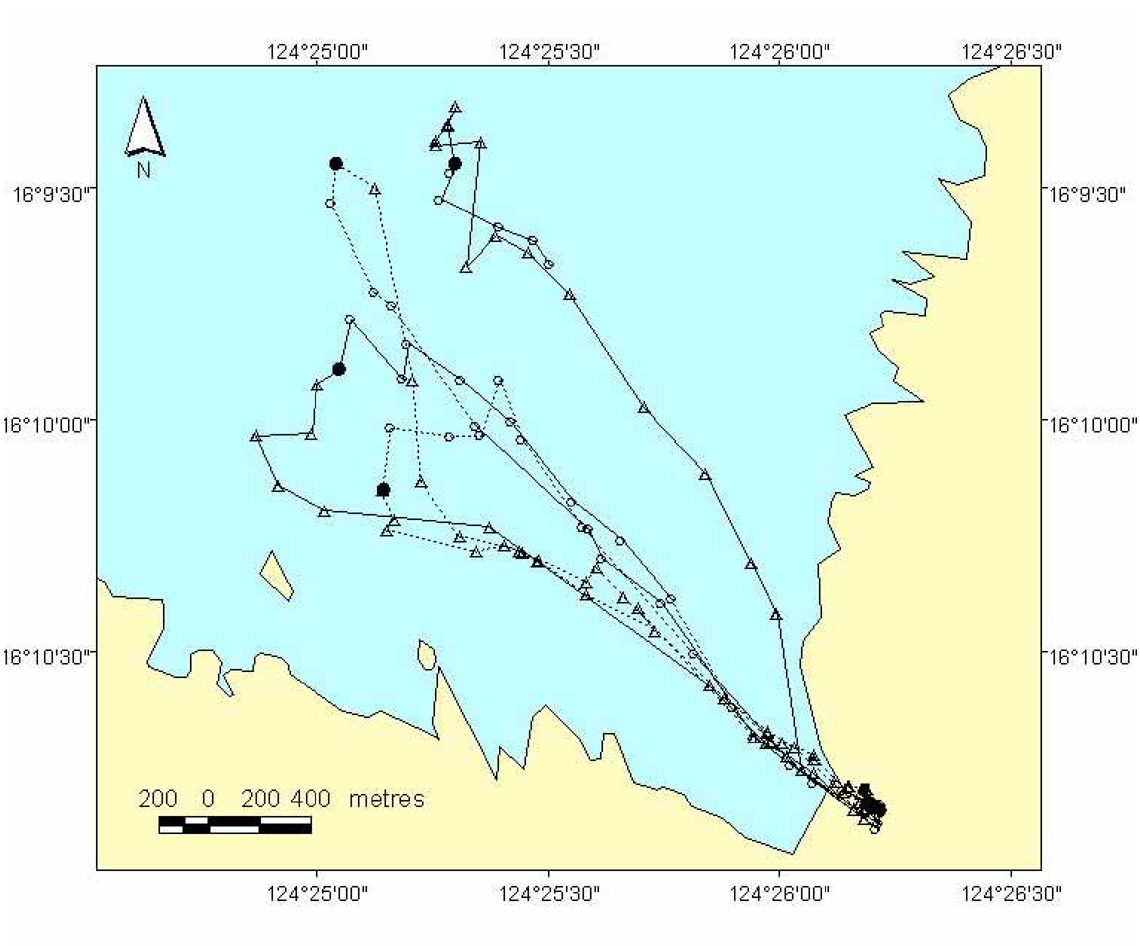


Figure 5. Track of 1357 (a 250 cm STL male *P. clavata*). (Dashed line = day, solid line = night, ■ = high tide, ●= low tide, ∆= rising tide, ○ = falling tide)

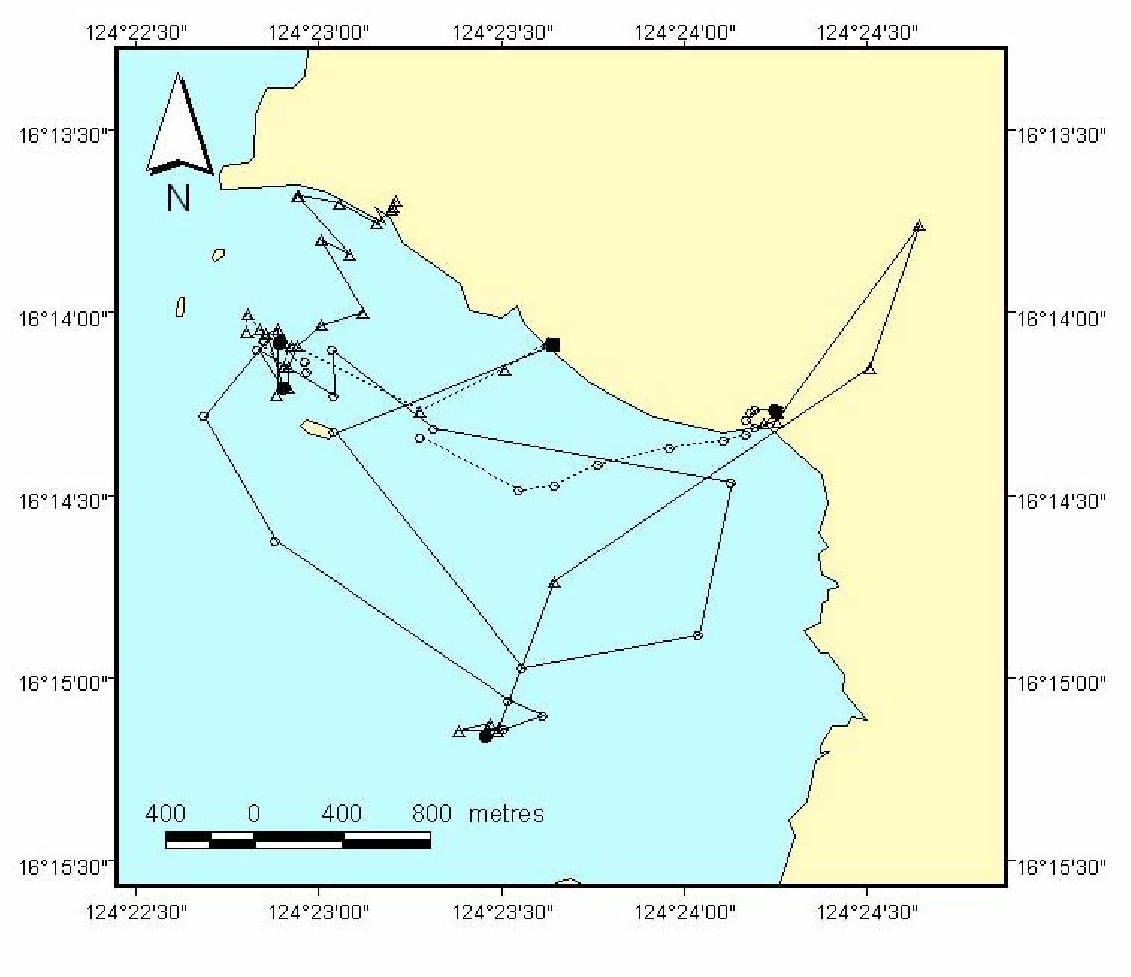


Figure 6. Track of 1035 (a 230 cm STL female *P. clavata*). (Dashed line = day, solid line = night, ■ = high tide, ●= low tide, ∆= rising tide, ○ = falling tide)

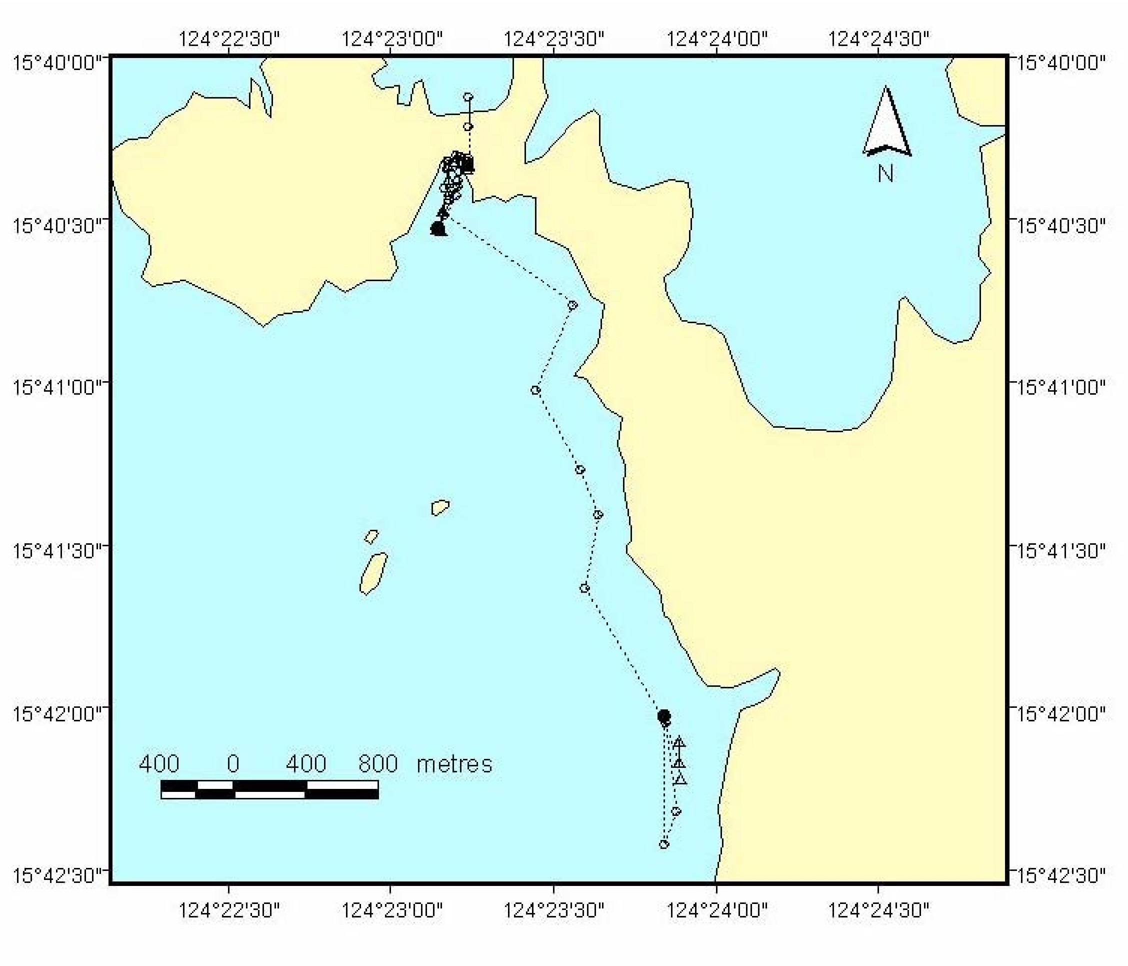


Figure 7. Track of 1034G (a 260 cm STL male *P. zijsron*)

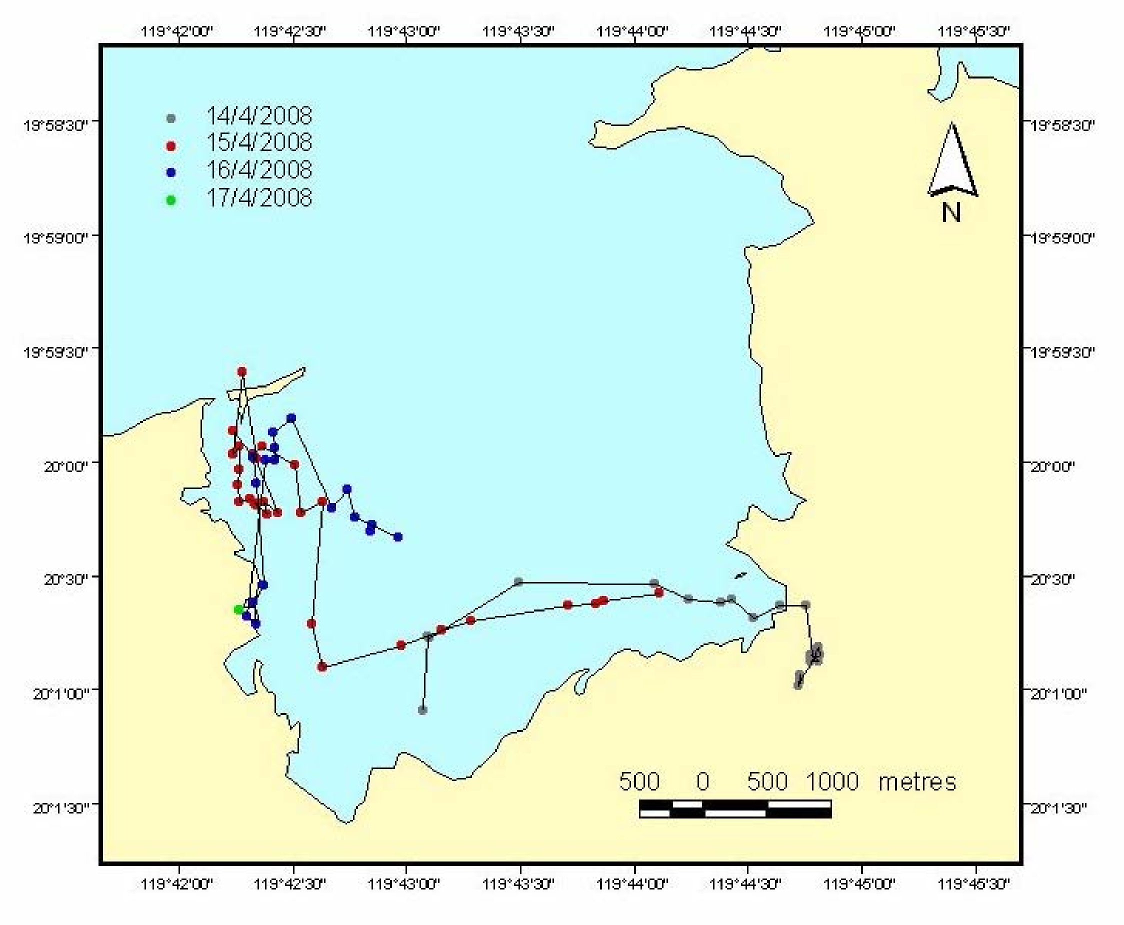


Figure 8. Water depth use by *P. clavata* as a function of tide

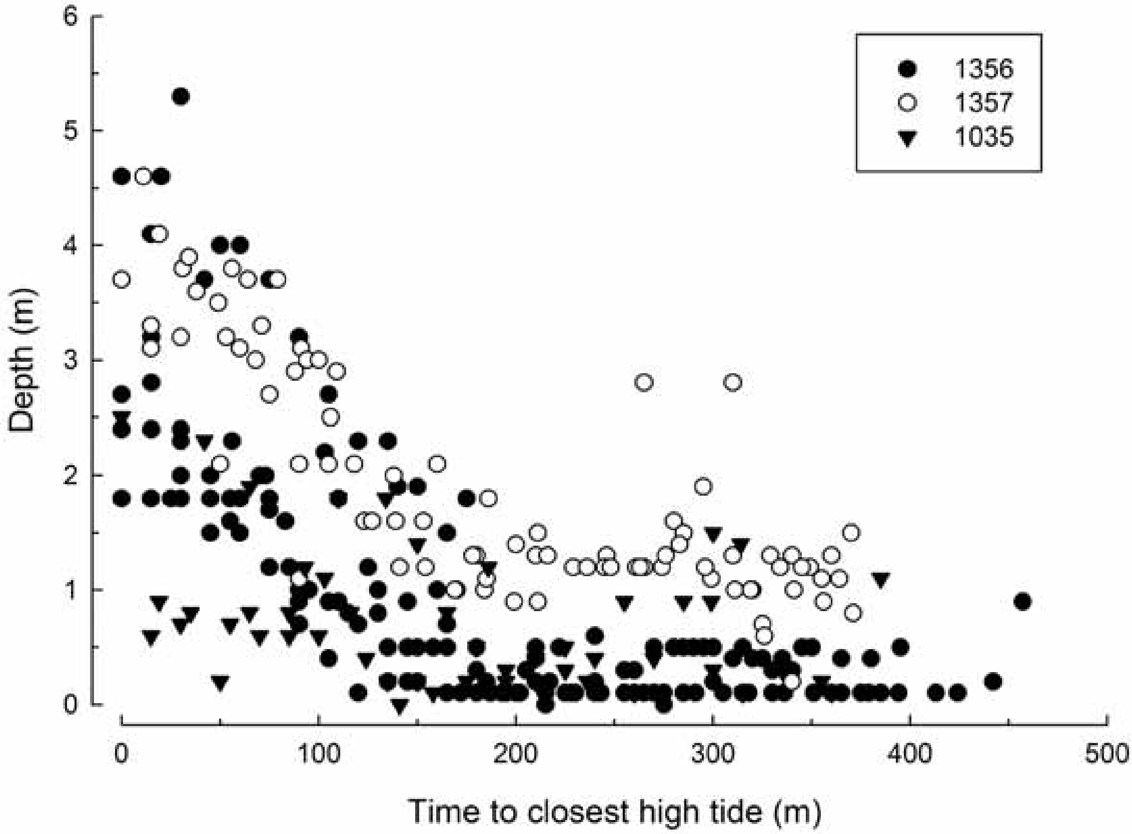
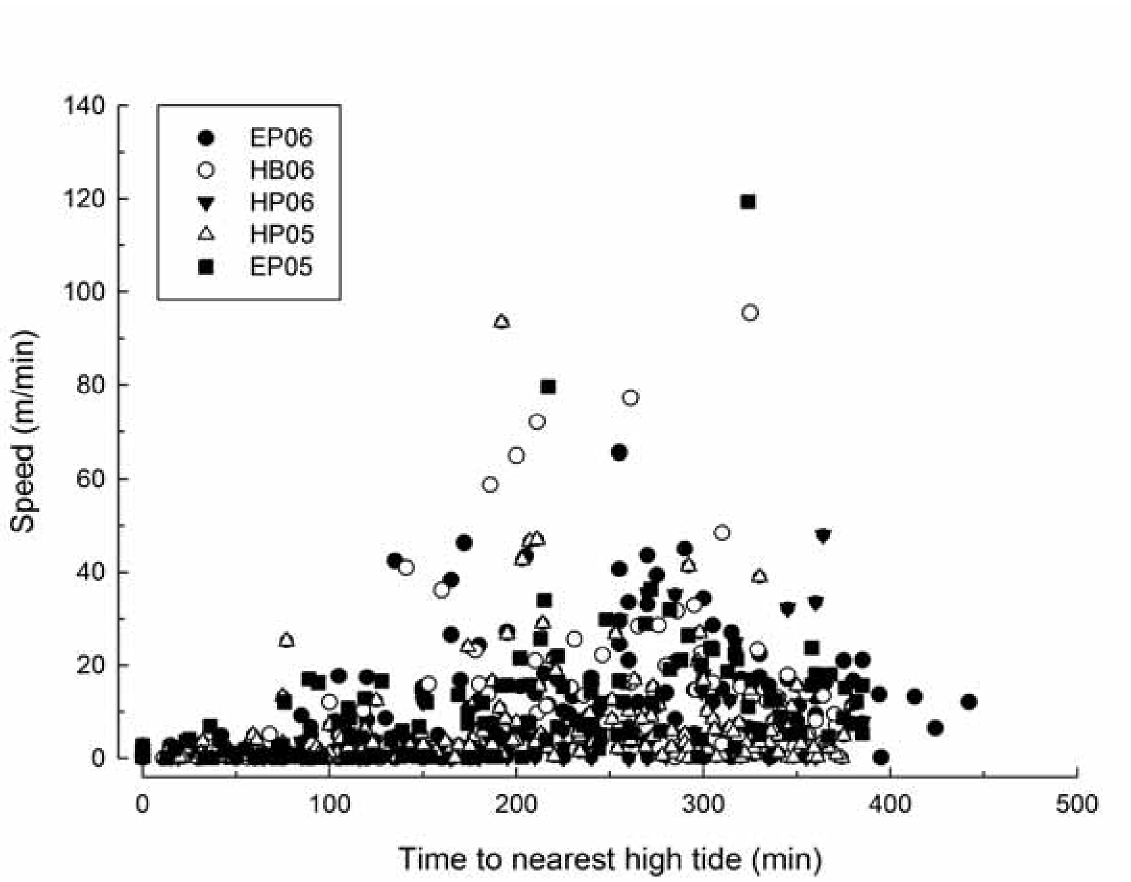


Figure 9. Speed of *P. clavata* as a function of tide



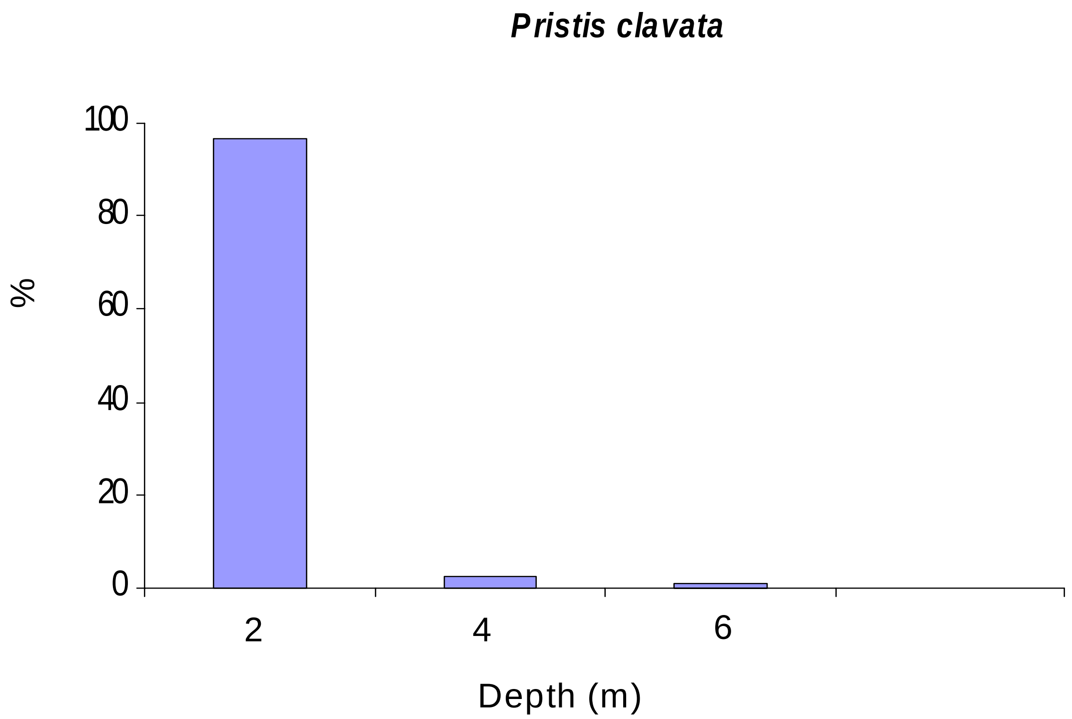
3.3 Satellite tagging

One pop-up archival tag (PAT) was deployed in 2005, one smart position or temperature transmitting tag SPOT tag in 2006 and six SPOT tags in 2008. Details are shown in Table 6.

Table 6. Satellite tagging details

Date	Time (h)	Species	TL (cm)	Sex	Location	Tag type	PTT No.
12.8.05		*P. clavata*	273	F	15° 40'S, 124° 23'E	PAT	03P0384
11.8.06		*P. clavata*	205	F	16° 09'S, 124° 26'E	SPOT	43543
13.4.08	1800	*P. clavata*	205	F	19° 58'S, 119° 48'E	SPOT	75726
13.4.08	1900	*P. clavata*	295	F	19° 58'S, 119° 48'E	SPOT	75725
14.4.08	2020	*P. clavata*	238	F	19° 58'S, 119° 47'E	SPOT	75727
14.4.08	2100	*P. zijsron*	164	F	19° 58'S, 119° 47'E	SPOT	75728
18.4.08	1630	*P. clavata*	318	F	20°.00'S, 119° 43'E	SPOT	83856
20.4.08	0130	*P. zijsron*	230	F	19° 58'S, 119° 48'E	SPOT	83855

Figure 10. Proportion of time at depth for *P. clavata* (273 cm TL female) from PAT tag



The PAT tag released from the fish on 30th September 2005 after 49 days, which was one day short of the programmed pop-off time. The release position of 15° 41'S, 124°

39’E was within a few km of the tagging location. The archived depth data showed that the sawfish spent 96% of its time in the 0-2 m depth range, reaching a maximum depth of 20 m. The one SPOT tag deployed in 2006 only transmitted three times within a few weeks of deployment. The location classes were of poor quality but were within the general tagging area.

At the current date (11th September 2008), of the six SPOT tags deployed in April 2008, two (75726 and 83855) have not been heard from since they were tagged. Both 75725 and 75727 only transmitted on 15th April. Tag 83856 transmitted on the 18th, 19th, 20th and 24th April, 4th May, 24th June and 9th August 2008. The position on the 4th May, 16 days after it was tagged, was a location class 3 with an estimated accuracy of < 150 m. This position at 19° 58’S, 119° 48’E is about 9 km from where it was tagged. The June and August transmissions were not of sufficient quality to register a position. Tag 75728 deployed on a 164 cm TL *P. zijsron* transmitted regularly on every day from the 14th April (the day it was tagged) until the 26th April; only two further transmissions have been received on the 14th May and 2nd September, but with no positions. On the 26th April a location class 2 position (estimated accuracy < 350 m) was within a few km of the tagging location.

4. DISCUSSION

4.1 Acoustic tagging

The five *P. clavata* and one *P. zijsron* that were tracked between 2005 and 2008 in the Kimberley and Pilbara regions of Western Australia all showed similar movement patterns that were driven primarily by the tides. The sawfish generally remained in water less than 1.5 m deep, entering the inundated mangrove forests at high tide where they mostly remained stationary for long periods within a small area, and retreated to mud flats and sandbanks at low tide. The majority of telemetry studies on elasmobranchs have related movements to the diel cycle usually showing increased activity at night (Nelson and Johnson 1980; Tricas *et al.* 1981; Gruber *et al.* 1988; Holland *et al.* 1992). However, Ackerman *et al.* (2000) found tidal movements to be the predominant factor influencing the movements and habitat use of another inshore elasmobranch species, the leopard shark (*Triakis semifasciata*), in Tomales Bay, California. During the flood tide, sharks moved towards the inner bay presumably to exploit the muddy bay’s littoral zone food resources. On the ebb tide, the sharks moved towards the outer bay just far enough to avoid very shallow water without having to move too far away (Ackerman et al. 2000). Juveniles of two carcharhinid species, the dusky shark *Carcharhinus obscurus* and sandbar shark *C. plumbeus*, and the Atlantic stingray *Dasyatis sabina* have also been shown to move mainly in the direction of the tidal current (Teaf 1978, Huish and Benedict 1978; Medved and Marshall 1983). Movements are probably governed by a number of factors, some yet to be studied, but data show that food, water temperature, bottom type and other environmental factors play a major part in an elasmobranchs decision of where and when to swim (Sunstrom *et al.* 2001). The movement directions of different shark species are known to be influenced by a number of different factors such as the sun, geomagnetic gradients, the earth's magnetic field or the ocean's electric fields (Gruber et al. 1988; Carey and Scharold 1990; Klimley 1993). For the sawfish in our study, the direction of movement seemed to be determined primarily to travelling towards the mangroves on the flood tide and away from them on the ebb tide. While tidal flow can act in several different ways to affect habitat use, for sawfish decreasing depth appears to force the animals to move to other habitats as shallow areas are exposed at low tide. They stay in shallow water following the tide except at higher tidal stages when they occupy inundated mangrove stands and appear to move very little. Presumably, during the ebb and flood tides sawfish utilise the shallow turbid water on the receding or advancing front of water to prey on fish concentrated in this area. Fish are probably concentrated in this zone in order to reach the safety of the mangroves on a flood tide or to reduce the amount of time without cover during an ebb tide. During high tide, the feeding opportunities for sawfish are presumably reduced and may explain why the animals rest during these periods.

It is not immediately clear why they occupy these mangrove areas. Feeding would seem to be the obvious reason, especially as mangroves are known to be rich feeding grounds with abundant invertebrates and small fish. However, based on the track data and on visual observations, the sawfish did not generally seem to be feeding in the mangroves. An alternate explanation may be that the mangroves provide a refuge from predation. This is certainly plausible for smaller sawfish but seems less likely for animals longer than about 2 m. Predation on these larger sawfish would seem limited to large shark species such as the great hammerhead (*Sphyrna mokarran*) and the tiger shark (*Galeocerdo cuvier*). Many sharks of a wide variety of sizes were caught in this study adjacent to the inundated mangroves and may also occur within this habitat. However, sampling in mangrove areas was restricted because of snags. To better understand the use of mangrove habitats by sawfish, further studies of their potential predators and of sawfish feeding behaviour are required.

Results from this study showed that sawfish often rest during the top and bottom of the tide when water movement is low. Their preferred habitat appears to be very shallow water over mudflats and sandbanks when the tide is moving. The huge tidal ranges of the Kimberley may be a more challenging environment for them than areas with smaller tidal ranges. There was little evidence of diel patterns in their movements, probably because the strong influence of the tides and the macrotidal environment was concluded to be the dominant factor controlling the movement of *Pristis clavata* in these regions.

4.2 Satellite tagging

At least in the short-term, the sawfish we studied appeared to move only small distances and occupied only a relatively restricted area. It was hoped that satellite tagging would provide information on longer term movements. The two *P. clavata* satellite tagged in 2006/2006 remained in the general tagging area for the 50 day period over which data was received.

Results from the April 2008 deployments are not very encouraging in terms of this technique providing long-term positions, at least for *P. clavata* and *P. zijsron* in this area. While two of these six tagged sawfish have transmitted on isolated occasions for up to 113 and 141 days after tagging, these transmissions have not provided positions. The longest time after tagging for a transmission that provided a position is only 16 days.

5. CONCLUSIONS

All of the acoustic tracking data and the limited information (to date) from satellite tagging suggest that both *Pristis clavata* and *P. zijsron* have limited, tidally influenced, movements and occupy a restricted range of only a few square km within the coastal fringe. In mangrove areas, they often spend high tide resting within the inundated vegetation where they would be relatively protected from fishing activities. However, on the moving tide they are relatively active, and presumably feeding, on the mud and sand flats. At this time, they are particularly vulnerable to any net fishing operations and this has implications for their conservation and management.

The strong short-term association of tracked sawfish with mangroves and adjacent mudflats emphasises the need to better evaluate and monitor the impacts on these populations of inshore gillnet fishing in the Kimberley and Pilbara regions of Western Australia. Both the Kimberley Gillnet and Barramundi Fishery (KGBF) and, until very recently, commercial intertidal gillnet fishing activities on Eighty Mile Beach (EMB) have had documented interactions with all four Australian sawfish species (McAuley *et al*., 2005). Although tracking data from the current study might suggest that any impacts from these low-intensity and sparsely distributed fishing operations may only be localised, without longer-term tracking data this hypothesis cannot be confirmed. An equally plausible explanation for the observed regularity of sawfish captures by gillnets on EMB and in the Roebuck Bay area of the KGBF is that catches are supported by immigration of animals from adjacent unfished areas.

Despite the uncertainty surrounding the longer-term movements of sawfish, the short-term site fidelity demonstrated by these tracking data indicates that there might be some additional conservation benefits in protecting important sawfish habitats. Determining the spatial scales for such measures however, remains problematic.

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