Movement and habitat use of smalltooth sawfish

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Background

The smalltooth sawfish (*Pristis pectinata*) was listed as Endangered under the Endangered Species Act in 2003. They were once common in the Gulf of Mexico and east coast of the United States. However, decades of fishing pressure, both commercial and recreational, and habitat loss caused the population to decline significantly during the second half of the twentieth century and today they exist mostly in southern Florida (Simpfendorfer 2000, 2002, Simpfendorfer and Wiley 2005).

There is a paucity of available information regarding the biology and ecology of the smalltooth sawfish. Data are required to determine the distribution, abundance, and short and long-term movements of the species. This information is vital to determine the potential recovery rates of the population, identify critical habitat requirements, determine the population status, and examine potential effects on the populations' genetic diversity. The utilization of both traditional and novel tagging methodologies can provide information on the habitat use and migration patterns of the smalltooth sawfish.

The purpose of this study was to investigate the habitat use, site fidelity, movements and abundance of the smalltooth sawfish population in Florida. This research employed a variety of techniques, including field surveys using longlines and gillnet, acoustic tracking and monitoring, satellite telemetry and the collection of data on encounters with sawfish by the public.

Materials and methods

**Encounter database**

**Data collection**

Rare marine species that inhabit areas with poor water clarity and that do not regularly surface to breathe are difficult to adequately survey. One method of overcoming this problem is to utilize observations by the public to multiply the observational effort substantially over that which a single researcher could achieve. Not all species are suited to such surveys, but in cases where identification is straightforward, reliable information can be obtained. Since sawfish possess a distinctive toothed rostrum, and only one species - *Pristis pectinata* - occurs regularly in Florida waters, sawfish are a suitable candidate for use of public sightings data.

Information on the occurrence of *P. pectinata* was gathered from the public between 1999 and 2005, with most collected between 2002 and 2005. To alert the public to the need for information on sawfish encounters a broad range of awareness-raising tools were used, including flyers posted at boat ramps, tackle shops and dive shops; articles in fishing and other marine-oriented magazines; articles in tourist information brochures; media releases; a web site and direct approaches to fishing guides, other researchers and
commercial fishers. To ensure that the requests for information were spread evenly throughout Florida the state was divided into six regions (Figure 1) and awareness-raising activities were focused in each region on a biannual basis between May 2002 and May 2004. Prior to 2002, awareness-raising activities were organized on an ad-hoc basis.

Figure 1. Map showing the boundaries of the six zones in which awareness-raising activities for information on encounters with smalltooth sawfish (Pristis pectinata) were biannually focused (heavy lines).

When a sawfish encounter was reported a standard questionnaire was completed. This ensured that the same data were collected for each encounter. The questions asked included the date and time of encounter, exact location of the encounter, the reporter's activity at the time of encounter, number of sawfish encountered, estimated size, activity of the sawfish at the time of encounter, whether the sawfish was captured while fishing or simply observed, if captured how it was captured, habitat at the site of the encounter, water depth, tidal state and other physical and environmental parameters. For encounters reported by researchers, exact length measurements were often available, along with sex and reproductive condition of males. Sizes of all other sawfish were estimates made during encounters and probably had a wide degree of error.

We used a rigorous set of criteria for inclusion of data into the data set. Firstly, the sighting had to have definitively been a sawfish. To help validate observations, reporters were asked to supply photographs or video whenever possible. Where photographs or video were not available, a series of questions about the form of the saw (number of lateral teeth, rostrum shape, possession of gill opening, etc.) were asked to distinguish sawfish from guitarfish (Rhinobatis lentigulosis), saw sharks (Pristiophorus spp.),
freshwater gars (*Lepisosteus* spp.), and paddlefish (*Polyodon spatula*). Secondly, only observations reported within three months of the sighting were included. This criterion was used as we believed that the probability of people supplying inaccurate data (exact location or date) increased with the amount of time after the observation. Thirdly, since the data were intended to be analyzed using a Geographic Information System (GIS) only observations where the location could be accurately determine (less than 500 m uncertainty) were included. The widespread use of global positioning system (GPS) technology in recent years has increased the accuracy with which many people reported locations. For sightings where GPS locations were not available, reporters were asked to provide detailed information on the location of their observation (location relative to local landmarks, a map showing the location, etc.).

**Data analysis**

Spatial data were plotted in a GIS (ArcView 3.3, ESRI, Redlands, California) on a high-resolution map of Florida. Encounter data were converted to encounter density by counting the number of data points within a 0.1-degree grid using the Spatial Analyst extension for ArcView 3.3. Although a wide range of habitat data were provided with encounter reports, the inconsistent nature by which it was observed made it impossible to use in any quantitative analysis. The one exception to this was depth, which the reporters were able to accurately record due to direct observation and the widespread use of echo sounders.

To examine the importance of habitat factors other than depth the proximity of encounters to three features – the shoreline, mangroves and seagrasses – were calculated in the GIS. GIS shapefiles for each of these features were obtained from the Florida Geospatial Library and the shortest distance from the encounter locations to the closest occurrence of each feature was calculated using the Nearest Features (v. 3.7) extension for ArcView. Three analyses were performed on these data. Firstly, the relationships between the distances and the estimated sizes of the sawfish were calculated by fitting a linear regression to the data. The distance-to-feature data were log-transformed to normalize the data before fitting the regressions. Secondly, the relationship between water depth and sawfish size was examined in the same way. Thirdly, the frequency distribution of the distance-to-feature data were compared to values from a randomized set of points to determine if sawfish observations were made closer to a feature than would have been expected by random. To do this we created 1,000 randomly located points within the depth range of 0-12 feet (0-3.6 m) based on a GIS shapefile describing Florida’s bathymetry that was obtained from the Florida Geospatial Library. We then calculated the distance-to-feature of these points for the shoreline, mangroves and seagrass. For comparison to the randomized points, encounters within the same depth range were selected, and the distance-to-features calculated. The two sets of distances were then log-transformed and a t-test used to determine if the observations occurred closer to the feature than was expected.

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1 <http://www.fgdl.org> [accessed on 10 October 2005]
Habitat suitability modeling

On the basis of the results of the MML Sawfish Encounter Database analysis three factors were selected for inclusion in a GIS-derived habitat suitability model: areas adjacent to mangroves, water depth and estuarine areas with significant freshwater input. The model was developed for juvenile sawfish less than 200 cm in length, as the encounter data and acoustic tracking data indicated these animals had the most specific habitat use patterns.

The model was implemented in ArcView 3.3 using the ModelBuilder extension (ESRI 2000). Four data layers were imported into ArcView: (1) Florida shoreline, (2) Florida bathymetry, (3) Florida lower salinity areas, and (4) Florida mangroves. The shoreline and bathymetry data were sourced from the Florida Fish and Wildlife Research Institute (FWRI, www.myfwc.com/research) and the mangrove and river layers from the Florida Geospatial Data Library (www.fgdl.org). The 0 - 3 ft and 3 - 6 ft depth ranges were extracted from the Florida bathymetry data to create a new data layer (shallow bathymetry). The four data layers to be included in the model were then transformed into gridded data with a grid size of 0.005°. All of the data layers except for mangroves were used in this form. Four buffers were created around the grids containing mangroves to represent the two areas where most juvenile sawfish are encountered: 0 – 500 m, 501 – 1000 m, 1001 – 1500 m and 1501 – 2000 m.

The suitability of each grid square was then determined on a nine-point scale giving equal weight to each of the three habitat factors (depth, mangroves and euryhaline). The shoreline layer was used to restrict the results of the model to non-land areas. Scores of individual components of each habitat factor reflected their relative importance as a nursery area for juvenile sawfish (Table 1). The final index values were grouped into very low (index 1 - 3), low (index 4 - 5), medium (index 6 - 7) and high (index 8 - 9).

Table 1. Index scores of individual habitat components in the habitat suitability model for smalltooth sawfish in Florida waters.

<table>
<thead>
<tr>
<th>Habitat component</th>
<th>Component value</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathymetry</td>
<td>0-3 ft</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3-6 ft</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>&gt;6 ft</td>
<td>1</td>
</tr>
<tr>
<td>Mangrove buffer</td>
<td>0 - 500 m</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>501 – 1000 m</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1001 – 1500 m</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1501 – 2000 m</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&gt;2000 m</td>
<td>1</td>
</tr>
<tr>
<td>Lower salinity areas</td>
<td>Euryhaline</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Not euryhaline</td>
<td>3</td>
</tr>
<tr>
<td>Shoreline</td>
<td>Land</td>
<td>restricted</td>
</tr>
<tr>
<td></td>
<td>Non-land</td>
<td>1</td>
</tr>
</tbody>
</table>
Model testing

To test the predictive power of the model two metrics were calculated: (1) the proportion of sawfish encounters (< 200 cm in length) reported within each of the four habitat categories, and (2) the distance from each sawfish encounter to an area of high or medium habitat quality. The distance from each encounter (n=333) to the nearest area of high quality habitat was calculated using the Nearest Features extension for ArcView 3.3. These metrics were calculated for the three parameter model, and also for all subsets of models with combinations of these factors (n=6, 3 single factor models and 3 two factor models). In addition, a subset of juvenile sawfish encounter data points from south of 28°N (n=318 encounters) was used to test the model since >95% of the encounters were reported in this area.

Field surveys

Two gear types were used to survey smalltooth sawfish – longlines and gillnets. Longlines consisted of an 800 m mainline of braided nylon rope that was anchored at each end. Gangions made of 1 m of nylon cord and 1 m of stainless steel cable were attached to the mainline with clips every 10 m. Gangions were terminated with tuna circle hooks ranging in size from 12/0 to 16/0. Longlines were used to target larger sawfish. Gillnets were constructed of 3 inch (stretched knot to knot) monofilament netting and ranged in length from 100 to 200 ft. Nets were weighted to be bottom set and anchored at either end. Gillnets were used to target small juvenile sawfish.

A total of 243 sampling events occurred from September 2004 to November 2005. One hundred and seven longline sets and 136 gillnet set were completed from Tampa Bay to the Outer Florida Keys (Figure 2). Longline sets ranged in duration from one to three hours, and gillnet sets were mostly of 30-60 minutes duration. The location, date, time, duration and environmental conditions for each set were recorded.

Captured sawfish were secured to the boat to avoid damage by the hook. Large sawfish had ropes tied around the saw, mid-section and tail. Smaller animals were scooped into a large landing net. Whenever possible, sawfish had five length measurements taken: saw length (SL), precaudal length (PCL), fork length (FL), total length (TL) and stretched total length (STL). Large sawfish were measured with a flexible fiberglass tape measure, while smaller animals were measured on a fish measuring board. Measurements were made to the nearest 0.5 cm. The weight of small individuals was determined by placing the sawfish in a mesh bag and suspended below a spring balance. Weight was determined to the nearest 0.1 kg. The sex of sawfish was determined by examining all individuals for male intromittent organs (claspers) on the pelvic fins. Small individuals had to be carefully examined as the claspers are small and can be easily missed.

All sawfish were fitted with individually numbered external identification tags. Two types of tags were regularly used: nylon headed dart tags and rototags. Dart tags were inserted at the base of the first dorsal fin, making sure that the nylon barb passed between the cartilaginous rays supporting the fin. Rototags were attached to the first or second
dorsal fin by first making a small hole in the fin with a leather hole punch and then clipping the two halves of the tag together through the hole in the fin. In addition to external identification tags, most sawfish were given an intra-muscular passive-integrated transponder (PIT) tag. These tags are very small (12 mm x 1.5 mm) and are uniquely coded. The tags were injected into the muscle at the base of the first dorsal fin using a syringe applicator. The tags send a code when they receive a signal at the correct frequency. The tags code is received and decoded using a PIT tag reader. These tags have the advantage of having an indefinite life and extremely low shedding rates, making the animal identifiable for its entire life.

Figure 2. Location of sawfish sampling using gillnets (circles) and longlines (crosses). Blue lines indicate 10 m bathymetric contours down to 200 m.

Acoustic tracking
A subset of smalltooth sawfish were fitted with acoustic tags to allow their movements to be followed. The tags applied were Vemco V8 or V16 individually coded tags that emitted a pulse-stream at 50 kHz. The tags were fitted to sawfish by first attaching the tag to a rototag, and then applying the tag to the sawfish’s first or second dorsal fin. The acoustic signal was located using a receiver (Vemco VR60 or VR100) with a directional hydrophone. The location of the animal, relative to the tracking vessel, was determined from the direction of the signal and the signal strength. The location of the animal was
determined at 15 minute intervals unless it was moving, and then positions were estimated every 5 minutes. Sawfish were tracked for as long as practical, and in most situations were re-acquired over several days to produce longer tracks and compare habitat use between days.

Acoustic tracking data were analyzed using the Animal Movement extension for ArcView 3.3. Sawfish tracks were plotted on aerial photographs rather than digitized maps as they produced more accurate and detailed information about the habitats in which these animals occur.

**Acoustic monitoring**

**Field methods**

To investigate the long-term site fidelity of juvenile smalltooth sawfish acoustic monitoring arrays were deployed in three nursery areas – two in the Ten Thousand Islands and one in the Caloosahatchee River (Figure 3). The arrays in the Ten Thousand Islands each consisted of three Vemco VR2 monitors moored in enclosed mangrove bays. The Caloosahatchee River array consisted of 20-23 acoustic monitors located along the estuarine portion of the river from the mouth to approximately 30 km upstream. This array was maintained by Mote Marine Laboratory’s Center for Shark Research primarily for research on bull sharks. Each of the VR2 monitors listened continuously on a frequency of 69kHz for coded identification tags (Vemco V8 Rcode). When tags were within the detection range of the monitors (600-800 m, Michelle Heupel pers. comm.) they logged the date, time and identification number.

Figure 3. Left panel: location of sites with acoustic monitors. Right panel: location of 23 VR2 acoustic monitors in the Caloosahatchee River (blue circles).

Sawfish captured in these three areas were fitted with V8 tags attached to fin tags. The tags transmitted their identification code at random intervals between 90 and 180 seconds and had a life expectancy of approximately 6 months based on battery capacity. In addition to sawfish captured by MML researchers as part of this project, tags were also provided to Florida Fish and Wildlife Research Institute researchers working in the Caloosahatchee River.
Data analysis

Data from each of the acoustic monitoring sites was used to determine the period of residency within the nursery areas. A sawfish was considered to be resident on a particular day if one or more signal detections occurred. For the Caloosahatchee River array the mean distance from the river mouth was determined by calculating the mean position of monitors receiving signals weighted by the number of detections at each monitor. Mean river distance was plotted against time for all sawfish present to show patterns in movement and residency. Salinity at the Cape Coral Bridge was also plotted. Salinity data were obtained from South Florida Water Management District loggers that record data every 15 minutes.
Results and Discussion

Field surveys
The 243 sampling events captured 23 sawfish, most during spring of 2005 (Table 2). Only three adult sawfish were captured: a 496 cm female captured in Florida Bay, and a 395 cm female and an unmeasured and unsexed adult-sized individual in the outer Florida Keys. The first of these was the largest sawfish captured in five years of field surveys by MML scientists. The animal was fitted with a popup archival satellite tag, but no information was received from this tag.

The juvenile sawfish were captured in three areas: Charlotte Harbor, Ten Thousand Islands and Florida Bay. Three were larger juveniles, probably a couple of years old, while the remainder were small and probably less than a year old.

The number of sawfish captured during this study period was high compared to other years. This catch, however, probably does not represent increasing abundance. Instead, it is probably a function of an increasing use of nets to target young sawfish and improving skill in target areas with greater chances of capturing of sawfish.

Figure 4. Capture locations of smalltooth sawfish (triangles) from September 2004 to November 2005. Some locations represent more than one capture. Blue lines indicate 10 m bathymetric contours down to 200 m.
Table 2. Capture dates and size measurements of smalltooth sawfish, September 2004 to November 2005.

<table>
<thead>
<tr>
<th>Species name</th>
<th>Date</th>
<th>Sex</th>
<th>PCL (cm)</th>
<th>FL (cm)</th>
<th>STL (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pristis pectinata</em></td>
<td>13-Oct-04</td>
<td>F</td>
<td>165</td>
<td>185</td>
<td>202</td>
</tr>
<tr>
<td><em>Pristis pectinata</em></td>
<td>21-Mar-05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pristis pectinata</em></td>
<td>24-Mar-05</td>
<td>F</td>
<td>459</td>
<td>491</td>
<td>496</td>
</tr>
<tr>
<td><em>Pristis pectinata</em></td>
<td>25-Mar-05</td>
<td>M</td>
<td>69.5</td>
<td>77</td>
<td>81.5</td>
</tr>
<tr>
<td><em>Pristis pectinata</em></td>
<td>06-Apr-05</td>
<td>M</td>
<td>128</td>
<td>144</td>
<td>151</td>
</tr>
<tr>
<td><em>Pristis pectinata</em></td>
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<td>69</td>
<td>74</td>
<td>78</td>
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<tr>
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<td>80</td>
<td>84</td>
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<td>76</td>
<td>80</td>
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<td><em>Pristis pectinata</em></td>
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<td>67</td>
<td>73.5</td>
<td>78</td>
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<td>337</td>
<td>375</td>
<td>395</td>
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<tr>
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<td>73</td>
<td>80</td>
<td>85</td>
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<tr>
<td><em>Pristis pectinata</em></td>
<td>16-May-05</td>
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<td>67</td>
<td>74</td>
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<tr>
<td><em>Pristis pectinata</em></td>
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<tr>
<td><em>Pristis pectinata</em></td>
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<td>67</td>
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<td>77.5</td>
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<tr>
<td><em>Pristis pectinata</em></td>
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<tr>
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<tr>
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<tr>
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<td>124</td>
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<tr>
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<td>10-Nov-05</td>
<td>F</td>
<td>165</td>
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<td>190</td>
</tr>
</tbody>
</table>

**Encounter database**

The database currently (to the end of November 2005) contains 667 verified sawfish encounters. Encounters were recorded from the Florida Panhandle (as far west as Pensacola) to St. Augustine (Figure 5). The majority of encounters were reported from the Caloosahatchee River to Florida Bay. Few encounters occurred on the east coast of Florida. The highest density of encounters occurred at the mouth of the Caloosahatchee River, the Ten Thousand Islands, the mouth of the Shark River and East Cape Sable (Figure 6).

Smalltooth sawfish encounter data were analyzed to investigate the importance of four environmental factors in accounting for their distribution. These four factors were depth, proximity to mangroves, proximity to seagrass and proximity to shore. Detailed methods for this analysis can be found in Simpfendorfer and Wiley (in review). The majority of encounters occurred in water less than 1 m deep, within 200 m of shore and 300 m of...
mangroves (Figure 7 a-c). Little relationship was found with seagrass beds and it was concluded that while smalltooth sawfish occur in seagrass beds they show no real preference for them (Figure 7 d). There were also significant positive relationships between sawfish size and depth ($R^2 = 0.08$, $F = 28.8$, $b = 4.78$, $df = 1$, $p < 0.0001$), and between sawfish size and distance to mangroves ($R^2 = 0.072$, $F = 30.3$, $b = 0.004$, $p < 0.0001$) or shore ($R^2 = 0.032$, $F = 12.8$, $b = 0.003$, $p = 0.0004$) (Figure 8 a-c). There was no relationship between sawfish size and the proximity to seagrass beds ($R^2 = 0.005$, $F = 1.82$, $b = -0.002$, $p = 0.179$) (Figure 8 d).

Figure 5. Location of 667 verified smalltooth sawfish encounters in Florida waters from 1998 to November 2005.
Figure 6. Density of sawfish encounters in 10 km$^2$ grids around the Florida coast.
Figure 7. Frequency distributions of (a) reported water depth, and (b-d) distances to habitat features, of encounters with smalltooth sawfish (*Pristis pectinata*). Distances to (b) shore, (c) mangroves and (d) seagrass, were calculated in ArcView 3.3 as the closest distance from the location of an encounter to the edge of a shape-file describing each feature. Data are all years from 1998 to 2004 combined.

Figure 8. Relationships between estimated length and (a) depth, (b) distance to shore, (c) distance to mangroves, and (d) distance to seagrass. Distances were calculated in ArcView 3.3 as the closest distance from the location of an encounter to the edge of a shape-file describing each feature. Data are all years from 1998 to 2004 combined.
The results of the encounter database section of this study demonstrate that *Pristis pectinata* in Florida waters is currently restricted largely to the southwestern portion of the state. Their core range extends along the Everglades coast from the Ten Thousand Islands to Florida Bay, with moderate occurrence in the Florida Keys and at the mouth of the Caloosahatchee River. Outside of these areas, sawfish were rarely encountered, and appear to be relatively rare. These data confirm the observations of Seitz and Poulakis (2002) and Poulakis and Seitz (2004) that this species occurs throughout southwest Florida, Florida Bay and the Florida Keys, but extends the range of observations beyond the scope of these studies to determine the distribution on a broad scale. The core range of *P. pectinata* corresponds to the section of Florida with the smallest amount of coastal habitat modification. The establishment of the Everglades National Park in 1947, which protected coastal habitats, and the banning of commercial fishing in the ENP in 1986 probably played an important role in this area remaining important for sawfish, when their abundance in many other areas declined.

The encounter data also indicate that *P. pectinata* currently do not occur in some areas that have been documented historically as being important. For example, only three encounters were reported from within the Indian River Lagoon system and all occurred in the southern portion of the system near the St Lucie Inlet. This observation corroborates the conclusion of Snelson and Williams (1981) that this species had been virtually extirpated from a system that around 1900 supported large numbers of animals (Goode, 1884; Henshall, 1895; Jordan and Evermann, 1896; Evermann and Bean, 1898). Bigelow and Schroeder (1953) also reported that *P. pectinata* were common in the lower reaches of the St. Johns River, but no encounters were reported from this area during this study. Based on these observations it appears that the depletion of *P. pectinata* has been the most dramatic on the east coast of Florida, and thus is an area where recovery efforts for this species should be focused.

The data collected in this study indicate that *P. pectinata* may be associated with a number of habitats. These include shallow areas, and areas close to shore, mangroves and seagrasses. However, two factors make the interpretation of these associations difficult. Firstly, there is a high degree of correlation between these habitats. For example, proximity to shore may be a function of selection of shallow depths or mangroves areas. Preliminary telemetry results for juvenile *P. pectinata* (Simpfendorfer, unpublished data) suggest that they may selectively use habitat based both on depth and mangroves presence, supporting the results of the current study. The second factor making interpretation of the associations more difficult is that although encounters occurred closer to the shore, mangrove and seagrass beds than was expected at random, we had no information on the fine scale distribution of the observational effort. Since the teleost species (snook and redfish) that fishermen commonly target when they encounter sawfish are closely associated with mangroves (Pattillo et al., 1997), it is likely that greater observational effort would have occurred in these areas and so may have biased the results. If this did occur then the level of association would have been over-estimated by these analyses. As a result further research on these habitat associations is required to validate the results. In particular, telemetry studies that investigate habitat use and selection patterns may prove especially beneficial. Assuming that *P. pectinata* has some
of these associations action to preserve and potentially restore these habitats may prove fruitful in conservation and recovery efforts.

The distribution and habitat associations of *P. pectinata* appear to change as they grow. The smallest juveniles occur in shallow water (<1 m) often closely associated with mangroves or the shoreline. Preliminary results from acoustic telemetry support this observation, showing that animals smaller than approximately 150 cm select these areas, possibly to avoid predators (mostly sharks such as *Carcharhinus leucas* and *Negaprion brevirostris*) or take advantage of high temperatures to maximize growth rates (Simpfendorfer, unpublished data). At sizes above 200 cm *P. pectinata* start to occur more frequently in water greater than 5 m, which may indicate that at this size they are less subject to predation enabling them to occupy a broader range of habitats. Comparative studies of the movement and habitat use patterns of animals above and below 200 cm, may help to further elucidate the changes in behavior that lead to these changes in distribution. At sizes over 300 cm a reasonable proportion of observations were made in deeper water. At this size they are approaching maturity, or are already mature (Simpfendorfer, 2000). These data suggest that at this size *P. pectinata* begin to spend a considerable proportion of time away from coastal habitats, although the encounters with large animals in shallow water indicate they do return at times, and so have a broad depth range. There was some indication in the data that animals greater than 300 cm in length moved to deeper waters off the Florida Keys, especially along the edge of the reef tract, during colder months. Several encounter reports of large individuals were received from this habitat. All of these encounters occurred during winter and spring, and all were from divers. Diving in this area is a popular activity year-round, thus these data support the hypothesis of a seasonal movement of larger sawfish into deeper water. Poulakis and Seitz (2004) also reported a substantial number of encounters in deeper habitats along the Atlantic side of the Keys, suggesting that this may represent an important winter habitat for this species.

The distribution of sawfish encounters will depend on many factors, but two that are important in interpreting the results are the actual distribution (the purpose of doing this research) and the distribution of the observational effort. If the observational effort is uneven it can lead to misinterpretation of the distribution. By dividing Florida into six zones we ensured that awareness-raising activities were equally distributed throughout the state. In addition, when processing the data to encounter density estimates research observations were excluded as this observational effort was focused mostly in the core range and so was not evenly distributed. However, it was impossible to ensure that observational effort was even across the state, and the results must be interpreted in light of this. Recreational fishing (the main source of encounter reports) is popular throughout Florida, but the numbers of fishers is probably lower in the Panhandle and upper west coast due to lower population density. It is unlikely that the resulting difference in observational effort would effect the interpretation of distribution, but makes investigating abundance from these data impossible.

The results of this research have shown that it is possible to use reports of encounters of sawfish by the public to determine the current range of *P. pectinata* in Florida waters.
These observations will help focus conservation efforts and provide a baseline from which to examine changes in the distribution following its listing as an endangered species.

**Habitat suitability**

The habitat suitability models developed for juvenile smalltooth sawfish using a combination of depth, mangrove and salinity data did a good job of identifying areas where they are observed. Models with all combinations of these factors predicted juvenile sawfish occurrence within 5 km of a high HSI zone in >90% of cases (Figure 9). The models including mangroves produced the lowest levels of occurrence in proximity to high HSI zones, primarily because mangroves occur infrequently in more northern sections of Florida. To determine if the distribution of mangroves affected the performance of the habitat suitability models only those encounter data from south of 28°N were examined. Using this reduced data set improved performance of the model considerably (Figure 10). Models that included salinity were the worst performing with the reduced data set.

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**Figure 9.** Distance from encounters with all smalltooth sawfish less than 200 cm in length to areas of high habitat suitability (HSI > 6) as predicted by GIS-based model with all combinations of three potential parameters. Blue line indicates final model selected.
Figure 10. Distance from encounters with smalltooth sawfish less than 200 cm in length encountered south of 28°N to areas of high habitat suitability (HSI > 6) as predicted by GIS-based model with all combinations of three potential parameters. Blue line indicates final model selected.

Since most of the models performed in a very similar way, the final model selected was the one that produced the smallest area (since conservation is best achieved with the smallest area possible to achieve the best results). The area of high suitability habitat was greatest for the salinity only model (Figure 11). The next largest were the depth only and depth/salinity models. The smallest area of high suitability habitat was the mangrove only model. However, this model was shown to not be representative throughout Florida (see above) and so was excluded. The next smallest area was the model containing all three habitat factors, and this was selected as the most representative of juvenile smalltooth sawfish habitat.

Figure 11. Areas of high habitat suitability (HSI > 6) for models with all combinations of the three habitat parameters (depth, salinity and mangroves).
The final models are shown in Figure 12. Areas with high suitability were distributed around Florida. Two areas were probably more poorly modeled than the rest – panhandle and outer Florida Keys. The former because of the lack of mangroves and the latter because of the lack of freshwater inflow that would have lowered salinity levels. However, the inclusion of all factors meant that areas of high suitability occurred in all sections of Florida; which was consistent with the encounter data (see Figure 5). Two regions in which few encounters were reported had substantial areas of high suitability habitat – Tampa Bay and Indian River Lagoon. Much of the Tampa Bay coastline showed high suitability, as did the northern areas of Sarasota Bay. In the Indian River Lagoon the southern half of the system contained the majority of the high quality habitat.

Figure 12. Three factor habitat suitability model for juvenile smalltooth sawfish. Areas indicated by white boxes are expanded in later panels.
The results of the habitat suitability models indicate that there is likely to be substantial amounts of habitat available to juvenile smalltooth sawfish outside of their current range which may enable the population to expand if measures to increase survival can be effective. The areas in Tampa Bay and the Indian River Lagoon in particular may represent areas with the greatest potential for future conservation efforts.

**Acoustic tracking**

Several juvenile smalltooth sawfish were acoustically tracked during the study period. The results of these tracks were combined with previous acoustic tracking results to investigate size related differences in the movement and habitat use patterns. Tracking of the smallest individuals (< 100 cm, Figure 13) indicated that they remain in relatively small areas on shallow mud banks. The movement pattern in these areas involves a great deal of turning so that they stay on the shallow bank. This highly non-directional movement was observed in all animals of this size. For larger juveniles (>100 cm, Figure 14) movements appeared aligned with mangrove shorelines. Individuals rarely moved more than a few meters away from the mangrove shorelines, but moved with relatively high directionality. This resulted in larger juveniles moving over larger areas. The change in movement patterns from small to large juveniles may represent a change in predation risk. The small sawfish are very vulnerable to predation by larger sharks (especially bull and lemon sharks) and they may use the very shallow mud banks as refuges from these predators. As they grow, however, the risk of predation diminishes because of their increased size and experience. Remaining close to the mangrove shore and the intricate prop root habitat still provides some protection from predators, but enables them to increase the space they occupy, which probably improves their access to food resources.

Figure 13. Acoustic tracks of two small juvenile smalltooth sawfish. Left panel: 78 cm male. Right panel: 89 cm male.
Ten Thousand Islands
Six small juvenile sawfish were fitted with acoustic monitoring tags during 2005 – three in Hurddles Creek and three in Faka Union Bay. All sawfish were less than one meter in length and were probably born within a few months of capture. Periods of residency within Hurddles Creek was 9-14 days, with one individual recorded occasionally over the next month. Periods of residency within Faka Union Bay were 17-29 days, with all individuals leaving within a six day window. These results indicate that small juveniles had short periods of residency in individual bays. This is consistent with previous results from Hurddles Creek in previous years where similarly sized individuals have been present for only a week or two. Previous monitoring of larger juveniles in Faka Union Bay has indicated that these animals may have longer periods of residency within these areas, often up to several months.

Caloosahatchee River
Six juvenile smalltooth sawfish (all were juveniles >100 cm in length) were released in the Caloosahatchee River during the study period. Off these three tags fell off after periods of 25, 27 and 52 days. This release was intentional so that tags did not remain on animals for too long. The other three individuals left the river after periods of 31, 35 and 51 days. Sawfish released between February and May moved up river at least 6 km, with movements on individual days over 4 km either upstream or downstream (Figure 15). Sawfish 3093 and 3094 were present for a substantial overlapping period and showed very similar movement patterns, suggesting that they were either moving together or responding to the same cues for movement. The two sawfish released later in the year (3091 and 588) remained closer to the mouth of the river, moving over much shorter distances (Figure 15). The difference in movement patterns between early and late in the year may be related to freshwater flow. It has been observed that newborn bull sharks in
the Caloosahatchee River change their location in the river depending on the salinity (which is in turn related to the amount of freshwater flow). In summer when river discharges are high bull sharks occur near the river mouth, and in winter when flow is low they occur up river (30km or more). There is some suggestion in the sawfish data of a similar pattern, with individuals moving further up the river in spring when flows are low. Further data will be required to test this hypothesis. However, if there is a relationship between the use of the river and salinity (and hence flow) then the water management practices utilized by the water management district will have a direct impact on sawfish.

Figure 15. Movement of acoustically tagged juvenile sawfish in the Caloosahatchee River. River km is a measure of distance upstream from the river mouth. Acoustic monitoring equipment started at river km = 2.

Literature cited


