CSIRO PUBLISHING

Marine and Freshwater Research, 2011, **62**, 648–657 www.publish.csiro.au/journals/mfr

Abundance, habitat use and movement patterns of the shovelnose guitarfish (*Rhinobatos productus*) in a restored southern California estuary

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Abstract. Coastal elasmobranchs such as the shovelnose guitarfish (*Rhinobatos productus*) seasonally use bays and estuaries for mating, pupping and feeding. However, many human-populated coastal areas have been developed, making them unavailable to coastal fish populations. The Full Tidal Basin (FTB) of the Bolsa Chica Ecological Reserve, California, USA, was completed in 2006, with the aim to restore lost estuarine habitat in southern California. Monthly abundance surveys conducted inside the FTB between June 2008 and September 2009 showed that shovelnose guitarfish were present throughout the year. Over 96% of the individuals caught were juveniles and these were most abundant in waters between 20°C and 24°C. Concurrently, 23 shovelnose guitarfish were fitted with coded acoustic transmitters and continuously tracked within the FTB for 16 months. Telemetry data showed individuals remained inside the FTB for, on average, 73.9 days (range 15–172 days), and made few movements between the FTB and the ocean. Tagged individuals disproportionately used mud habitats and waters at temperatures of 22°C, both of which are more common in the FTB than the neighbouring coastal ocean. The present study examined the structure and functionality of a restored estuary and suggests that the FTB is important habitat for a benthic predator, a promising result three years after restoration.

Additional keywords: assessing restoration success, biomass, habitat restoration, monitoring, wetland.

Introduction

Coastal elasmobranchs use bays, estuaries and lagoons as foraging, resting, mating and nursery areas (Pratt and Carrier 2001; Heupel and Simpfendorfer 2005; Heupel *et al*. 2010). However, in many parts of the world these coastal habitats have been urbanised, converted for aquaculture or destroyed (Zedler *et al*. 2001), which has led to a decrease in many estuarine-associated populations (Kennish 2002). In southern California, where urban development has overwhelmed a large portion of coastal habitats (Van Dyke and Wasson 2005), restoring or creating new estuarine habitats has become the preferred approach for protecting coastal species and ecosystems (Pondella *et al*. 2006). However, the ecological success of restoration efforts has been difficult to assess (Zedler and Callaway 1999). Restorations in southern California have so far only been evaluated based on the structure of the ecosystem (plant, invertebrate, bird and fish species composition: Zedler *et al*. 2001), and need to also address ecosystem functionality (how organisms use the system: Zedler *et al*. 1997).

Estuaries in southern California tend to have relatively low trophic complexity (3–4 trophic levels) (Zedler *et al*. 2001), and predators have a direct influence on the entire ecosystem. The top predators of these systems are usually marine-associated fishes (West *et al*. 2003), which can exert a strong top-down control on lower trophic levels (Peterson *et al*. 2001; Able *et al*. 2004). In addition, many elasmobranchs use estuaries seasonally, and at these times they can make up a significant portion of the fish biomass in these areas (Allen *et al*. 2002; Vidthayanon and Premcharoen 2002). During the summer, elasmobranchs may spend several months in these warm coastal waters to feed (Talent 1982) and thermoregulate (Matern *et al*. 2000). Furthermore, some species seasonally return to the same coastal area annually (Chapman *et al*. 2009). Therefore, understanding the degree to which elasmobranchs use restored habitats may provide a means to determine the functionality of these ecosystems.

Shovelnose guitarfish, *Rhinobatos productus* (hereafter ‘shovelnose’), display summer movements into estuaries and bays throughout their range. In Baja California, shovelnose are harvested as part of an artisanal fishery, which targets them in shallow bays exclusively during the warm summer months (Márquez-Farias 2005). The catch is primarily adults with many pregnant females early in the summer, and mixed sexes at the end of the summer, suggesting that inshore movements may have a potential reproductive purpose (Villavicencio-Garayzar 1993). In California, shovelnose are common in bays and estuaries (Talent 1985; Allen *et al*. 2002) and feed extensively on benthic invertebrates and fishes (Talent 1982), indicating that they are an important component of these ecosystems. However, it is unclear how long individuals stay inside bays or estuaries, how much space and what kind of habitat they use while in these areas, and whether they return to the same estuarine area every year.

 10.1071/MF10173 1323-1650/11/060648

The Bolsa Chica Ecological Reserve in Orange County, California, USA has recently opened the Full Tidal Basin (FTB) as mitigation for habitat loss from the expansion of the Port of Los Angeles. The FTB offers conditions similar to the natural summer habitats of shovelnose (coastal, calm and shallow water with fine sediment) making it a potentially suitable environment. As the FTB has only been available since August 2006, it offers a unique opportunity to study the behaviour of a benthic coastal predator in a newly restored habitat. In the present study, monthly abundance surveys were used in conjunction with acoustic telemetry to simultaneously examine the structure and habitat use of the shovelnose population in the FTB. If the FTB provides adequate habitat for the growth and reproduction of this benthic predator, it is reasonable to expect: (1) a seasonal increase of shovelnose abundance during the warm months with neonates and a female-biased sex ratio early in the summer, (2) residency times of 3–4 months within the FTB during the warmer months, (3) evidence of site fidelity from one year to the next, and (4) use of the warmest temperatures and mud habitats inside the FTB.

Methods

Study site and environmental data

The Bolsa Chica Ecological Reserve (33°42′09″N, 118°03′01″W) is in Orange County, California, USA (Fig. 1*a*). Originally a 9.3-km^2 estuary, it was closed off from the ocean in 1899 and filled in for agriculture and oil drilling. Restoration began in 2004 and in August 2006 a 100-m-long inlet was opened to the ocean and into the newly restored FTB (Carlberg 2009). The FTB is now a full tidal wetland with a 3-m-deep central channel and shallow mudflats on either side. At high tide, the entire basin is inundated (area 1.48 km^2), whereas at low tide mudflats are exposed, leaving only 0.84 km^2 submerged. Although the natural freshwater input has not yet been restored to the FTB, making it a fully marine system, the FTB is still referred to as an estuary as that was its original condition and it may be reconnected to its freshwater source in the future.

Most of the FTB is subtidal mud (42.7%), with other important habitat types including intertidal mudflats (16.5%), mud–gravel (15.6%) and eelgrass (9.8%). Soon after opening of the ocean inlet, over 0.004 km^2 of eelgrass (*Zostera marina*) was planted, which has expanded to cover ~0.13 km^2 of the FTB by October 2009. Sand substratum habitats (including sand, sand–mud and sand–mud–gravel mix) are concentrated immediately inside the inlet and add up to 15.4% of the total area. The basin is surrounded by rock rip-rap and marine animals can only exit through the inlet into the ocean. Water temperatures were monitored by 17 immersible temperature dataloggers (Onset computers, Pocassett, MA) deployed at 2 m depth throughout the FTB. Average daily water temperatures inside the FTB were warmer during most of the year compared with coastal ocean temperatures measured at Newport Beach, CA (www.ndbc.noaa.gov). To determine the thermal spatial heterogeneity of the FTB, water temperatures for the entire FTB were interpolated from the datalogger estimates using a spline interpolation technique in ArcGIS v9.2 (ESRI, Redlands, CA). These methods allowed us to produce base maps of the FTB.

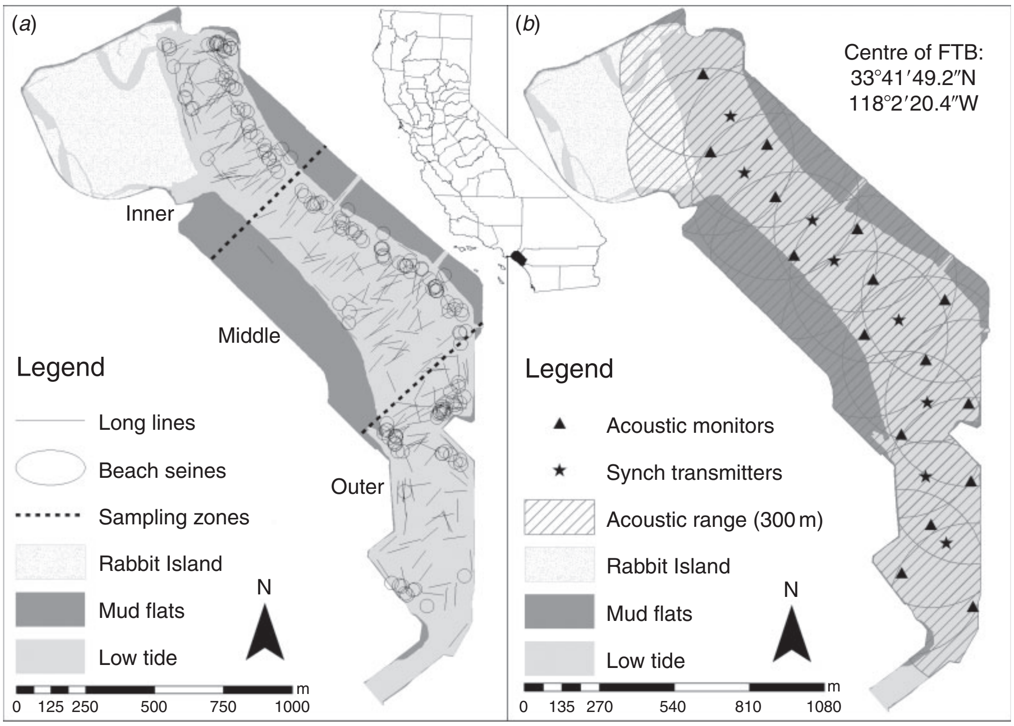

Fig. 1. Study area of the Full Tidal Basin (FTB) of Bolsa Chica, Orange County, California, U.S.A. (shaded in inset map of California). (*a*) Location of the abundance surveys for beach seines (circles) and longlines (lines). (*b*) Acoustic VR2-W receiver array within the FTB (triangles), including location of 8 positional 'synch' transmitters (stars) used for estimating fine-scale positions.

Based on water temperature and benthic substratum differences, the FTB was divided into three equally sized zones along the length of the basin. The outer zone, closest to the inlet, was characterised by sand substratum coming in from the ocean, as well as cooler water temperatures (12.8–25.1°C). The middle zone was intermediate in water temperature (12.3–26.0°C), containing mud substratum and eelgrass. The inner zone was the warmest (12.1–27.9°C) and comprised mostly mud substratum.

Abundance surveys

Monthly abundance surveys were carried out between June 2008 and September 2009. Three beach seines and 3–6 longline sets were conducted in each zone every month. The beach seine (26 m long × 3 m deep, 5-cm mesh on the wings and 1.3-cm mesh in the bag) was used to sample areas within 50 m of the shore during low tide. The longline (100 m long mainline, 10 barbless 4/0 circle hooks) was used to sample the deeper central channel of the FTB. Hooks were baited with thawed squid, attached to the mainline with a gangion that allowed them to rest on the bottom and left to soak for 30–40 min. Beach seine and longline locations were chosen randomly within each zone to ensure even sampling of all available habitats (Fig. 1*b*). Some areas (such as the west bank of the middle zone) were not accessible owing to nesting of endangered birds.

Shovelnose caught were sexed, weighed to the nearest 5 g and total stretch length (TSL) was measured to the nearest millimetre. All individuals were tagged with a Peterson disc tag (Floy Tag, Seattle, WA) containing a unique ID code. Shovelnose were then released at the site of capture after a maximum delay of 10 min. Beach seining effort was equal across months and zones and catch per unit effort (CPUE) was calculated as the number of shovelnose caught per net set. Longline abundances were also converted to CPUE as the number of shovelnose caught per hook per hour to account for differences in the number and duration of sets.

All statistical analyses were carried out with SAS *v*.9.1 (SAS software, Cary, NC). Female to male sex ratios were calculated for each season and compared using a chi-square test. CPUE estimates were analysed for each fishing technique separately. CPUE was $\log(x + 1)$-transformed to ensure equal variances and compared across zone and month in two-way ANOVAs and season in a one-way ANOVA. The 16-month study period was divided into four seasons based on water temperature: Summer 2008 (June to September 2008), Winter 2008 (October 2008 to January 2009), Spring 2009 (February 2009 to May 2009) and Summer 2009 (June 2009 to September 2009). In addition, CPUE was compared with zone and month simultaneously with water temperature as a covariate in a General Linear Model (GLM) (Zar 1999). Shovelnose biomass was estimated by multiplying the average weight of shovelnose caught (excluding recaptures) per seine net set by the average surface area sampled by the seine net (650 m^2). This was only done with beach seine data as the area sampled could not be estimated with longline sets.

Site fidelity

A subset of 23 shovelnose was tagged with coded V13–1 L-R64K acoustic transmitters (Vemco Ltd, Halifax, Canada; 13 mm diameter × 36 mm, 6 g in water, 147 dB output), with a nominal pulse interval of 120 s (90–180 s), providing 1123 days battery life. Eleven transmitters were deployed between July and December 2008, and 12 were deployed between March and June 2009. All transmitters in 2008 were externally mounted; transmitters in 2009 were surgically implanted into the peritoneum while the individual was in tonic immobility (Henningsen 1994). The transmitters were detected by a gridded array of 16 VR2-W underwater omni-directional acoustic receivers (Vemco Ltd) placed throughout the FTB (Fig. 1*c*) (Heupel *et al*. 2006). Range tests indicated that receivers had an average (±s.d.) detection range of 440 ± 83 m.

In the present study, we define site fidelity as an individual remaining in or returning to the same area over time. Residency time (intra-annual site fidelity) of tagged shovelnose was estimated as the number of days each individual was detected at least three times by any receiver in the FTB. However, because tagging took place earlier in 2009 than 2008, we used average date of departure to compare residency time between years. Inter-annual site fidelity was assumed to be occurring when an animal returned to an area it was found in the previous year (Vaudo and Lowe 2006) and was calculated as the percentage of individuals tagged in 2008 that were re-detected in 2009.

Fine-scale movements

We used the VR2-W Positional System (VPS) to determine positions of the 23 acoustically tagged individuals. The VPS uses ‘synch’ transmitters (Fig. 1*c*) to synchronise the internal clocks of the VR2-W receivers so that a position can be triangulated based on the detection time of a transmission from a coded transmitter at three or more receivers. The VPS was tested within the FTB and found to estimate stationary reference transmitters with an accuracy of 2.64 ± 2.32 m (Espinoza *et al*. 2011*a*). Each VPS position was binned within a tide level (low slack, high slack, incoming, outgoing) and diel stage (day, night, crepuscular) based on the time of the position, and within a habitat type and water temperature based on the location of the position. Tide and sunset or sunrise information was downloaded from the National Oceanic and Atmospheric Administration (NOAA, www.ndbc.noaa.gov). High and low slack tides were assumed to occur for 1 h before and after high and low tide times, respectively, and crepuscular periods were defined as 1 h before and 1 h after sunrise and sunset.

Habitat type was determined by overlaying VPS-measured shovelnose positions with the habitat base maps using ArcGIS. Water temperature for each position was determined by running the ArcGIS interpolation model described above every 30 min. A 50 × 50-m grid was placed over each temperature map and the interpolated temperatures within each grid was averaged and entered into a database. A temperature was estimated for each VPS position by linking the 50 × 50-m grid number and 30-min period of the VPS position with the temperature database. Benthic habitat selection by tagged shovelnose was determined as the number of VPS positions over each habitat divided by the availability of each habitat. Water temperature selection was determined using the same methodology. Benthic habitat and temperature selection were analysed using a chi-square test with the individual as a random variable. This technique treats individual shovelnose as replicates and runs the chi-square on each individual, thereby eliminating the problem of autocorrelation (Rogers and White 2007).

The 95% kernel utilisation distributions (KUD) were used to calculate the extent of individual home ranges excepting occasional forays (Worton 1987). Because KUDs depend on sample size and there was an uneven number of positions for each tagged shovelnose, Monte Carlo simulations were run for each tagged individual: 100 positions were randomly chosen and used to calculate 95% KUDs. This was repeated 100 times for each individual and the 100 resulting KUDs of each individual were then averaged using ArcGIS. The averaged KUDs were compared with shovelnose length, sex and residency times using Pearson's correlations (the assumption of normality was verified for both the 50 and 95% KUD).

Rate of movement (ROM) was calculated as the distance travelled between two positions divided by the time elapsed between those positions. However, the ROM values were not normally distributed and had unequal variances across the factors tested, even after log-transformation. In addition, shovelnose are known to rest on the seafloor for extended periods of time (Love 1996), which may bias the ROM estimate. Therefore, ROM values were converted to periods of activity and inactivity. If the ROM was more than 1 m min^{-1} between two positions, the animal was considered to be active. Threshold values of 0.5, 1 and 10 m min^{-1} were tested and all showed the same pattern. The 1 m min^{-1} value was chosen because it was similar to the accuracy of the VPS system, therefore all movements would be detected and errors in the VPS should be removed. The proportion of time spent active was then used as the response variable and compared across diel and tidal stages and temperature using chi-square tests.

Results

Abundance and population structure

A total of 144 beach seines and 218 longline sets were conducted within the FTB between June 2008 and September 2009. During this 16-months period, 269 shovelnose were caught, sexed, measured, weighed and externally tagged. The female to male sex ratio was 1.24 : 1 and 96% of the shovelnose caught were immature (Fig. 2) based on published size-at-maturity for the southern California population (Timmons and Bray 1997). The smallest individual caught was 36.6-cm TSL, at least 15 cm longer than the reported size at birth (Eschmeyer *et al*. 1983; Villavicencio-Garayzar 1993).

Length frequencies were not distributed differently between the sexes, with most individuals measuring between 50 and 80 cm TSL (Kolmogorov–Smirnov: $D = 0.2$, $P = 0.493$). Average length of shovelnose caught in the FTB was significantly shorter in September 2008 and May 2009 compared with December 2008, January and February 2009 ($F_{15,250} = 2.20$, $P = 0.007$). Overall, TSL was not different between males and females ($t_{256} = 1.51$, $P = 0.132$). However, shovelnose caught with beach seines were significantly smaller than those caught with long lines ($t_{261} = 9.92$, $P < 0.0001$).

The biomass of shovelnose inside the FTB was estimated at 1.3 g m^{-2}, which extrapolates to 1952 kg (±1788 kg) for the entire FTB area. Monthly beach seine data showed that shovelnose abundance was nearly significantly lower during the winter season (Fig. 3*a*, $F_{3,140} = 2.61$, $P = 0.054$). However, there was no significant difference in catch per unit effort (CPUE) across seasons for longlines (Fig. 3*b*, $F_{3,209} = 1.47$, $P = 0.274$). CPUE analyses were run on $\log(x + 1)$-transformed data, but raw values are plotted in Fig. 3. There was no significant difference in shovelnose abundance among months or zones, likely a result of low sample sizes and the high occurrence of zero catch during some months (month, $F_{15,128} = 0.54$, $P = 0.774$; zone, $F_{2,141} = 0.89$, $P = 0.12$ for beach seines; month, $F_{15,197} = 0.65$, $P = 0.585$; zone, $F_{2,210} = 1.73$, $P = 0.175$ for longlines). There was no evidence of sexual segregation by season ($\chi^2_3 = 3.09$, $P > 0.05$) based on sex ratios of catch.

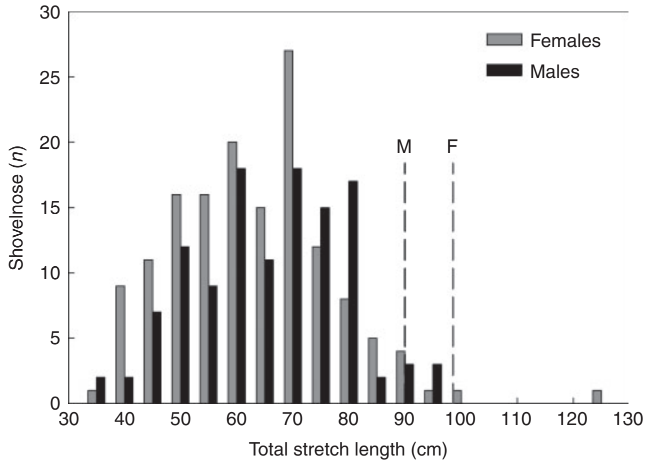

Fig. 2. Length–frequency of all shovelnose caught by seine and longline for females (grey) and males (black). Published sizes at maturity are shown by the dashed lines (90- and 99-cm TL for males and females, respectively: Timmons and Bray 1997).

Ten individuals externally tagged with Peterson disc tags were recaptured between 0 and 135 days after initial tagging. One individual was recaptured twice; once after 55 days and again after 135 days by a fisherman at the mouth of the inlet. No other reports of tagged shovelnose were received. None of the shovelnose tagged in 2008 were recaptured in 2009. The recaptured individuals moved between 37 and 1515 m after initial tagging.

Habitat use of the FTB

Long-term acoustic tracking data showed shovelnose stayed within the FTB an average of 73.9 days (range: 15 to 172 days). Average residency time was not correlated with sex or size of the individual ($t_{18} = 1.55$, $P = 0.143$ for sex; $r = 0.083$, $P = 0.720$ for size) and size of the tagged individuals was not different according to sex ($t_{18} = 0.37$, $P = 0.714$). Based on acoustic data, no individuals made daily movements in and out of the FTB and only 2 individuals were found to leave and return a couple weeks later (Fig. 4). Average date of departure out of the FTB was not significantly different between 2008 (7 September 2008) and 2009 (15 August 2009) ($t_{18} = 0.78$, $P = 0.223$).

Positions were successfully estimated for all tagged individuals yielding 32 000 VPS positions. Tagged shovelnose strongly selected for subtidal mud habitat, with some use of eelgrass and intertidal mud habitats, and little use of any habitat

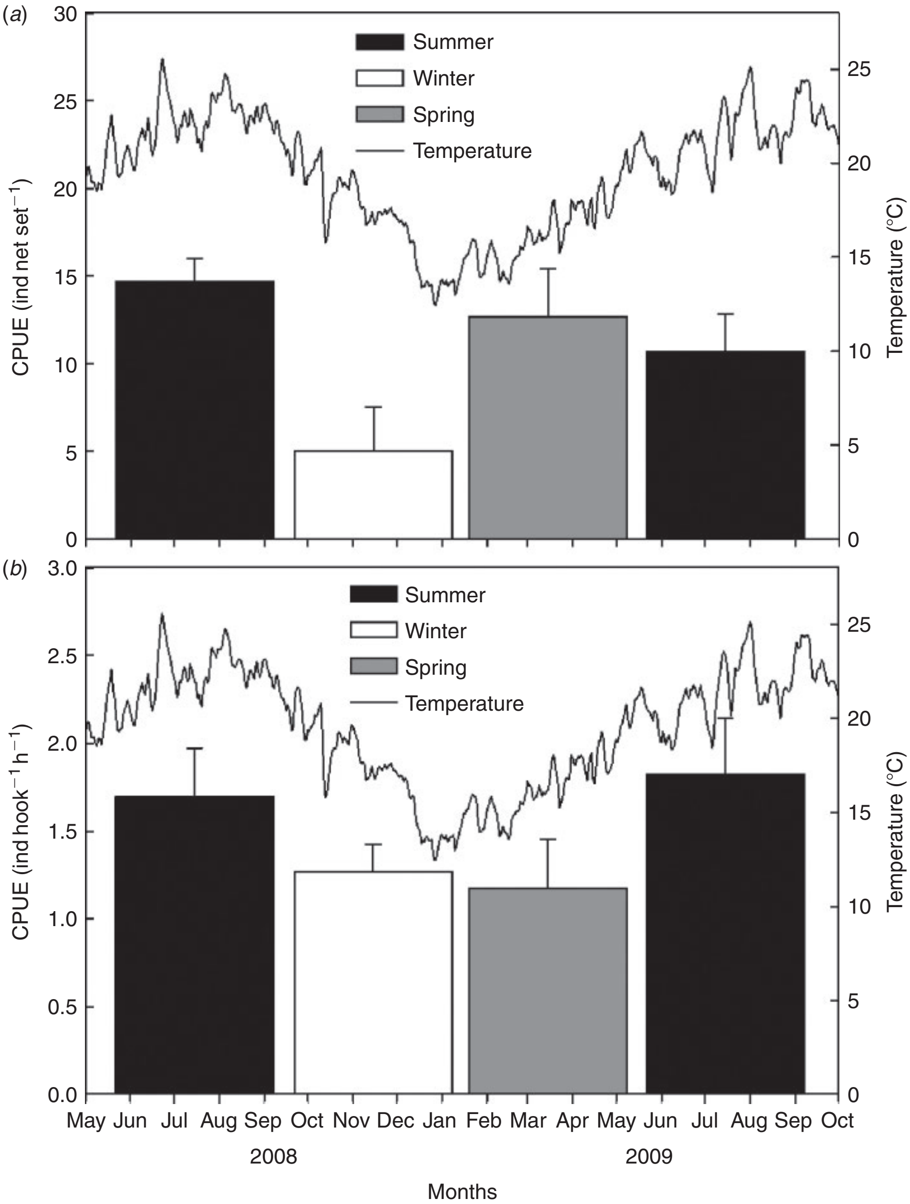

Fig. 3. Seasonal abundances (+s.e.) for (*a*) beach seines and (*b*) longlines. Water temperature is shown on the secondary *y*-axis. Note the difference in scale for CPUE between beach seines and longlines.

with sand ($\chi^2_6 = 18\,727$, $P < 0.001$, Fig. 5). The high chi-square value comes from treating each individual separately in the analysis to remove problems of autocorrelation (Rogers and White 2007), thereby adding all individual chi-square values and calculating an overall chi-square. Average home-range size of all shovelnose estimated using the 95% KUD was $0.18 \pm 0.03\,km^2$. This represents 12% of the FTB area, mostly in subtidal areas, which explains why average KUD did not vary across tidal stage ($F_{3,22} = 1.07$, $P = 0.632$). The 95% KUD estimates were not correlated with residency time inside the FTB ($r = 0.145$, $P = 0.532$) or TSL of the individual ($r = -0.058$, $P = 0.802$ for 95%). KUDs were also not different between the two sexes ($t_{17} = 1.39$, $P = 0.183$ for 95%). The VPS allowed position estimates of multiple individuals simultaneously. Even with 32 000 position estimates and up to 10 individuals with acoustic transmitters inside the FTB at the same time, there were only 23 instances when two individuals were found within 50 m of each other during the same 30-min period.

Activity patterns and temperature use

The proportion of time shovelnose were active was greater at night and in the morning than in the afternoon ($\chi^2_{138} = 551.73$, $P < 0.001$). Shovelnose were also more active during incoming and high tides than during outgoing and low tides ($\chi^2_{138} = 38.87$, $P < 0.05$). Higher activity rates were observed in the warmer water temperatures ($\chi^2_{138} = 490.08$, $P < 0.001$). Shovelnose were disproportionately found in habitats with

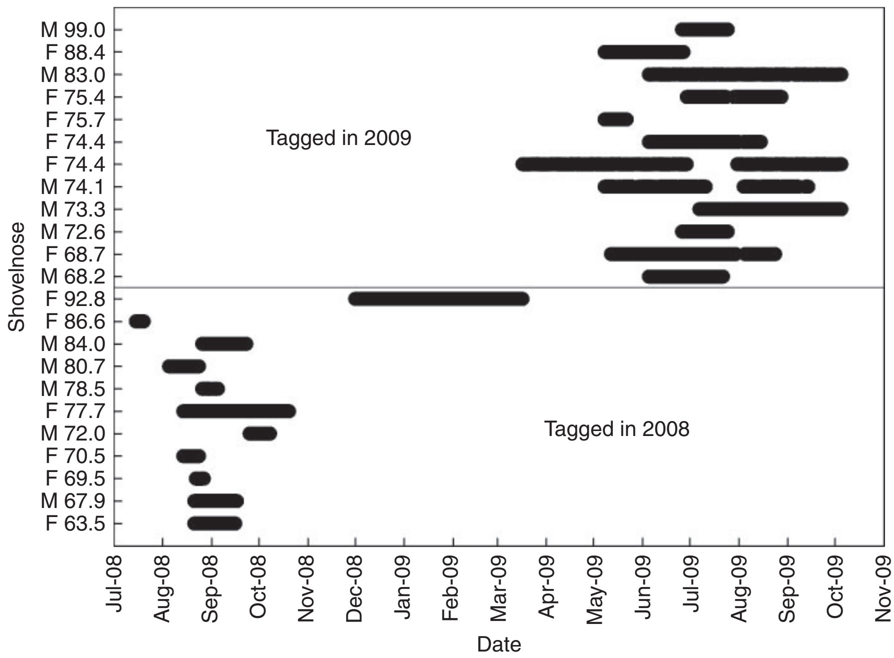

Fig. 4. Daily detection plot of tagged shovelnose inside the FTB. Black dots represent at least three detections of the transmitter for that day. Tagged individuals are identified on the *y*-axis by their sex (Female or Male) and their TSL (cm). Within each tagging year, individuals are arranged by size.

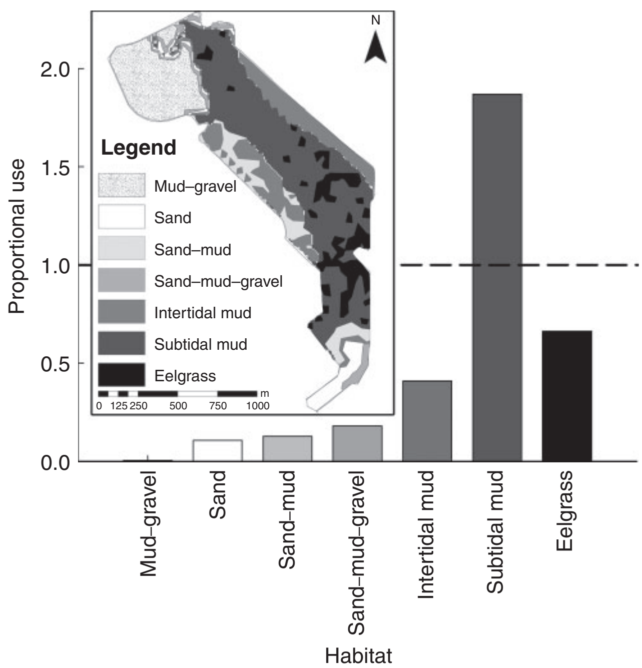

Fig. 5. Proportional habitat use for all tagged individuals. Values above 1 (dashed line) represent a selection for that habitat. Inset map shows the location and distribution of habitats using the same colour scheme as the bar graph.

water temperatures at 20–24.5°C, with a peak at 22°C ($\chi^2_{18} = 2541$, $P < 0.001$; Fig. 6). Males and females did not show a significantly different pattern of thermal habitat selection (Kolmogorov–Smirnov: $D_{18} = 0.200$, $P = 0.771$). Interestingly, this is very similar to what was found during the abundance surveys where more shovelnose were caught using both fishing methods when water temperatures were 19–24°C, with a peak at 22°C (Fig. 6; $r = 0.72$, $P = 0.0365$ for beach seines; $r = 0.85$, $P = 0.0022$ for longlines).

Discussion

Abundance and biomass

The biomass of the shovelnose population inside the FTB (1.3 g m^{-2}) was higher than the shovelnose biomass in San Diego Bay (0.423 g m^{-2}), a larger habitat also in southern California that has remained accessible to fish despite its use as a major shipping port (Allen *et al*. 2002). This suggests that the ecosystem in the recently opened FTB is developed enough to support a mobile benthic predator like the shovelnose during at least the summer months, and that the ecosystem may be moving towards stable trophic interactions. Shovelnose in San Diego Bay were found year-round over the four years of sampling, and were most abundant during the summer and autumn months (Allen *et al*. 2002), similar to what we found in the FTB. The population structure of shovelnose in the FTB was heavily skewed towards juveniles. We do not think that gear selectivity was an issue here since the same fishing methods allowed us to catch a wider range of shovelnose sizes at the nearby Seal Beach, CA (Farrugia 2010). Similarly, the gray smooth-hound (*Mustelus californicus*) population in the FTB is composed of over 83% of juveniles (Espinoza *et al.* 2011*b*). There was no evidence of spatial or temporal sexual segregation inside the FTB, with a sex ratio inside the FTB close to one, and no difference in behaviour between sexes of acoustically tagged shovelnose. These findings are all consistent with elasmobranch populations

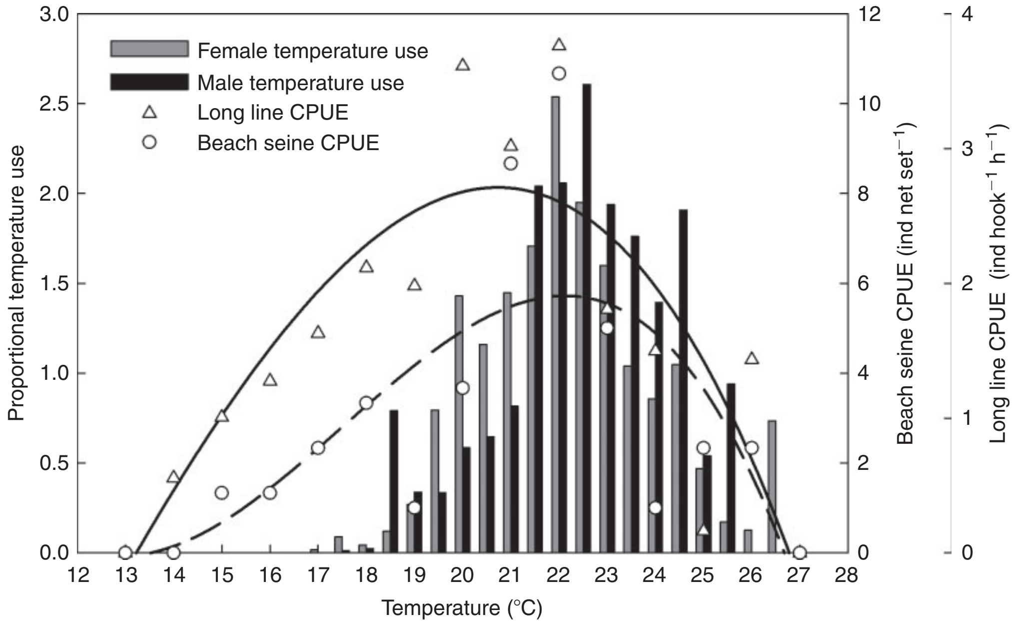

Fig. 6. Proportional temperature use for all tagged individuals (bar graph, grey for females, black for males) and catch per unit effort at different temperature for longlines (triangles and solid line) and beach seines (circles and dashed lines). Note the difference in scale for CPUE between beach seines and longlines.

composed primarily of immature individuals, which would not be expected to show sexually dimorphic behaviour.

Along with few adults, no neonate shovelnose were found within the FTB, suggesting it is currently not an important mating or pupping area for shovelnose. Juveniles may seek foraging opportunities and protection inside bays and estuaries to maximise growth rates (Morrissey and Gruber 1993; Simpfendorfer and Milward 1993). In sampling the FTB, fish species that could prey upon shovelnose were not encountered. Their dark grey colouration, behaviour of staying close to the bottom, and the murky conditions within the FTB offer them protection from most predatory bird species (e.g. osprey, *Pandion haliaetus*; great blue heron, *Ardea herodias*). Only once did we observe a California sea lion (*Zalophus californianus*), a potential predator of juvenile shovelnose, swimming inside the FTB. Therefore the FTB may offer a safer area for juveniles during the summer compared with the open ocean.

Feeding and growth

Although no diet or stable isotope analyses were conducted in this study, we have behavioural evidence of shovelnose feeding inside the FTB. Talent (1982) found shovelnose mostly feed on benthic crustaceans, molluscs and fish, all of which are already present at this level of the FTB restoration (Farrugia 2010). An average residency time of over two months with little or no movement in and out of the FTB during that period would only be possible if shovelnose were feeding to some extent within the FTB. In addition, animals may be expected to scale their home ranges according to their metabolic requirements (Kramer and Chapman 1999; Lowe and Bray 2006). Acoustically tagged individuals were found to have home ranges that spanned only 12% of the FTB area, suggesting that they may have only been foraging in a relatively small portion of the total habitat available. Some elasmobranchs have been found to forage only during certain times of the day (Matern *et al.* 2000; Cartamil *et al.* 2003), indicated by increased activity levels. In the FTB, shovelnose showed a typical diel pattern in activity, with an increase in activity at night and early in the morning as well as during incoming and high tide. It is hypothesised that shovelnose may be actively foraging during these time periods to take advantage of nocturnally active prey, as well as to forage for prey on the mudflats. Additionally, like brown smooth-hounds (*Mustelus henlei*) using localised areas to feed in Tomales Bay, CA (Campos *et al.* 2009), areas of more intense use in the FTB by shovelnose may indicate areas of high prey density.

In addition to potential increased feeding opportunities, the FTB may attract juvenile shovelnose because it presents conditions favourable for growth. Water temperature can be an important factor in elasmobranch metabolism, somatic growth and reproduction (Economakis and Lobel 1998; Wallman and Bennett 2006). Faster somatic growth may translate to less time to reach sexual maturity, less time being vulnerable to predators, and greater fitness. Physiologically, warmer water temperatures within the thermal optima of an organism should increase its metabolic rate (Fauconneau *et al.* 1983), thereby improving its ability to perform important behaviours (Huey 1991) such as foraging (Vaudo and Lowe 2006). Past the optimal temperature range, however, base metabolic rates increase until somatic growth is no longer maximised (Magnuson *et al.* 1979) and animals should avoid these extreme temperatures (Magnuson and Destasio 1997). Indeed, both abundance and movement data show that shovelnose in the FTB select water temperatures in a narrow range of 20–24°C (from a possible range of 12.1–27.9°C).

By contrast, bat rays (*Myliobatis californica*), which are known to be very thermally sensitive ($Q_{10} = 6.8$: Hopkins and

Cech 1994), show daily behavioural thermoregulation by feeding in warm waters and resting in cooler waters to lower metabolic costs during digestion and increase nutrient assimilation (Matern *et al*. 2000). In this study, shovelnose did not show this behaviour, indicating that they are probably less thermally sensitive than bat rays, and simply seek out one optimal temperature, similar to that of leopard sharks (who have a Q_{10} of 2.51; Miklos *et al*. 2003). It is likely that shovelnose have a thermal maximum >24°C, as they can be found as far south as Mazatlan, Mexico (Eschmeyer *et al*. 1983); therefore, 20–24°C water may be the temperature at which maximum growth is achieved, at least for the southern California population. Interestingly, waters along coastal beaches of southern California rarely reach temperatures >22°C, which are more common in calm, shallow areas like the FTB during summer and autumn months. Therefore, shovelnose may be coming in to the FTB during the warmer months to maximise growth, consistent with the conclusions of Timmons and Bray (1997), who used band formation in shovelnose vertebral centra to determine that growth was greatest during the summer.

Habitat use and site fidelity

Although shovelnose abundance in summer 2008 was similar to that of summer 2009, there were no recaptures of externally tagged individuals and no detection of acoustically tagged individuals from 2008 in 2009. Therefore, there was no evidence of juvenile shovelnose inter-annual site fidelity to the FTB, despite it being a suitable area. Individuals may have lost their tags or been preyed upon after leaving the FTB. However, we do not think this is likely to explain the lack of any recaptures. Alternatively, some tagged individuals may have found other suitable areas such as the nearby Newport and Anaheim Bays. Beach seine surveys conducted from 2007 to 2009 indicated that summer aggregations of adult male shovelnose occurred off Seal Beach, 10 km north of the FTB (California Department of Fish and Game, unpubl. data). This may explain the lack of adults inside the FTB and suggests that the FTB may not yet be sufficiently developed to attract adult shovelnose, or simply is not adult habitat.

Despite the lack of mature shovelnose inside the FTB, adult elasmobranchs are known to use bays and estuaries seasonally for mating and pupping (Castro 1993; Simpfendorfer and Milward 1993; Pratt and Carrier 2001). Adult shovelnose have been found during the summer in bays and estuaries in California (Talent 1985) and Baja California (Salazar-Hermoso and Villavicencio-Garayzar 1999), but their presence in these areas was predominantly during summer. Shovelnose are the most commonly landed batoid in Baja California (Márquez-Farias 2005), where fishers catch them exclusively during the summer in shallow bays (Salazar-Hermoso and Villavicencio-Garayzar 1999). The artisanal elasmobranch fishery in Baja has been economically and culturally important for decades with catch rates over 30 000 tonnes year^{-1} (Cartamil 2009). The longevity and intensity of the shovelnose fishery in Baja California and results from our study suggest that shovelnose in the FTB are not philopatric, as a highly philopatric population in Baja would certainly have been extirpated by now considering the high degree of fishing pressure on this species. Therefore, shovelnose may simply seek out an area of suitable habitat, and newly opened areas like the FTB may now provide additional habitat to support population growth of this species.

Conclusions

Our results suggest that the FTB is a good candidate for future elasmobranch nursery habitat (Heupel and Simpfendorfer 2005; Heupel *et al*. 2007). Juvenile shovelnose and other mobile benthic predators may be important in the ecological succession and shaping of the benthic community so that the FTB can support adult shovelnose in the future as in Elkhorn Slough (Talent 1985) and San Diego Bay (Allen *et al*. 2002). Further monitoring is required to assess how fish population structure will change as the estuary progresses, and studies of other levels of the ecosystem are also needed to confirm that the FTB has been a successful restoration. Presently, the FTB seems to be important habitat for a benthic predator, a promising result only three years after restoration. This is the first study that has looked at both the structure and function of a restored coastal ecosystem by simultaneously measuring the abundance and habitat use of a marine benthic predator. Shovelnose were used successfully as a model species because they had one of the highest biomasses in the FTB (Farrugia 2010) and have a known behaviour and population structure in natural environments (Talent 1982; Salazar-Hermoso and Villavicencio-Garayzar 1999).

Marine habitat loss is a growing concern around the world (Halpern *et al*. 2008) and habitat restoration is one strategy to reverse this trend. Specifically, restorations aim to '…ensure that ecosystem structure and function is increased or repaired, and that natural dynamic ecosystem processes are operating effectively again' (National Research Council 1992). To attain this goal, we recommend that restoration assessments examine the use of the restored habitat by top level predators. Elasmobranchs are particularly useful because they are easy to tag, highly mobile and seasonally abundant in coastal ecosystems.

Acknowledgements

We thank Drs Bengt Allen and Ashley Carter for their advice and counsel. This research would not have been possible without the financial support of the Southern California Academy of Sciences, SCTC Marine Biology Educational Scholarship Foundation, the LA Rod and Reel Club Foundation, the USC Sea Grant, Project AWARE, the PADI Foundation, the Reish Research Grant in Marine Biology and the CSULB Graduate Research Fellowship. Kelly O'Reilly (DFG) provided support and access to the Bolsa Chica Reserve, and data were collected under CDFG Scientific Collecting Permit # SC-9759 and IACUC protocol #254. This research project involved an enormous amount of fieldwork. We would like to thank all the field volunteers who helped us. Finally we are grateful to the anonymous reviewers and referees who commented on earlier versions of the manuscript.

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Manuscript received 28 June 2010, accepted 8 November 2010