

Mapping the spatio-temporal distribution of threatened batoids to improve conservation in a subtropical estuary

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The spatio-temporal distributions of four batoid species were examined in a subtropical estuary. Fluvial gradient was the most important factor explaining abundances, reflecting positive relationships with either salinity or distance from urbanised areas that were consistent across seasons and depths. The results support existing protected areas.

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Estuaries provide essential habitat for diverse fish assemblages including migratory anadromous and catadromous species, and those that are resident throughout their entire life cycle (Day *et al.*, 1981; Claridge *et al.*, 1986; Potter *et al.*, 1986). Many marine fishes that have broad salinity tolerances also invade lower estuarine reaches. These so-called marine stragglers often have highly variable distributions and abundances, particularly within systems in the tropics and the tropic and temperate convergence zone, owing to the concomitantly variable environmental parameters (Elliott *et al.*, 2007).

The Paranaguá estuarine complex (PEC) is one such estuary in Paraná, southern Brazil. Located at 25° S and surrounded by one of the last remnants of Atlantic rainforest, the PEC is open to the sea and elongates along two fluvial gradients: an east–west inlet forming Paranaguá and Antonina bays (56 km long) and a north–south inlet constituting Laranjeiras and Guaraqueçaba bays (40 km long). The system incurs extensive artisanal fishing (passive gears only), but also encompasses the environmental protected area (EPA) of Guaraqueçaba and borders a Natural World Heritage

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site (UNESCO, 1999). The structure of the PEC makes it an important habitat for a plethora of marine stragglers, including several batoids (Passos *et al.*, 2012).

Despite the evolutionary success of batoids, globally many species are threatened, primarily because of their inability to sustain intensive fishing effort owing to their low fecundity and late-stage maturity (Compagno, 1990; Heppel *et al.*, 1999). Several batoids occur in Paran and virtually all suffer overfishing (Bornatowski & Abilhoa, 2012), including species which are listed as concerns by the International Union for Conservation of Nature (IUCN): the guitarfish *Rhinobatos percellens* (Walbaum 1792) listed as ‘near threatened’ (Casper & Burgess, 2009) and butterfly ray *Gymnura altavela* (L. 1758) listed as ‘vulnerable’ (Vooren *et al.*, 2007). The latter species is also listed as ‘critically endangered’ by the Brazilian Ministry of the Environment (MMA, 2014). Populations of numerous other species, including the common stingray *Dasyatis guttata* (Bloch & Schneider 1801) and electric ray *Narcine brasiliensis* (Olfers 1831) are also of considerable concern, with both considered to be ‘data deficient’ (Rosa & Furtado, 2004, 2007).

Understanding the spatio-temporal habitat use of batoids is an essential prerequisite to their effective conservation, and especially within and around protected areas. Given the above, the aim of this short communication was to document some of the batoids found in the PEC and to identify any variability in abundances, and possible influencing variables. A second aim was to use this information to propose mechanisms for conserving local populations.

Based on known variables of the PEC, including substratum particle size, and the temperature, density, chlorophyll a, turbidity, salinity and suspended particulate matter of water (Lamour *et al.*, 2004), the north–south and east–west fluvial gradients described above were each divided into three sectors: outer (sector 1), middle (sector 2) and inner (sector 3; Fig. 1). The sector delineation variables were incorporated into a database, integrated by ArcGIS software (Esri Pty Ltd; <http://www.esriaustralia.com.au/>) and then, using the Hawth’s Tools (developed for the ArcGIS software; Beyer, 2004), random monthly sampling points were selected within sectors ($n=6$ per sector). All sampling points comprised appropriate grid sediments (>3 m depth and coarse grain size).

During each month between November 2012 and September 2013, the sectors were sampled using one of three penaeid trawls [in a single-rig; Broadhurst *et al.* (2013)] deployed from a 9 m canoe (18 kW engine power) across six replicate 5 min deployments in a straight line (with the start and end positions marked using a global position system; GPS map 76S; Garmin; <http://www.garmin.com/>). All trawls had identical mesh sizes (42 and 26 mm stretched mesh openings in the bodies and codends, respectively), materials (0.6 and 1.0 mm diameter polyamide twine, respectively) and designs; varying only slightly in their total opening lengths (9.44, 9.46 and 9.92 m). None of the trawls had sweeps and their opening heights were all dictated by the otter-board height (0.47 m).

Prior to each 5 min deployment, salinity and temperature were measured on the bottom with a multiple sensor (Alec Electronics Co., ASTD. 687; <http://www.jfe-alec.com/>). Depth was subsequently recorded at 1 min intervals using an echosounder (Eagle Cuda 168 EX; <http://www.eaglenav.com.au/>). At the end of each deployment, the codend was emptied onto a sorting tray and all batoids were photographed with a metre scale (for eventual identification), weighed (to the nearest 10 g), sexed and

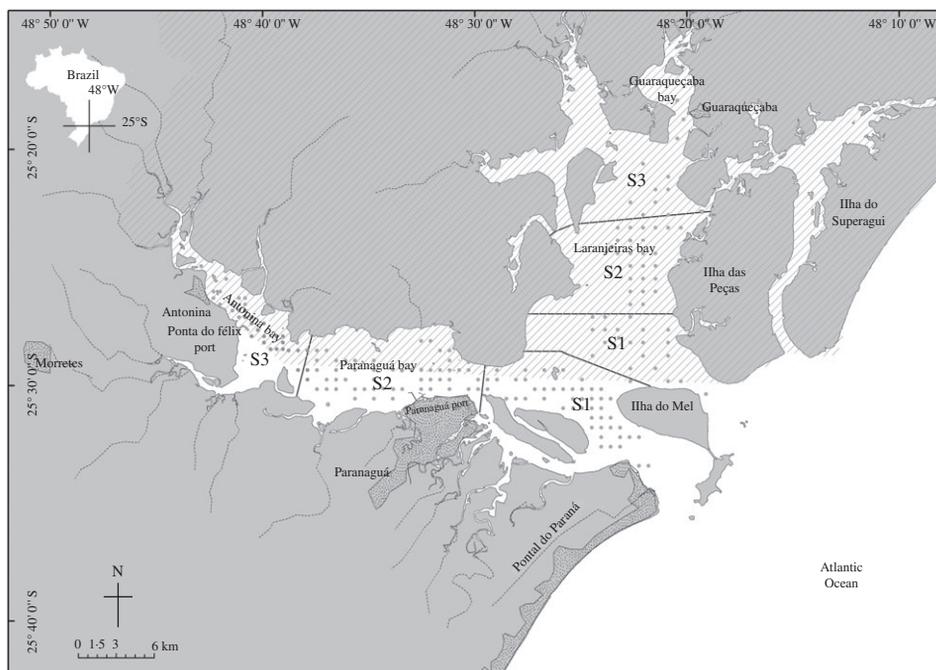


FIG. 1. Location of the Paranaguá estuarine complex in southern Brazil, and the key cities and sites. The samples were taken along three sectors in the north–south and east–west fluvial gradients: outer (S1), middle (S2) and inner (S3); totalling six sectors. The trawl deployments are represented by *; main drainage channels; —, sectors; //, environmental protected area of Guaraqueçaba; ▣, urban area; ◻, land.

had their total length (L_T) recorded to the nearest 0.1 cm before being immediately released.

To incorporate broader temporal scales and the potential influence of rainfall, monthly rainfall patterns between 2003 and 2013 were used (SIMEPAR:<http://www.simepar.br/>) to aggregate months into four seasons: early wet (October, November and December, with a mean \pm s.d. combined monthly rainfall of 235.1 ± 37.5 mm), late wet (January, February and March; 345.2 ± 73.2 mm), early dry (April, May and June; 136.2 ± 52.6 mm) and late dry (July, August and September; 146.0 ± 61.2 mm). The area (ha) of each replicate deployment within seasons was calculated by multiplying the distance trawled by the estimated individual trawl wing-end spreads; derived by considering key technical variables (*i.e.* towing speed, water depth at 1 min intervals, length of warp deployed and the trawl system area) within the ‘Prawn Trawling Performance Model’ proposed by Sterling (2005).

The fixed effects of season, fluvial gradient and depth were considered along with the random terms of sectors and deployments in generalized linear mixed models (GLMM) fitted to explain variability among the counts of total batoids and the most abundant species (and with the area trawled included in the models as an offset). For each analysis, a stepwise variable search algorithm was employed with the most parsimonious model based on the lowest Akaike’s information criterion. All fits were obtained using the lmer function in the lme4 package of the freely available R language (R Core Team;

TABLE I. Mean \pm S.D. salinity, temperature and depth at three survey sectors (S) within two fluvial gradients (east–west and north–south) of the Paranaguá estuarine complex

| Sector | Salinity | Temperature (°C) | Depth (m) |
|--------|------------------|------------------|------------------|
| S1 E-W | 29.72 \pm 1.74 | 23.75 \pm 3.17 | 10.68 \pm 3.88 |
| S2 E-W | 26.78 \pm 2.27 | 24.02 \pm 3.11 | 7.25 \pm 2.73 |
| S3 E-W | 20.47 \pm 3.49 | 24.47 \pm 3.28 | 4.35 \pm 1.59 |
| S1 N-S | 28.83 \pm 2.21 | 23.75 \pm 3.18 | 8.03 \pm 4.68 |
| S2 N-S | 27.68 \pm 2.57 | 23.91 \pm 3.08 | 6.93 \pm 2.97 |
| S3 N-S | 24.21 \pm 3.10 | 24.07 \pm 3.02 | 4.59 \pm 1.79 |

www.r-project.org). Pooled sex ratios across species were investigated using a general linear model (GLM).

In total, 369 tows were completed (for 46 ha). Across all sectors, water temperatures ranged between 23.75 \pm 3.18 and 24.47 \pm 3.28° C and salinities ranged between 20.47 \pm 3.49 and 29.72 \pm 1.74 (mean \pm s.d.; Table I).

Four batoid species were caught, including *G. altavela* ($n=4$ individuals; L_T range of 29.5–71.8 cm and masses of 0.9–9.5 kg), *N. brasiliensis* ($n=4$; 9.0–37.0 cm L_T and 0.05–0.5 kg), *D. guttata* ($n=23$; 62.4–222.0 cm L_T and 0.2–14.5 kg) and *R. percellens* ($n=37$; 18.0–76.0 cm L_T and 0.05–2.0 kg). There were no differences in sex ratios among the four species (which ranged from 1:1.22 to 0.45:1 for females:males; GLM, $P>0.05$).

Analyses of spatio-temporal variation in abundances were limited to *D. guttata* and *R. percellens* and the total number of batoids. In all three GLMMs, there were no significant effects of season or depth ($P>0.05$; which ranged between 4.35 \pm 1.59 and 10.68 \pm 3.88 m, mean \pm s.e., among sectors; Table I), with the parsimonious models limited to the fixed effect of fluvial gradient. While there were consistent trends (Fig. 2), this latter factor was only significant for *D. guttata* (GLMM, $P<0.05$), with few differences between fluvial gradients for the outer sectors, but considerably more individuals in the middle and inner sectors (2 and 3) of the north–south, than the east–west fluvial gradients [Fig. 2(b)].

The mechanisms underlying the above observed variability in collective abundances can be described by considering the key associated environmental diversity, although prior to which the sampling method warrants discussion in terms of its utility for accurately estimating relative abundance indices.

It is important to acknowledge that the low catches (*e.g.* total abundance of 1.47 ha⁻¹) can be considered a function of both absolute abundances and gear selectivity. Specifically, because the ability of fishes to avoid capture by mobile gears is positively related to their size (Wardle, 1983), many batoids probably escaped the approaching trawls. Contributing factors would have included the lack of sweeps, low headline height, steep body taper and slow towing speeds; all of which have been demonstrated to preclude the retention of some fishes (Broadhurst *et al.*, 2014; McHugh *et al.*, 2014). Assuming similar water quality and available light (a reasonable assumption given the lack of any effect of depth on catches), however, such characteristics would have remained fairly consistent across sectors and seasons. Therefore, while the abundances may not be adequate indices of absolute populations, the relative differences in catches can be considered representative.

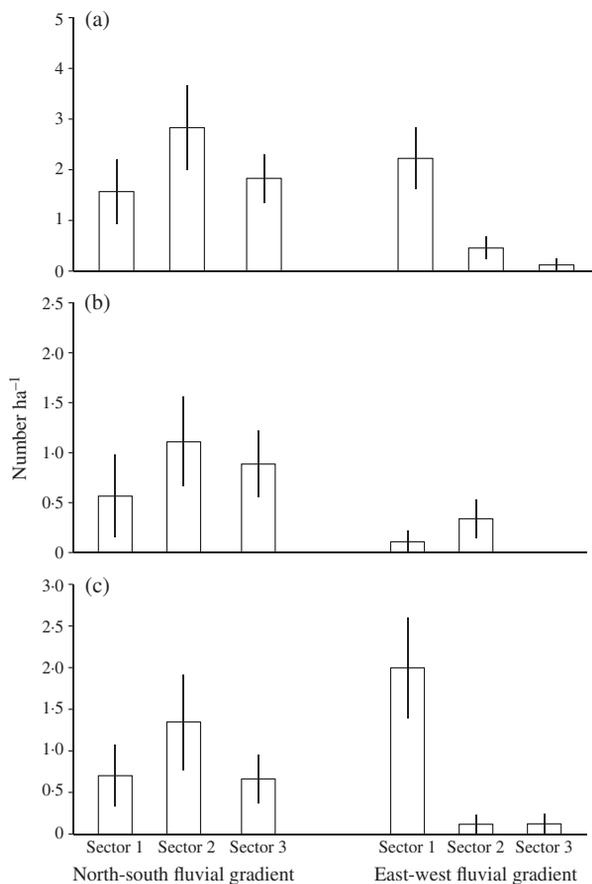


FIG. 2. Mean \pm S.E. abundances of (a) total batoids, (b) *Dasyatis guttata* and (c) *Rhinobatos percellens* in each trawl deployment between November 2012 and September 2013 in the north–south and east–west fluvial gradients in the Paranaguá estuarine complex.

Considering the above, the lack of any observed temporal effect for *D. guttata* and *R. percellens* may indicate minimal seasonal migrations in the PEC, although there could be size-specific movements and across smaller temporal scales, especially in response to tidal flows. The present study was done during neap tides to minimise confounding influences. Further research is required to assess the importance of the full range of tides on marine-straggler distributions. Notwithstanding such a caveat, Carmo (2011) also observed *R. percellens* in the PEC across all size classes and in all reproduction stages, confirming and highlighting the local importance of this area as a nursery ground.

It is clear that irrespective of substantial differences in seasonal rainfall and other variables, spatial rather than temporal factors mostly explained batoid abundance variability in the PEC. There are at least two possible reasons for this result. The first might relate to the relatively more saline middle and inner sectors (2 and 3) of the north–south fluvial gradient being more suitable for batoids (Table I). Similar results have been observed for batoids in other estuarine systems (Hopkins & Cech, 2003). Such salinity differences were caused by the north–south fluvial gradient being shorter and wider (c.

40 × 13 km) than the east–west (*c.* 56 × 7 km) and therefore more suitable for seawater penetration. Further, according to Noernberg *et al.* (2006), the river discharges in the east–west fluvial gradient are significantly greater (irrespective of seasonal rainfall) than those in the north–south.

The second possible reason to explain the observed gradient-specific differences in abundances is that the inner sectors of the east–west fluvial gradient are near cities and a port, and therefore considerable human activity. By comparison, the shorter inner and middle sectors of the north–south fluvial gradient are surrounded by protected areas, and while this does not prohibit fishing or vessel activity, the minimal urban development may nevertheless evoke ancillary flow-on benefits for surrounding waterways. Conceivably, any such benefits (combined with ocean proximity) might extend to the adjacent outer sector of the east–west fluvial gradient where, although not significant, there was a greater mean abundance of *R. percellens* [GLMM, $P > 0.05$; Fig. 2(c)].

Considering the above, at a broader level, a marine protected area encompassing at least some of the north–south fluvial gradient (and limiting fishing and other anthropogenic activities) could contribute towards conserving batoids in the PEC. Similar zoning has had measurable benefits in several other countries (Halpern, 2003; Kenchington *et al.*, 2003). Like for many other estuaries (Halpern, 2003), however, a lack of studies on species biology has hindered assessments and therefore justification for zoning in the PEC. Clearly, more research is required to assess the importance of the north–south fluvial gradient within the PEC for batoid reproduction. In the interim, the current results further support a trend in the international literature of spatially regulating human activities for conserving local populations of vulnerable elasmobranchs (Stevens, 2002).

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