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Site fidelity and sex-specific migration in a mobile apex predator: implications for conservation and ecosystem dynamics

Adam Barnett [a,b,*], Kátya G. Abrantes [a,c], John D. Stevens [b,1], Jayson M. Semmens [a]

[a] Tasmanian Aquaculture and Fisheries Institute, Marine Research Laboratories, University of Tasmania
[b] CSIRO Marine and Atmospheric Research
[c] Coastal and Estuary Ecosystems, School of Marine and Tropical Biology, James Cook University, Australia

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Combining movement behaviour with other ecological information of predators and their prey is essential for an adequate understanding of ecosystem dynamics. The movement patterns of broadnose sevengill sharks, *Notorynchus cepedianus* , were monitored with acoustic and satellite technology in coastal areas of southeast Tasmania, Australia. Individuals were tagged in two habitats (Norfolk Bay and the Derwent Estuary) for which we had ecological information such as diet, population structure and abundance. *Notorynchus cepedianus* showed seasonal site fidelity in the use of the coastal habitats. The general pattern was for sharks to exit coastal areas over winter and females to return the following spring and males in summer. Their movement into these coastal areas coincided with high seasonal abundance of their known prey species during summer, suggesting feeding site fidelity. Individuals tagged in two coastal areas showed low spatial and dietary overlap, suggesting localized site fidelity and fine spatial scale resource partitioning. This has rarely been reported for large mobile predators. Both satellite and acoustic methods showed that males make northerly migrations during winter to distances of at least 1000 km. The combined use of tracking, diet and abundance information demonstrated that *N. cepedianus* are likely to exert significant predation pressure on prey inhabiting these areas during summer. Overall, this study highlights the benefit of complementing movement data with other ecological information to understand the habitat use of large mobile predators and their potential influences on ecosystem structure and function.
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Recently, studies have started to address the complex ecological roles of large predators with wide distributions (Ferretti et al. 2010), but for the vast majority of these species, their roles are yet to be defined and quantified (Estes et al. 2001; Williams et al. 2004; Ferretti et al. 2010). Because many large predators use large areas they can be important predators of multiple species in a number of systems and/or habitats (Ferretti et al. 2010). Therefore, characterization of spatiotemporal habitat use is crucial for understanding how large predators affect the structure and function of the different systems they use (Williams et al. 2004; Austin et al. 2006; Smout & Lindstrom 2007) and for the conservation of both the predators and the systems of which they are integral components (Jorgensen et al. 2009).

Many large marine vertebrates that move over large spatial scales annually restrict their movement to smaller specific areas. Site fidelity, defined as the return to and reuse of an area over time, has mainly been attributed to mating, parturition and feeding (Switzer 1993; Speed et al. 2010). For example, numerous species of turtles, seals and penguins migrate seasonally between specific breeding and foraging areas (Lloyd et al. 1995; Stewart 1997; Charrassin & Bost 2001; Myers & Hays 2006; Lee et al. 2007). Killer whales, *Orcinus orca*, minke whales, *Balaenoptera acutorostrata*, bluefin tuna, *Thunnus thynnus*, and a number of large migratory sharks (e.g. white sharks, *Carcharodon carcharias*, tiger sharks, *Galeocerdo cuvier*, and salmon sharks, *Lamna ditropis*) annually move to exploit seasonally abundant prey at aggregation sites (Lowe et al. 2006; Smout & Lindstrom 2007; Weng et al. 2008; Jorgensen et al. 2009; Walli et al. 2009; Foote et al. 2010; Meyer et al. 2010). Identification of these specific areas is often the initial step in understanding habitat use of large mobile predators, and for formulating appropriate management and conservation strategies (Martin et al. 2007).

One of the main conservation strategies is to protect habitats critical to the survival of a species (Heupel et al. 2007). For shark

* Correspondence: A. Barnett, Marine Research Laboratories, Private Bag 49, Hobart, TAS 7001, Australia.
E-mail address: adam.barnett@utas.edu.au (A. Barnett).
[1] J. D. Stevens is at CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia.

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species, most research on critical habitats has focused on relatively small species or the use of nursery areas by juveniles. However, given that protecting nursery areas has only limited value in conserving shark populations (Kinney & Simpfendorfer 2009), there is a distinct need to understand when and how older life stages are using coastal areas (Simpfendorfer & Heupel 2004; Speed et al. 2010). Similar scenarios are apparent for other large slow-growing vertebrates such as sea turtles (Heppell et al. 1996; Mazaris & Matsinos 2006). For example, to sustain a healthy population of sea turtles, it is more important to ensure the health of adults than the survival of hatchlings.

The broadnose sevengill shark, *Notorynchus cepedianus*, is a large (up to 3 m) coastal-associated apex predator with a wide temperate distribution (Last & Stevens 2009). This species' trophic position rivals that of other species considered important upper trophic predators, such as tiger sharks and white sharks (Cortés 1999). Yet, in contrast to the latter two shark species, besides dietary work there is very little information on the ecology or movement behaviour of *N. cepedianus*. This is a significant gap in understanding the behaviour of this shark and, in general, the role apex predators such as this have in the coastal systems they inhabit. For other large mobile marine species such as pinnipeds, cetaceans and turtles, there is a better understanding of where and why they move in coastal areas (Kuhn et al. 2009). Considering that many of these mesopredator species are either prey and/or competitors of sharks in coastal systems, the lack of information on habitat and resource use for species such as *N. cepedianus* means an incomplete understanding of interspecies dynamics (e.g. competition and predation) and the ecological role of co-occurring predators in coastal systems (Ferretti et al. 2010).

Although movement information is useful by itself, the incorporation of movement behaviour with other ecological information is necessary for a better understanding of ecosystem dynamics and species interactions. However, to date, not many spatial studies of sharks have included information on other aspects of shark ecology such as diet or reproduction (Simpfendorfer & Heupel 2004; Speed et al. 2010). Recently, in an intensive study on the ecology of *N. cepedianus* in two coastal habitats of southeast Tasmania, Australia, information on its diet, population structure, prey abundance and seasonality in abundance was collected (Barnett et al. 2010a, b).The addition of movement data makes this an ideal case study to examine resource area use of apex predators in two distinct coastal habitats in close proximity.

Our study had four aims. (1) The first was to test the hypothesis that *N. cepedianus* display seasonality and site fidelity in the use of coastal areas. Catch rate information suggests a seasonal abundance of *N. cepedianus* in coastal areas, as catches decrease significantly in winter (Barnett et al. 2010b). In addition, tag and recapture data indicate that sharks show site fidelity to these coastal areas over multiple years (Barnett et al. 2010b). (2) Because previous studies indicate relatively low dietary overlap between sharks caught in two coastal locations (Barnett et al. 2010a), and since individuals were mostly recaptured in the location they were originally tagged (Barnett et al. 2010b), our second hypothesis was that *N. cepedianus* show fine-scale habitat partitioning and site fidelity in these areas. (3) Since catch rates also indicate that female abundance increases in spring, whereas males are not caught in large numbers until summer (Barnett et al. 2010b), we predicted that there is sexual segregation in the use of these areas. (4) Our final aim was to evaluate the effectiveness of shark protected areas in southeast Tasmania.

METHODS

Study Area and Acoustic Receivers

An array of 74 acoustic receivers was deployed in coastal areas of southeast Tasmania, Australia (VR2 receivers, VEMCO Ltd, Halifax, Canada; Fig. 1). *Notorynchus cepedianus* individuals were tagged in two locations, Norfolk Bay and the Derwent Estuary (Fig. 1). Norfolk Bay is a relatively shallow (average depth 15 m; maximum depth 20 m), semi-enclosed bay with an area of 176 km^2. The Derwent Estuary runs through the City of Hobart before opening into Storm Bay, and consistently reaches depths of 20–30 m, with a maximum depth of 44 m. The acoustic array was set up as single curtains and gates, so that sharks could be detected moving across and between entrances and choke points of the coastal areas. With this design, an individual would need to be detected on two subsequent curtains to confirm that it had entered a given area.

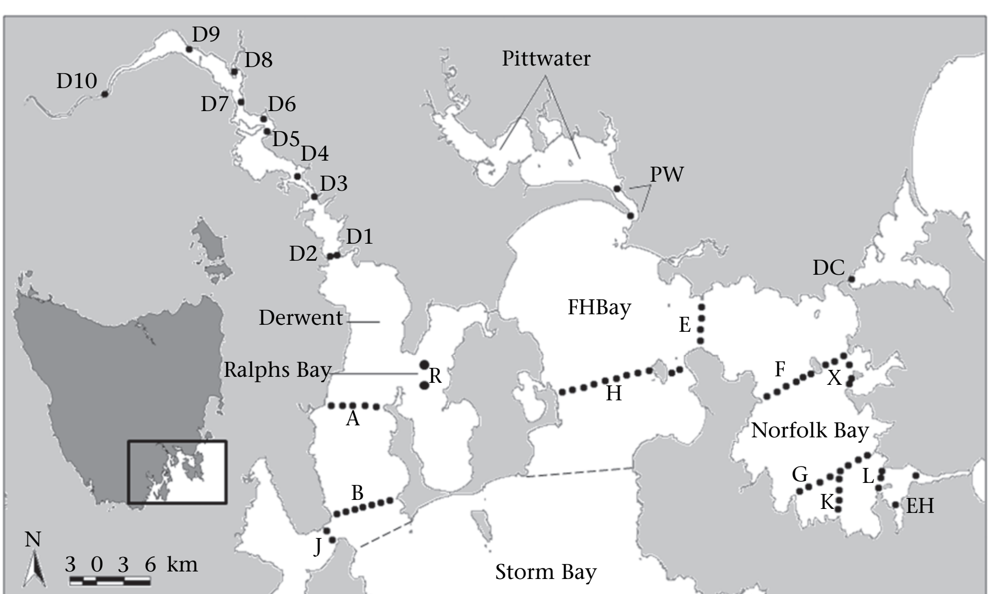

Figure 1. Map of study area. Filled circles represent receivers and each curtain or gate of receivers has a designated code. Dashed line is the boundary of the shark protected areas.

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