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To go or not to go with the flow: Environmental influences on whale shark movement patterns

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ABSTRACT

Seven whale sharks were tracked using satellite-linked tags from Ningaloo Reef, off northern Western Australia, following tagging in April and June 2002 and April–May 2005. We investigated how the movements of those whale shark tracks were influenced by geostrophic surface currents during sequential one-week periods by using a passive diffusion model parameterised with observed starting locations of the sharks and weekly maps of surface current velocity and direction (derived from altimetry). We compared the outputs from the passive diffusion model and maps of chlorophyll-*a* concentration (SeaWiFs/MODIS) and with the actual tracks of the sharks using GIS and generalized linear mixed-effects models (GLMM). The GLMM indicated very little support for passive diffusion with sea-surface ocean currents influencing whale shark distributions in the north eastern Indian Ocean. Moreover, the sharks' movements correlated only weakly with the spatial distribution of sea-surface chlorophyll-*a* concentrations. The seven whale sharks had average swimming speeds comparable with those recorded in other satellite tracking studies of this species. Swimming speeds of the seven sharks were similar to those reported in previous studies and up to three times greater than the maximum sea-surface current velocities that the sharks encountered while traversing into lower southerly latitudes (moving northward towards the equator). Our results indicate that whale sharks departing from Ningaloo travel actively and independently of near-surface currents where they spend most of their time despite additional metabolic costs of this behaviour.

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1. Introduction

It has been hypothesized that many migratory marine animals including birds, cetaceans (Ballance et al., 2006), turtles (Polovina et al., 2000, 2004; Luschi et al., 2003; Gaspar et al., 2006; Lambardi et al., 2008; Shillinger et al., 2008) and sharks (Montgomery and Walker, 2001; Sims et al., 2003) use geophysical directional clues such as the Earth's magnetic field and thermoreception of large water temperature gradients associated with fronts and eddies for navigation. For example, the basking shark (*Cetorhinus maximus* Gunnerus) is a large filter-feeding migratory shark that actively seeks out productive biological habitats along the continental shelf over areas of several hundred to thousand kilometres to forage in temporally discrete, high productivity areas associated with ocean fronts (Sims, 2003). Similarly, the broad-scale migrations of several species of marine turtles are influenced by oceanographic processes. Olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*) turtles have been shown to use major surface currents and eddies to assist migration to feeding areas (Polovina et al., 2000, 2004; Luschi et al., 2003).

Whale sharks (*Rhincodon typus* Smith) are the world's largest fishes and are broadly distributed throughout tropical and subtropical oceans. These animals are highly migratory, travelling large distances (thousands of km, Rowat and Gore, 2007; Eckert and Stewart, 2001) and appear predictably at some coastal localities in the tropics to take advantage of ephemeral increases in the abundance of their zooplankton prey (Heyman et al., 2001; Wilson et al., 2001; Meekan et al., 2006).

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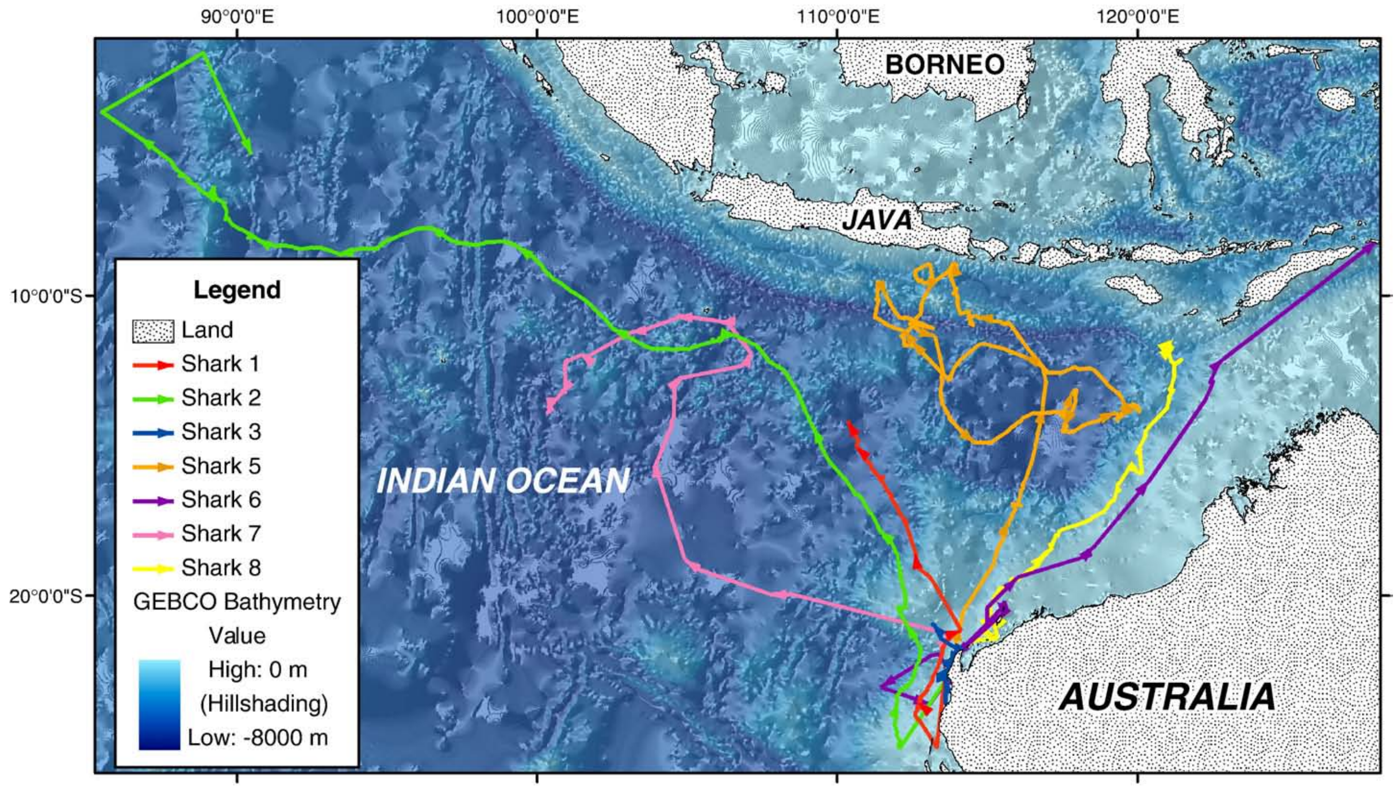

Fig. 1. Distribution of whale shark tracks in the Indian Ocean and associated bathymetry.

It remains a mystery how whale sharks navigate to and from these aggregation sites and whether they use active locomotion or they are assisted via passive drifting in currents. We examined this issue by comparing the movements of whale sharks monitored with satellite-linked transmitter tags and sea-surface geostrophic currents and chlorophyll-*a* concentration gradients during weekly intervals to test

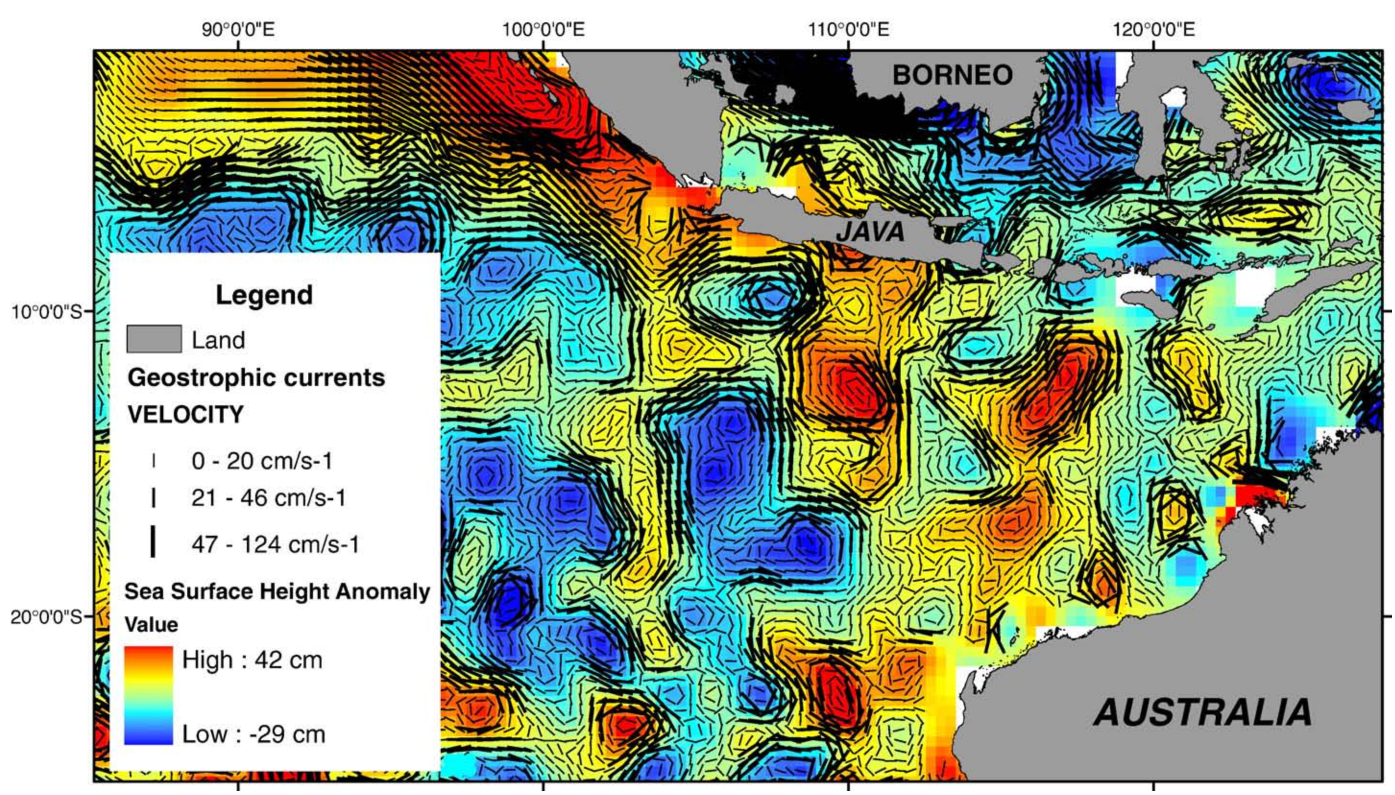

Fig. 2. Example of geostrophic current map (velocity cm/s^{-1}) for the mid Austral winter period (June 2005).

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