How can movement ecology support marine protected areas in preventing illegal fishing?

In their recently published work, David Jacoby and colleagues combine long-term shark tracking data with that of enforcement patrols to see how behaviour can influence the vulnerability of marine life to illegal fishing in one of the world's largest marine protected areas.

Laid out side-by-side along a sun baked pier, shark upon shark awaiting measurement by the authorities, offer a sobering reminder of the challenges still facing marine conservation even *after* protected areas have been established. With over three hundred dead animals seized from a single illegal vessel intercepted inside one of the world's largest Marine Protected Areas (MPA), it's difficult to make the mental connection between these and the graceful animals that cruise past us while we undertake research dives throughout the coral reefs of the British Indian Ocean Territory (BIOT).

Slow growing, wide-ranging reef sharks often comprise a high proportion of the animals seized and remain a coveted target for the illegal, unreported and unregulated (IUU) fishery. The juxtaposition between this macabre scene and the vibrant predator community that once thrived across the Chagos Archipelago, and indeed can still be seen during occasional dives even today, seems metaphorical of the difficulty of protecting something so remote and far removed from our normal, everyday lives. This almighty challenge lies firmly with a single patrol vessel, tasked with enforcing over 640,000 km^2 of MPA.

Eight years ago, a consortium of research organisations funded by the Bertarelli Foundation, began to establish a comprehensive animal monitoring network across the archipelago to track a host of mobile species, including reef sharks, tagged with acoustic transmitters. A firm understanding of movement ecology and connectivity is fundamental for assessing the efficacy and improving the management strategy of large remote MPAs. To assist the BIOT Patrol Vessel (BPV) in its task of intercepting an unpredictable, multipronged and co-ordinated IUU fishing fleet, we utilise a vast shark tracking database to mine for patterns in the movement data that might reveal how (and where) these animals are most at risk.

The most abundant species of sharks on the reef are grey reef (*Carcharhinus amblyrhynchos*) and silvertip sharks (*Carcharhinus albimarginatus*); sympatric species, which have, historically, faced rather different population trajectories in response to fishing. Our data comprise 101 sharks detected across a network of 52 underwater acoustic receivers, data that overlap in both space and time with information gathered by the consultancy group Marine Resources Assessment Group (MRAG) that enforce and monitor illegal activity in the MPA. It was this collaboration that proved key to our research, allowing us to link movement ecology with associated risk to IUU. Applying network analyses to telemetry data is not new, nor is using this approach to look at connectivity between management zones. Our study however, combines network analyses with individual-based models and data on spatially-explicit risk to explore species differences in connectivity and predictability of movement; we demonstrate that silvertip sharks are more dynamic in their movement, more connective, have a larger activity spaces and are statistically more vulnerable to IUU then the more resident, yet sympatric grey reef shark.

So, what are the management implications for these results and how can this information reduce the burden on BIOT enforcement officers? We highlight areas where our models fail to predict the

unexpectedly high rates of movement between habitat, arguing that regular enforcement of these areas will help mitigate mass removal of sharks from these seemingly important movement corridors. Further we argue that telemetry data, and the associated analyses, might provide an important tool for informing enforcement strategies for typically underfunded, over stretched managers.

Enforcement strategies of MPAs need to be complemented with plans to disincentivise criminal activity and the Bertarelli Programme in Marine Science has a component that already focuses on the socioeconomic drivers of IUU activity in BIOT. However, including information about the 'prize', as well as focusing on the threat, will be crucial for collaboratively working to reduce the threat of illegal activity in the MPA with a more sustainable and cost effective approach.

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