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# Pattern of movements within a home reef in the Chesterfield Islands (Coral Sea) by the endangered Giant Grouper, *Epinephelus lanceolatus*★

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**Abstract –** This study determined the movements of a Giant Grouper, *Epinephelus lanceolatus*, in which an acoustic tag was surgically implanted and monitored by an array of six VR2W acoustic receiver units from August 2010 to January 2013 in the remote, uninhabited Chesterfield Islands, Coral Sea (800 km West of New Caledonia). Our data revealed a home reef area (residency rate of 44.9%) with an increased activity revealed by movements at dawn and dusk toward and between two adjacent reef passages, probably for foraging. The fish was absent from its resident reef between October and December 2010 and 2012, corresponding to the time known for spawning aggregations of this species in New Caledonia. A skipped spawning seems to have occurred in 2011. We hope these data will be complemented in the future by locating the spawning site or sites and thus provide adequate conservation measures. The Coral Sea links two World Heritage Sites, the Australian Great Barrier Reefs and the New Caledonian coral reefs. It would be fitting to create a Marine Protected Area for the Chesterfield Islands between these two major conservation areas of the sea.

**Keywords:** Coral reefs apex predator / serranidae / site fidelity / acoustic telemetry / spawning aggregations

## 1 Introduction

With a maximum total length (TL) of 2.3 m and weight of 300 kg, the Indo-Pacific Giant Grouper, *Epinephelus lanceolatus* (Bloch 1790) is the largest known reef fish. It is usually found on coral reefs, especially where there are large caves, but it is also known from harbours and deep estuaries, as well as on wrecks and man-made structures, such as those for oil exploration or wind generators. Although reported to a depth of 100 m, it is usually found in much shallower water. It preys mainly on spiny lobsters, small elasmobranchs, a variety of bony fishes, large crabs, octopuses, and juvenile marine turtles (Witzell 1981; Heemstra and Randall 1993). It is the most widely distributed grouper in the world, from South Africa and the Red Sea to the Pitcairn Islands (Randall and Heemstra 1991; Randall 1995).

Information on the biology of *Epinephelus lanceolatus* is incomplete compared to that of its sister species, the Atlantic *E. itajara* (Randall 1967; Bullock et al. 1992; Sadovy and Eklund 1999). Both species are particularly vulnerable to fishing when they form large spawning aggregations (Coleman et al. 1996; Sadovy and Domeier 2005; Saenz-Arroyo et al. 2005). *E. lanceolatus* does not become sexually mature until it reaches 129 cm TL. It is highly valued in Asian fish markets (Randall and Heemstra 1991; Lee and Sadovy 1998; McGilvray and Chan 2003), resulting in special effort to catch it at islands of the western Pacific. Based on knowledge of fishermen and divers, local extinctions and extreme scarcity have been reported for Western Pacific localities (Lavides et al. 2009; Zgliczynski et al. 2013). The species is classified by the IUCN as "vulnerable", the second highest risk of extinction (Shuk Man and Chuen 2006).

Fishing pressure on this species has recently decreased in some areas as a result of protective legislation. It is illegal to spear this species in South Africa, where it is known as Brindle

★ Supporting information is only available in electronic form at www.alr-journal.org.

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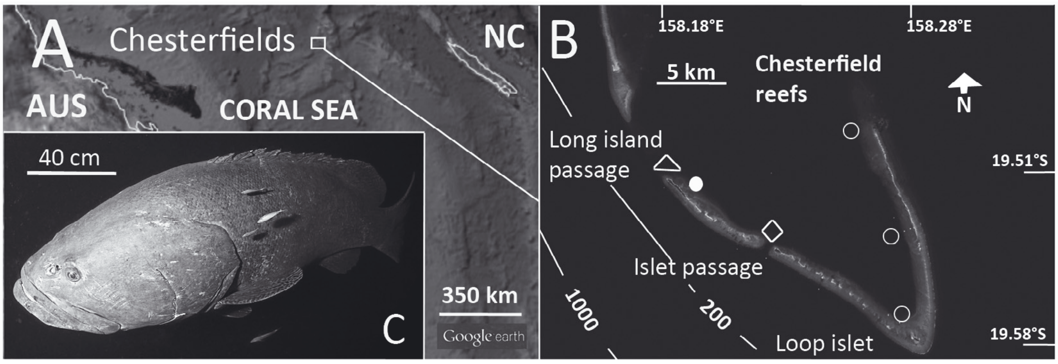


**Fig. 1.** A: The Chesterfield reefs in the Coral Sea situated midway between the east coast of Australia (AUS) and New Caledonia (NC). B: Close up on the study site that includes Long Island (North-West of the Chesterfield reefs), which is delineated by two passages. The plain white circle indicates the VR2W receiver called "Home" as it was standing in the vicinity of the Giant Grouper cave. The triangle indicates the VR2W called "LP" standing for "Large Pass", corresponding to the large passage North of Long Island. The diamond indicates the VR2W called "SP" standing for "Small Pass", corresponding to the Islets passage. These three receivers recorded detections from the tagged Giant Grouper and these same symbols were also used to describe spatial and temporal distributions of detections in Figure 2A. The three other receivers on the Eastern side of the Chesterfields reef lagoon are represented by empty circles; they did not record any detection from the giant grouper. C: Picture of the 1.95 m TL *Epinephelus lanceolatus* that was caught and released in good health near receiver Home.

Bass (van der Elst 1981), and in Australia, where it is called Queensland Grouper; such protection should be adopted elsewhere. The rearing of the species for human consumption has been successful (McGilvray and Chan 2003).

The capture of a large adult of *Epinephelus lanceolatus* during a program of acoustic tagging of adult tiger sharks in the Chesterfield Islands provided the opportunity to tag as well as document its movements.

## 2 Materials and methods

The Chesterfield Islands are a series of 11 islets, of which the largest is Long Island (length of 3.4 km). Numerous reefs and channels, typically 30–40 m deep, lie on a north-south oceanic ridge in the Coral Sea, isolated from Australia to the west and New Caledonia to the east by app. 800 km in either direction (Fig. 1A). The islands are surrounded by deep drop-offs to over 1000 m. The islets were named for the whaling ship *Chesterfield* that explored the Coral Sea in the 1790s. They were used for commercial whaling in the early 1860s, and guano was extracted in the 1870s. They have been uninhabited for over 40 years. Large-scale illegal fishing still takes place for sharks and reef fishes of high value, such as the Giant Grouper (Clua et al. 2011). Kulbicki et al. (1994) published a checklist of the fishes of the Chesterfield Islands. They reported 866 species, representing 34 families, noting closer affinity to the fish fauna of New Caledonia than to the Great Barrier Reef.

Acoustic telemetry was used for studying the movements of large sharks in the Chesterfield Islands. An acoustic array of six Vemco VR2W receivers were moored on concrete-filled tyres at depths of 5–25 m in August 2010 and maintained until January 2013 to track the movements of tagged Tiger Shark (Fig. 1B, see Werry et al. 2014). One receiver was moored on a patch reef in the lagoon opposite Long Island at a depth of approx. 5 m. For the purpose of this study, it was named "Home". Another receiver was moored at the edge of the large passage north to Long Island, down the reef slope at 25 m depth and 1300 m from the receiver Home; this receiver was named LP for "Large Pass". A third receiver was moored 8250 m south of the receiver Home at a depth of 22 m, at the entrance of a smaller passage; it was named SP for "Small Pass". The three other receivers were moored on the Eastern side of the lagoon and did not get any specific name during this study (see Fig. 1B). On August 16, 2010, while fishing for large sharks with a barbless hook and heavy line, a Giant Grouper 1.95 m TL was caught in close vicinity of receiver "Home" (Fig. 1B). The fish was restrained in a special harness in the sea that provided efficient protection and oxygenation of the animal, and avoided the use of anesthetic during tagging. A small incision was made on the central part of the abdomen, a transmitter (Vemco V16, 69 kHz, length 54 mm, weight in the water 8.1 g, battery life > 7 years, delay pulse 90 s) was inserted into the peritoneal cavity, and the incision was closed with stitches. The fish swam away vigorously on release (Fig. 1C).

Range tests were conducted to assess the distance from which the receivers were able to detect the tagged fish. These showed that detections significantly dropped after 400 m.

In November 2011, the acoustic data were downloaded, batteries were replaced, and the receivers redeployed. The gear was completely retrieved in January 2013. Following the data download, we cleaned the raw data by deleting the rare false detections. The valid detections were then sorted by site, date, and time. For each receiver, we determined the number of detections and a residency index, defined as the number of days the fish was detected at a given receiver, divided by the total number of days at liberty since tagging.

We used a generalized linear modelling framework (GLM) to examine the effects of time of year (Month), time of day (Hour) and site (Receiver) factors on the presence of the grouper. The cyclicity of the "Month" and "Hour" factors were modelled by including the variables as the cyclical function of their sine and cosine components. The analysis used a binomial error structure with a logit link function. We coded the binomial dependent variable with 1 when the fish was detected

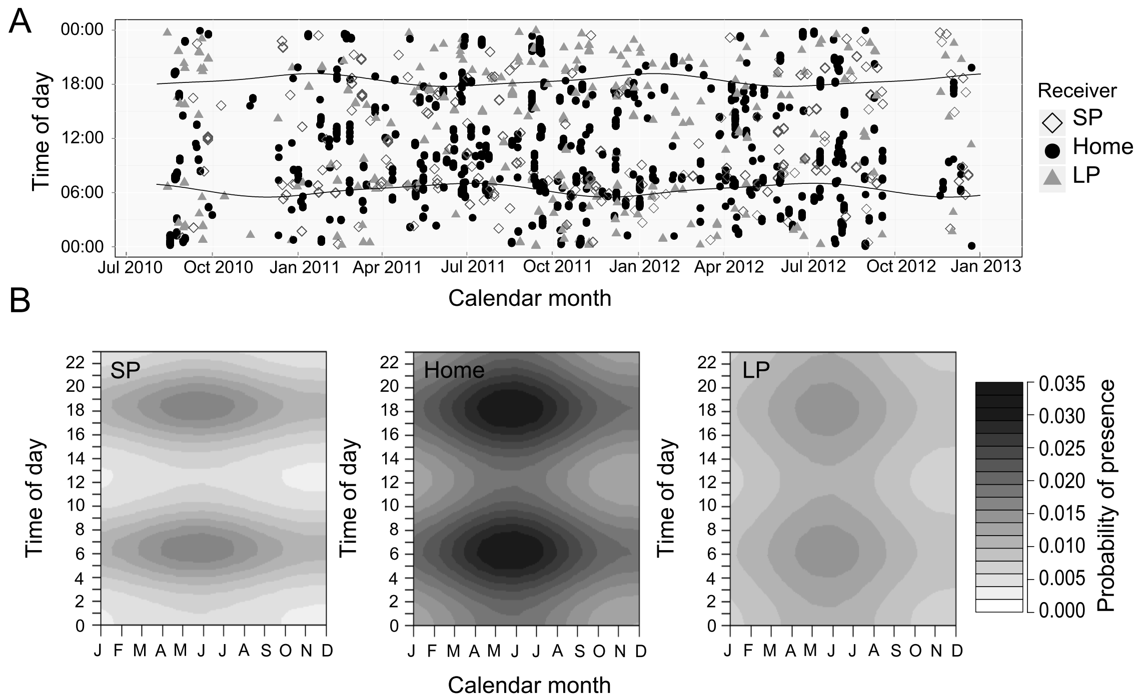


**Fig. 2.** A: Scatterplot of diel detection patterns of the Giant Grouper recorded at Chesterfield reefs between August 2010 and January 2013. Horizontal curves show daily sunrise and sunset. Shapes of the symbols on the scatterplot correspond to the receiver locations indicated in the map in Figure 1B. B: Predicted probability of presence of the grouper at the three receivers for each calendar month and time of day inferred from the most parsimonious GLM model.

and 0 when not detected for each hour of each day, and at each receiver. Therefore, the fish had a total of 72 records for each calendar day. Akaike's Information Criterion (AIC) was used to compare relative model support, where lower AIC values indicate greater support for the model.

We used network analysis to investigate the spatial dynamics of the grouper. We implemented an Empirical derived Markov chain (EDMC) analysis, which takes into account the frequency of movements between receivers but also the residency times and absence from the array (see Garcia et al. 2015; Stehfest et al. 2015). A Markov chain is a random process and consists of transitions from one state to another (in our case from receiver to receiver). The raw series of acoustic detections was organized into an hourly detection time series. For every hourly time step, if the fish was detected by a receiver, then the receiver ID was assigned to the state; if the fish was not detected, it was assigned an absent state. A movement count matrix was then computed containing movements between each receiver, as well as the movements from each state to itself (residency periods when the fish stayed at the same receiver) and movements to the absent state (transition periods outside of detection range). The transition probability matrix was constructed by dividing each number of transitions made from one state to another or itself by the number of transitions made from the state. We also calculated the eigenvector centrality of each receiver which is a measure not only of the centrality of a receiver, but also of the centrality of the receivers it is connected to (see Stehfest et al. 2015). The same analysis was reiterated using day of year instead of hour in order to test for differences in movement and residency timing.

## 3 Results

The Giant Grouper was monitored for a total of 857 days within the study area. It was detected on 135 days (15.75%) at receiver LP, 196 days (22.87%) at receiver Home and 161 days (18.78%) at receiver SP, for a total of 385 days (44.92%) on at least one receiver, 101 days (11.78%) on a minimum of 2 receivers and 6 days (0.70%) on the three receivers (Fig. 2A; Table 1). The best GLM model determined by the lowest AIC was one that incorporated the factors Month, Hour and Receiver and an interaction between Hour and Receiver (Model 9; Tables S.1 and S.2). For all receivers, the lowest probability of presence was in October and November and the greatest probability of presence outside these two months was in the morning between 6:00 and 8:00 AM (Fig. 2B). Based on real detections, the fish was totally absent from the area during October and November 2010 and 2012, but still present during the same months in 2011 (Fig. 2A). Although the fish was more present at receiver Home compared to the others, the patterns of probabilities were consistent across all receivers (Fig. 2B) as the fish was detected by all receivers similarly throughout the monitoring period (Fig. 2A).

Transition probabilities between states revealed low residency at the daily scale (Fig. 3A) and relatively high residency at the hourly scale (Fig. 3B) with the highest probability of hourly residency being at receiver Home. Movements between receivers occurred mostly at a daily scale (Fig. 3A) rather than at an hourly scale (Fig. 3B). Most movements occurred between receivers Home and LP but some direct movements in both directions did also occur between the receivers LP and SP,

**Table 1.** Receiver statistics. The residency index and number of detections are given by receiver as well as for all receivers combined. Residency index is defined as the number of days the fish was detected divided by the number of monitoring days. The eigenvector centrality values of the matrices of movement between receivers are given for the daily and hourly time scales.

| Receiver | Residency index | Number of detections | Eigenvector centrality (Day) | Eigenvector centrality (Hour) |
|---|---|---|---|---|
| SP | 0.157 | 678 | 0.099 | 0.008 |
| Home | 0.228 | 3587 | 0.145 | 0.020 |
| LP | 0.187 | 1098 | 0.118 | 0.010 |
| All | 0.449 | 5363 | | |

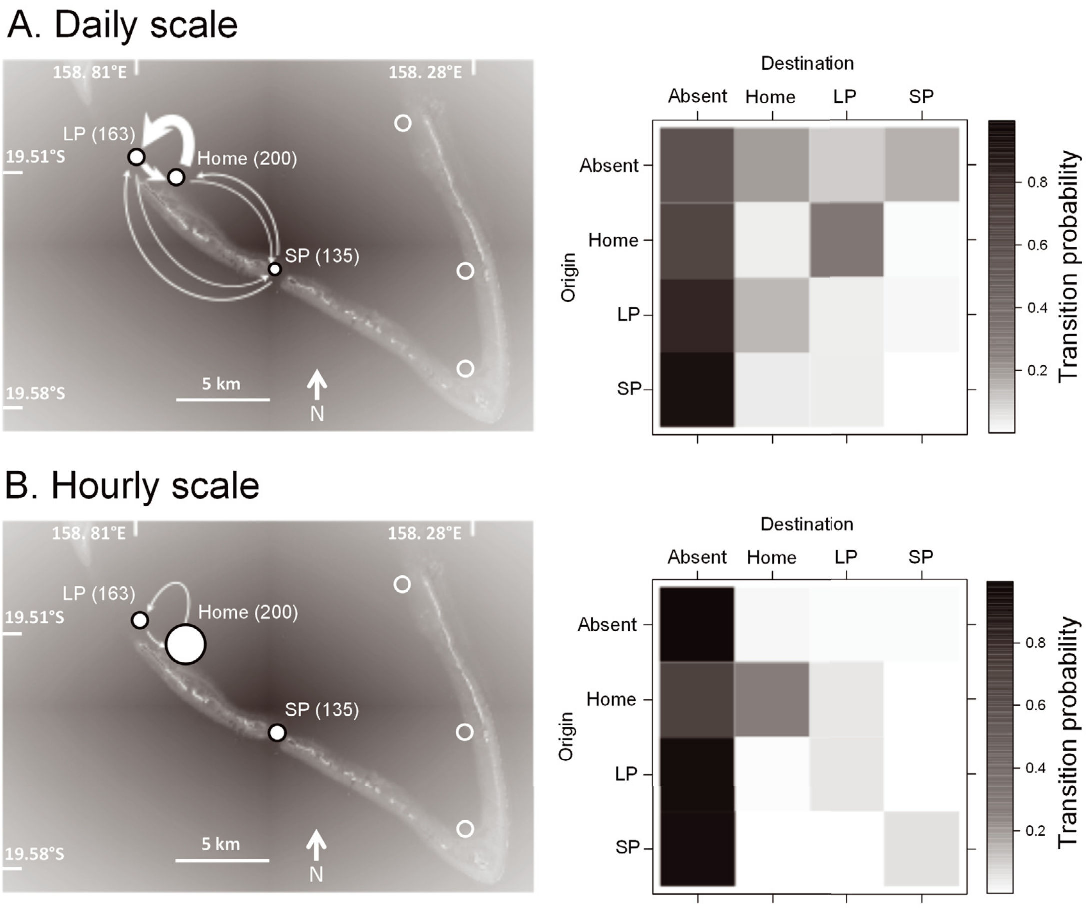


**Fig. 3.** Movement and residency of the grouper over two temporal scales: using A- daily and B- hourly time series of detections. For each case, a map showing the movements is presented in which arrow size is proportional to the transition probabilities between receivers and filled circles are proportional to the probability of residency. Number of day the fish was detected at each receiver is indicated in parentheses. Empty circles represent the three other receivers located on the east side which did not record any detections.

probably along the outer slope of the barrier reef (Fig. 3A). The receiver Home was the most central as suggested by the highest eigenvector centrality (Table 1). Probabilities of being in an absent state or coming from/going to an absent state were higher at the hourly scale (Fig. 3). The fish was never recorded by the three other receivers on the opposite side of the lagoon (Fig. 3).

## 4 Discussion

Movements occurred between the three receivers in the lagoon and channels surrounding Long Island, but the distribution of detections suggests that the usual shelter of this grouper would be around receiver Home, as confirmed by the sighting during a diving session of a Giant Grouper of a similar size in a reef cave of the area in August 2010 (J.C. Toison, Pers. Comm.). The fish used the adjacent passages (in particular the closest Long Island passage) mainly at dawn (between 5:00 and 12:00 AM), probably for foraging purposes. The lower detection rate recorded outside the morning period (Fig. 2B) may be due to the fish residing in a cave, which would reduce its detection by the receivers. High probabilities of being out-of-receiver range are common in reef fish (Garcia et al. 2015) which may be due to the distance between receivers or to the sheltering behaviour of the studied species. Analysis of the movement sequences also showed that the grouper went from one passage to another by swimming either inside the lagoon or along the outer slope. The second hypothesis seems more plausible as the way inside the lagoon preventing any detection by the receiver Home would oblige the grouper to swim and remain on a nearly bare sandy bottom area, which is probably less attractive than the outer slope of the barrier reef that hosts more potential prey. The differences between movement matrices at hourly and daily scales (Fig. 3) indicate that movements between receivers took more than one hour. The absence of any detections on the three other receivers located inside the Chesterfield lagoon indicated a strong attachment to the passages and outer slope, with a strong residency pattern (44.9% of days) in an area of about 12 km of diameter delineated on the North and South sides by the two reef passages.

Based on the definition provided by Colin et al. (2003), spawning aggregations of *E. lanceolatus* were observed along the west coast of New Caledonia in October and November (C. Chauvet, Pers. Comm.). The absence of the tagged *E. lanceolatus* in the Chesterfields during this period and could be explained by migration for spawning. Our observations of *E. lanceolatus* in the Chesterfields are also consistent with a 2-month period which is dedicated to mating by its sister species, *E. itajara*, in the Caribbean Sea (Mann et al. 2009).

The detection of the tagged grouper in the network of receivers during the mating period in 2011 could be explained by its failure to build up the caloric reserve needed for the long migration in the open sea to the spawning site. "Skipped spawning" has been documented for several fish species (Rideout and Tomkiewicz 2011).

A slight increase in activity, mainly at dusk, was noted for the months May to August prior to the migration before the end of September (see Fig. 2B), indicating an increase in foraging needed for the production of gametes and the upcoming intense activity of spawning (Rideout and Tomkiewicz 2011). Regarding the observed site fidelity of the tagged *E. lanceolatus*, Elkund and Schull (2001) showed that among the 50 tagged Goliath Grouper (*E. itajara*) that were resighted in the framework of their study, 64% had been tagged inshore (outside the spawning season) and resighted on the same site within two weeks to two months post-tagging. They could then show evidence of site fidelity, already mentioned by Sadovy and Elkund (1999). One fish tagged at a popular diving site was resighted on the same wreck repeatedly for eight months. Our findings on *E. lanceolatus* are consistent with such site fidelity, except for the spawning season.

## 5 Conclusion

Our data suggest that *Epinephelus lanceolatus* moves beyond its Chesterfield Islands home area only for spawning. As a large apex predator, the population of *E. lanceolatus* at any site within its broad distribution is very low, even without fishing. Because of its enormous size, it is the goal of fishermen, whether by hook and line or spear, to land one of these huge fish. Its high value in the live reef fish trade (McGilvray and Chan 2003), makes it very susceptible to targeted fishing, especially if spawning sites are discovered. This results in the removal of a higher percentage of the males of the population and increases the danger of extinction. The low population of the species, its high value, and its vulnerability should be taken into account for conservation and management strategies. Artisanal fishing does occur in the Chesterfield Islands. It primarily targets invertebrates (such as sea cucumbers and lobsters) but it also includes reef fishes (Clua et al. 2011). The data provided by our study will help to define the Essential Fish Habitat (see Conover et al. 2000) of this endangered species and will aid in creating a Marine Protected Area (MPA) for the Chesterfield Islands. The optimal MPA would be one that includes the entire critical habitat for the species, including one or more spawning sites. Further acoustic tagging, especially if based on satellite tracking methodologies, is needed to identify and protect the spawning sites.

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