Adequacy of zoning in the Ningaloo Marine Park

Final Report

WAMSI Milestone 3.2.2.40

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1. Executive Summary

We assessed the adequacy of marine park zoning at Ningaloo by studying the movements of fish and asking asked the question whether sanctuary zones were large enough and in the right locations to protect targeted species of fish. Analysis has focused on four species, spangled emperor *Lethrinus nebulosus*, gold spot trevally *Carangoides fulvoguttatus*, black wrasse *Coris aygula* and drummer *Kyphosus sydneyanus* for which we have significant amounts of data. These species represent a range of target species as well as an important herbivorous species on the reef. An additional 300 fish and elasmobranchs from 23 species have also been tagged within the Mangrove Bay array.

The behaviour of each fish from the four main species, spangled emperor *Lethrinus nebulosus*, gold spot trevally *Carangoides fulvoguttatus*, black wrasse *Coris aygula* and drummer *Kyphosus sydneyanus* was summarised by calculating fixed kernel distributions. This statistic summarises the probability of an individual being located within the perimeter of a given area with varying probabilities (we have used 50% and 95% probabilities). Estimates of kernel size were then compiled for the overall population of tagged fish.

Most spangled emperor *Lethrinus nebulosus* were found to have surprisingly small activity ranges, with diameters of 2.5 to 3.5 km for 95% activity kernels. This is an even more restricted range than previously suggested for the majority of *L. nebulosus* by Moran et al (1993) who reported approximately 60% of all recaptured fish were returned from the same 6 nm statistical area in which they were tagged. The proportion of fish which we found to remain near the point of capture was 68%, remarkably similar to that reported by Moran et al. (1993). Because the majority of individuals appear to use areas of reef that are small in relation to the size of most sanctuary areas in the Ningaloo Marine Park, it seems likely that the reserves are of an adequate size to protect substantial proportions of the population. That said there are important caveats that must be placed on this conclusion.

Our data span 12 months to two years, for each individual. The conclusion of adequacy is dependent on individuals retaining their resident behaviour for large proportions of their life span. Adequacy and the degree of protection afforded at a population level will be sensitive to variation in this behaviour and to the proportion of the population that displays non-resident behaviour. Our data suggest that some fish change their behavioural patterns leaving long term sites of residence for varying periods. Since these are long lived fish, living up to at least 30 yrs, each individual may be protected for relatively short periods of time, with the potential for adequacy to be reduced. A significant proportion of the population (36%) never appeared to establish residence in a particular area and may be nomadic.

Other aspects of the behaviour of *L. nebulosus* at Ningaloo may influence the adequacy of the current zoning system in the marine park. There was significant variation among habitats in both kernel size and the distance between capture location and kernel centre. Shoreline and reef slope habitats had the highest values for kernel areas and for distance to kernel centre. Movement analysis in particular suggests that there are high levels of movement among shoreline areas. With the activities of fish apparently focused on these shoreline and reef slope habitats they may be particularly exposed to the effects of fishing. While the recent re-zoning of the marine park has achieved a much higher level of protection for reef slope habitats, there remain significant areas of shoreline habitat within sanctuary zones reserved for fishing as Special Purpose (Shore Based Activities) Zones. Such zones may present a disproportionate threat to the adequacy of zones due to the importance of shoreline habitats for *L. nebulosus* at Ningaloo.

Spawning aggregations are another important behaviour that may affect the success of sanctuary zones. Tracking of *L. nebulosus* at Mangrove Bay suggests seasonal spawning activity occurs outside the array between October and December. Sites for spawning have not been located but may include sites adjacent to the Tantabiddi passage, adjacent the passage at the north end of the main Tantabiddi reef line (south of Jurabbi Sanctuary) and off Helby Banks. Other such potential spawning sites must exist, but data from the Mangrove Bay area suggest they are outside the lagoon and may be outside the immediate reef slope habitats. *Lethrinus erythropterus*, a Pacific emperor species, is known to spawn adjacent or in reef passages. Should the timing and location of spawning aggregations become common knowledge there could be serious impacts on the spangled emperor population of the region.

The full implications of individual behaviour and habitat utilization for the adequacy of marine park zoning at Ningaloo requires the calculation of numerous trade-offs may play out in the context of a dynamic population. Such implications are best addressed by means of a spatially explicit numerical population model. While models currently being used to assist management of fish populations at Ningaloo do not include individual adult behaviours, it seems likely that the results of such modelling could be improved if fish behaviour were to be explicitly incorporated.

Home range areas for the gold spot trevally *Carangoides fulvoguttatus* were surprisingly small. Despite the fact that trevallies are pelagic fishes, there is increasing evidence that they are strongly linked to reef structures in terms of their behaviour. For example mark-recapture studies of the blue trevally *Caranx melampyga* have shown that it spends most of its time within 500m of the site of capture, while active tracking revealed these fish to mainly travel along reef walls rather than out in open water with movement distances averaging 4.6km. Movements by the white trevally (*Pseudocaranx dentex*) have been shown using acoustic tracking to be larger (average maximum excursion 9.7km) than those of *P. melampygus*, but nevertheless to be restricted to certain areas of coast or to particular high relief bathymetric features. The scale of habitat use by *C. fulvoguttatus* is 5.6 km probably similar to the blue trevally, considering the tracking periods of C. *melampyga* were much shorter than for our study. The scale of these movements is sufficiently small that some degree of protection should be afforded to *C. fulvoguttatus* populations by most of the sanctuary zones in the Ningaloo Marine Park, although clearly there would be reduced levels of protection for individuals within a range of 2-3 km of the reserve boundaries.

The behaviour of trevallies such as the *P. dentex* has been shown to be unexpectedly diverse, with different behaviours shown by individuals in different. Similar complexity is evident in *C. fulvoguttatus*. Although the reef passage was a focus of activity there was relatively little movement of animals from lagoon to reef slope or vice-versa, and activity kernel centres were either inside or outside the reef. Similarly, there were apparently relatively limited movements across reef passages from north to south. It is important to ensure that reef pass habitats are adequately represented in the Marine park zoning in order to ensure protection of key habitats for this species.

Black wrasse *Coris aygula* are a medium sized wrasse that are most abundant within the lagoon and reef flat and feed primarily on gastropods and echinoderms. At Ningaloo they are an important predator on the urchin *Echinometra mathaei* and as such they may have an important role in trophic relationships across the reef. Lagoon tagged fish were rarely captured more than 100 m from their activity centres, suggesting a limited activity area, however modal 50% kernel area was between 2 and 3 km^2, or areas 1.6-2 km in diameter and 95% kernel areas were larger, (5-10km^2) modal size. These kernel sizes are much larger than those for the only other wrasse for which equivalent tracking data exists. The California Sheephead *Semicossyphus pulcher* was found to spend 90% of its time within areas 600m in diameter. Larger scale movements of *C. aygula* were occasionally recorded, for example in the case of some individuals tagged on the reef flat, which moved offshore. These movements out of the tagging area may be similar to those reported for Napoleon wrasse *Cheilinus undulatus*, which was tracked for short periods in New Caledonia. The fish moved out of the small array after approximately 25 days, potentially to undertake spawning activity in another part of the reef.

Kyphosus sydneyanus displayed limited movement centred around the tagging location with evidence of discreet groups of individuals moving around together, but separately from other groups tagged at different locations or at the same location on different days. Kyphosids tracked in the Caribbean had home sizes of 30 – 40 000 m^2) which is significantly smaller than estimates of habitat use by *K. sydneyanus* at Ningaloo Reef where 50% kernel area was between 45,000,000 – 12,000,000 m^2. these differences may in part be due to differences in methodololgy, but it is more likely that there is more available habitat within Ningaloo Reef, resulting in this species moving further than kyphosids in the Caribbean. Species specific differences in habitat utilisation and home range are likely to occur and can not be excluded as the cause of the large difference in home range between these species.

Tracking of drummers at Ningaloo suggests groups of animals use the available habitat in different ways. At Ningaloo where *K. sydneyanus* are frequently observed schooling around selected bommies within the lagoon. At Ningaloo, these schooling sites are associated with high large coral bommies and have much lower algal cover than surrounding areas attributed to increased grazing by herbivorous fish using the area of high rugosity as a shelter from predators and primarily feeding in an area around the central shelter. In the Caribbean, schooling sites were characterised by high rugosity but had higher algal cover than surrounding areas.

Overall, the results of the analysis to date suggest that for spangled emperor *Lethrinus nebulosus*, black wrasse *Coris aygula* and drummer *Kyphosus sydneyanus* sanctuary zones are of sufficient size to offer adequate protection to populations of these species. For the more mobile gold spot trevally *Carangoides fulvoguttatus*, existing zones should still be large enough to offer some degree of protection. These conclusions require further examination in light of the details of habitat usage (e.g. for nearshore habitats or for spawning) and should be included in population modelling studies in order to reach firm conclusions on adequacy.

1.1. Date
28/02/2011

1.2. Project Title & Number
Adequacy of Zoning in the Ningaloo Marine Park Final Report WAMSI Node 3.2.2

1.3. Project Leader
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1.5. Dates Covered
1/11/2008 – 28/02/2011

2. Key Findings and Recommendations

2.1. Objectives and Outcomes – Key Findings
The key objective and outcome of this project was an assessment of the adequacy of sanctuary zones at Ningaloo for exploited species and related ecological effects.

Key findings are:

- A hierarchy of movement ranges were evident among the species studied with the least mobile being the several species of serranids, followed by *Coris aygula*. The herbivore *Kyphosus sydneyanus* used both areas of lagoon and reef slope, but the majority (~68%) remained in the array area for significant periods of the tracking period. A larger proportion of *Lethrinus nebulosus* and *Carangoides fulvoguttatus* left the array, although those that did stay used relatively small areas of habitat.
- It appears that most of the sanctuary zones within Ningaloo Marine Park are of a size adequate to protect a significant proportion of the fish populations, though this will vary with each species.
- Certain habitats appear to be of particular importance for feeding, resting and movement between habitats. Most of the species tracked made extensive and frequent use of the reef passage for travel between the lagoon and the reef slope. There are suggestions, still to be confirmed, that reef passage areas are also of particular importance for spawning of spangled emperor *Lethrinus nebulosus*. This study did confirm however that spangled emperor made extensive use of nearshore areas.
- Reef passages and channels are well represented in the Ningaloo Marine Park with an estimated 53% of major reef passages within the park included within sanctuary zones.
- Both emperors (Lethrinidae) and groupers (Serranidae) are know to spawn in aggregations at sites with particular characteristics. Spawning related behaviour of spangled emperor *Lethrinus nebulosus* was inferred to take place over a period of up to two months in November-December based on

movements of larger individuals. It appears that spawning takes place offshore but the precise locations of spawning are not known. Similarly there was little or no suggestion of spawning aggregations from the records of serranid fishes observed within the array.

- Additional observations have been made for a range of species but the number of individuals tagged is as yet too small to enable us to make valid inferences about the species behaviour on which management decisions could be made. These observations are valuable however in that they can be added to over time to build up an understanding of the habits and habitat use of a wide range of fish species, sharks and rays, as well as marine reptiles and mammals and their interactions with human uses of the park.

2.2. Implications for Management – Recommendations

- A significant knowledge gap exists in terms of our understanding of the movements of fish at scales larger than the Mangrove Bay array. This gap has significant implications for the understanding of connectivity among the sanctuary zones in the Marine Park.
- Lagoon and reef flat areas are well represented within the sanctuary zone system of Ningaloo marine park however many shoreline areas within sanctuary zones are exposed to fishing because of special purpose shore based angling zones. These zones may put populations of spangled emperor Lethrinus nebulosus within such sanctuary zones at disproportionate risk of capture.
- It is important to improve our knowledge of the timing and location of spawning behaviours of key target fish species such as *Lethrinus nebulosus* and groupers in Ningaloo Marine Park.
- Mechanisms should be sought to ensure the ongoing presence of the IMOS AATAMS tracking array and cross shelf lines at Ningaloo.
- This study of the adequacy of zoning in the Ningaloo Marine Park represents a significant investment of resources through the WA Government and WAMSI partners. Additionally there is a major ongoing investment from IMOS to maintain the array. Mathematical models are tools increasingly being used to maximise the ability to understand the implications of how of fish habits and habitat use interacts with human uses of the park in order to assist management. The data obtained in this study provides the opportunity to include fish behaviour in these models, just as the models currently include human behaviour.
- Population models and other modelling approaches used to inform management of the Ningaloo Marine Park should explicitly include animal behaviour.

2.3. Other Benefits

2.3.1. Tools, Technologies and Information for Improved Ecosystem Management

This project has played a key role in securing a substantial infrastructure investment in acoustic receiver equipment by the Australian Animal Tracking and Movement System (AATAMS) in WA as part of

Australia's Integrated Marine Observing System (IMOS). This is a facility now available to the entire scientific community.

2.3.2. Impacts

The results of this project are most likely to have immediate impact in two ways, confirming that the spatial scale of sanctuary zoning undertaken in the Ningaloo Marine Park review has by and large resulted in zones that are large enough to protect a significant proportion of targeted fish species. This will have substantial relevance to zoning decisions made in other parts of tropical Western Australia..

Other potential impacts from of this project will be in relation to revelations of the importance of nearshore habitats for key species, in particular spangled emperor, and of reef slope habitats for species of groupers. Both these habitats have been excluded from a number of sanctuary zones through special provisions of the marine park zoning. These provisions may need to be altered in order to achieve desired conservation outcomes.

2.4. Problems Encountered (if any).

3. Adequacy of zoning in the Ningaloo Marine Park

3.1. Introduction

Understanding fish movement and home range is critical for effective marine reserve design as the size of the reserve and the mobility of the fish populations will influence the degree of protection offered to species. In a network of reserves along a narrow band of coastline (such as the Ningaloo Marine Park) fish that move large distances, either along the coast or offshore, may not be adequately protected. Similarly, if sanctuary zones do not include sufficient amounts of key areas of habitat used by particular species, they may not achieve sufficient levels of protection.

Until recently there has been little or no data on the movement patterns, spatial distribution and habitat utilisation of commercially and recreationally important fish species within the Ningaloo Marine Park (or virtually anywhere in the country for that matter) at scales relevant to the marine park zoning design. As a result, the effectiveness of the size and spacing of existing no take areas (green zones), in terms of protecting these species from exploitation, is uncertain. Conversely, the movements also have important implications for so called spill-over of fish from no-take areas to fished zones. Multiple-use management of marine ecosystems must achieve a balance between the competing objectives of conservation and resource utilization. Increasingly, numerical models are used to assist managers in trying to achieve these objectives, however these models will only be useful if they incorporate realistic assumptions and understanding of habitat use and ranges of movement.

The same lack of data exists for some important taxa such as sharks, rays and turtles that are less subject to fishing effects. Acoustic tracking of tagged fish is the best method for obtaining this data on scales relevant to the ecology and management of the species of interest (i.e. species representative of major fishing target groups as well as major trophic groups will be the subjects of this project e.g. *Lethrinus nebulosus, Coris aygula; Carangoides fulvoguttatus. Kyphosus sydneyanus* and a range of groupers (Serranidae) including *Epinephelus rivulatus, E. multinotatus, E. tauvina, Plectropomus leopardus and Variola louti..*

3.2. Materials and Methods

Array

A permanent receiver array was established at Ningaloo as part of the Australian Integrated Marine Observing System (IMOS) co-managed by the Australian Animal Tracking And Monitoring System (AATAMS). At the time of its establishment this array which consists of cross shelf curtains and an array of receivers at Mangrove Bay was the largest of its kind undertaken within the Australian region (Fig. 1). In deeper water the receiver curtains are deployed on temporary moorings constructed for deployment on the sea floor. Receivers are placed no more than 800m apart to provide good overlap in receiver coverage (Fig. 1). Lines or 'curtains' of permanent listening stations were established running perpendicular to the coast from the inshore region of the lagoon out across the reef and into deep water. This provided approximately 4 km of listening line running across the reef and into deepwater (>100m depth) beyond the reef edge. For smaller scale tracking (e.g. Spangled Emperor) we deployed a matrix of VR2 receivers in the easily accessible Mangrove Bay region of Ningaloo Reef (Fig. 2). The array was designed to cover a full range of habitats such as mangrove inlets, beach rock reefs, lagoon, bommies, reef flats, reef passages and reef slopes. The array also encompasses both sanctuary and recreational fishing zones. The high density array in the Mangrove Bay region now contains 58 VR2 receivers. Most of these receivers are located near the sea floor by attaching them to star pickets. At selected locations a mini logger has also been deployed to record temperature at 30 minute intervals.

Data were regularly uploaded off the receivers (at least at 6 month intervals) and uploaded into a database. We provided the data from each download to AATAMS as well as the collaborators working on elasmobranchs.

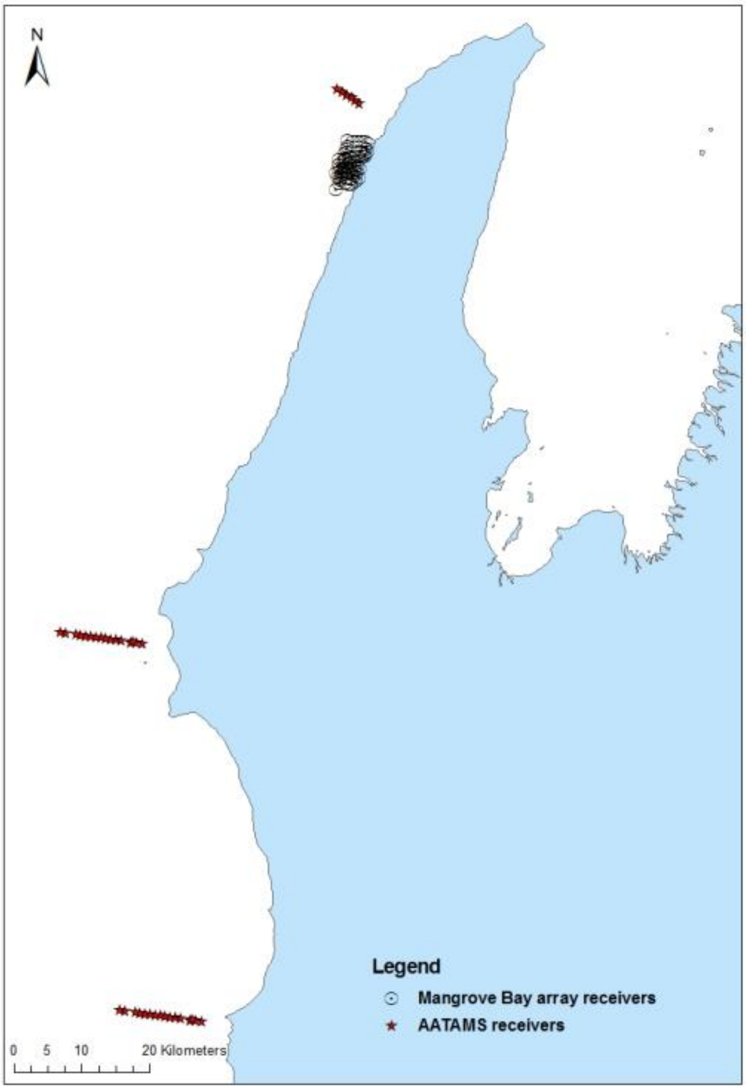


Fig. 1. Ningaloo showing the approximate location and length of the receiver curtains and the receiver array in the northern part of the region at Tantabiddi. Because the shelf south of Point Cloates is much wider, the receiver curtain there must be approximately 22 km long to reach the 100 m depth contour.

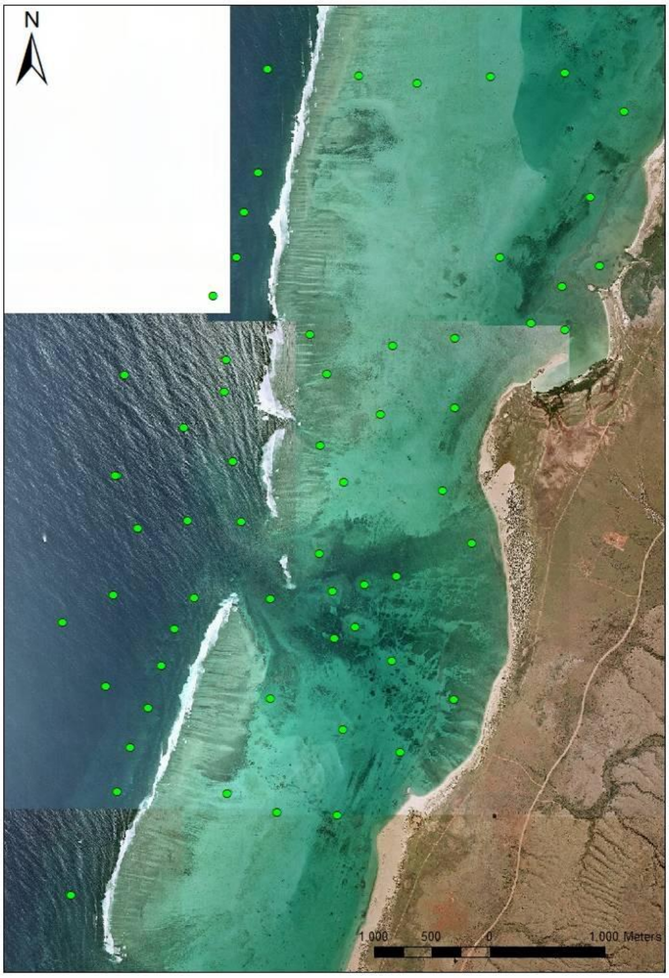


Fig. 2. Detail of the small scale array at Mangrove/T-Bone Bay. Locations originally planned were varied as necessary at the time of deployment due to local conditions of depth or locally bathymetry (e.g. bommies or rock bars may block signals in some locations).

Tagging

Animals were captured by hook and line to ensure that they were brought to the boat as fast as possible. Barbless hooks were used to minimise damage to the fish. In addition, circle hooks (designed to hook fish in the mouth) may be used to minimise internal injuries. For herbivorous fish, barrier nets were used to direct fish to a dead end where fish were captured with hand held nets.

Fish and sharks larger than 50 cm TL were lifted into the vessel with specially designed nets that prevent fish from damaging themselves and placed directly into a 120 l round plastic tub filled with seawater and clove oil. Small fish were lifted straight into the tub. Clove oil concentration in the container was sufficient to induce stage 5 anaesthesia within 5 minutes (2-3ppm). Air was bubbled through the water via a diffuser to ensure the water remained well oxygenated.

Once animals reached stage 5, we removed hooks from their mouths and inverted them in the container. Fish were placed in a foam cradle for surgery. Both persons wore surgical gloves during the surgery and all surgical procedures were carried out with disposable scalpels and suture packs. The skin around the surgical site was sterilised with betadine spray and an alcohol wash before a small incision (1.5 cm long) was made with a scalpel and an acoustic tag (9- 16 mm diameter × 35 - 62 mm long) was placed into the peritoneal cavity of each fish and the wound closed by 2-3 dissolving sutures. Forceps were sterilised between surgeries by submerging then in Savlon solution. Internal tags will be sterilised in a Savlon bath for 30 min immediately prior to use.

Once the wound had been sealed with sutures, betadine was sprayed over the wound. A mass dependent dose of ENGEMYCIN (Oxytetracycline 100 mgml-1) was administered intramuscularly via a 1 ml syringe and 26 gauge needle. Following this, animals were transferred to a holding tank with seawater only. Once animals had recovered from surgery, they were released. The average time from capture to completion of surgery was 6-7 minutes while recovery times varied depending on species from 10 to 30 minutes.

Among the finfish, the primary species for the study were *Lethrinus nebulosus* since it is abundant and is the most heavily targeted reef fish species at Ningaloo (Sumner *et al* 2002). It has also been suggested that this species may play a role as a key predator suppressing grazing urchins (Westera 2003). *Lethrinus nebulosus* was thought likely to be a species with moderate rates of movement and substantial but not extensive activity centres. Contrasting species will be the focus of additional work, the carangid (*Carangoides fulvoguttatus*) which is likely to be quite mobile but still reef associated to a degree. Black wrasse *Coris aygula* an invertebrate feeder with limited movement, and an herbivore *Kyphosus sydneyanus* a schooling species with unknown movement patterns were also the focus of tagging activity. Fish tagged were of a range of sizes, with the aim of incorporating any ontogenetic shifts in habitat or size of activity centre in the observations. Other species will be tagged opportunistically, particularly where these fish may be rare (larger groupers), or charismatic species such as and sailfish or grey reefs sharks. In time, enough individuals of these species will have been tagged to allow more detailed analysis of these species also.

Analysis

Lethrinids, Carangids and Kyphosids

Area utilisation was estimated using the utilisation distribution (Van Winkle, 1975) and its estimates with kernel techniques (Worton, 1989). Utilisation distribution is a probability density function that quantifies an individual's relative use of space (Kernohan et al., 2001). It depicts the probability of an animal occurring at a location within its home range as a function of relocation points (data obtained from receiver detections) (White and Garrot, 1990).

Fixed kernel distribution was calculated for those animals that had spent sufficient time within the array and had been detected on more than one receiver. Kernel distribution (50 and 95%) was calculated using the Hawth's tools extension for ArcMap. Kernel area was calculated using the animal movement extension for Arcview (ANME). Although the smoothing factor (Hlscv) was calculated using ANME in Arcview, calculated values greatly underestimated home range. A smoothing factor of 1000 was used for all animals. Using a larger smoothing factor allowed for gaps in the detection radius of individual receivers to be accounted for. Since, detection probability varied considerably (from 0 – 100%) throughout the array, using higher smoothing parameters was more appropriated. Higher smoothing parameters tended to result in larger kernel distributions and also resulted in less variation between animals (i.e., values tended to be similar). This provides a much greater degree of confidence in the final values as they are more biologically relevant.

Behaviour at the individual level, as characterised by the kernelling density function, was summarised at the species level in order to evaluate whether there were size specific differences in movement characteristics, as well as to provide probability distributions of the scale of movement and habitat use, and the range of variation in behaviour within the population.

Serranids

All data was analysed using R (R Development Core Team 2009), with spatial analysis using the package adehabitat (Calenge 2006). All data presented is with "ghost detections" (n=29) removed. Ghost detections occur when detections are recorded for an individual within an array at a time or location where it is unlikely that the animal occurred, be due to multiple acoustic signals from either multiple acoustic transmitters or biologically derived acoustic pulses colliding causing the detection of an otherwise valid record. They were identified as single detections, outside the area of other detections or capture location for the particular individual, or at times considerably after the time of the previous valid detection.

The initial design of the array was based on a number of adjacent receivers having abutting detection zones providing good coverage throughout the array. However, there is considerable temporal variation in the detection range of acoustic receivers due to a range of biotic and abiotic factors (How & de Lestang in prep). This resulted in the occurrence of acoustic "holes" within the array of varying extent throughout the study. As such, position estimates of individuals were restricted to the location of the receiver on which they were detected for analysis purposes.

Utilisation distribution kernels with the "ad hoc" smoothing factor (Calenge 2006), generally resulted in a number of separate polygons around the receivers where an individual was detected. Biologically, this is unlikely and is an artefact of using the location of the receiver, when the fish may be up to 400m from the receiver. As such, adjustments were made to the smoothing factor such that, the 95% kernel formed a single polygon. When the smoothing factor generated by the ad hoc method fitted these criteria, this smoothing factor was used.

3.3. Results

Detection summary

A total of 300 individuals of 17 species of teleosts (Table 1) and nine species of elasmobranchs (Table 2) have been tagged within the Mangrove Bay acoustic array, of these, only 24 animals have not been detected. Given that animals can move out of the array without being detected, mortality attributed to tagging was insignificant. A total of 2,200,000 tag detections from tagged animals have been recorded. The number of detections per individual ranged from 1 – 247691 and individuals were detected by as few as one receiver and as many as 46 (Table 3).

Table 1. Number of each species of teleost tagged between December 2007 and May 2009.

Family	Species	Number tagged
Acanthuridae	*Naso unicornis*	3
Carangidae	*Carangoides fulvoguttatus*	13
Kyphosidae	*Kyphosus sydneyanus*	19
Labridae	*Coris aygula*	20
Lethrinidae	*Lethrinus nebulosus*	71
Lethrinidae	*Lethrinus atkinsoni*	37
Lutjanidae	*Aprion virscens*	2
Scaridae	*Chlorurus sordidus*	14
Scaridae	*Scarus rivulatus*	6
Scaridae	*Hiposcarus longiceps*	1
Scaridae	*Scarus gobban*	1
Serranidae	*Variola louti*	9
Serranidae	*Epinephelus multinotatus*	7
Serranidae	*Epinephelus tauvina*	7
Serranidae	*Epinephelus rivulatus*	5
Serranidae	*Plectropomus leopardus*	1
Serranidae	*Plectropomus maculatus*	1

Table 2. Number of each species of elasmobranch tagged between December 2007 and May 2009.

Family	Species	Number tagged
Carcharhinidae	*Carcharhinus melanopterus*	16
Carcharhinidae	*Carcharhinus amblyrhynchos*	9
Carcharhinidae	*Carcharhinus cautus*	11
Carcharhinidae	*Negaprion acutidens*	4
Carcharhinidae	*Galocerdo cuvier*	1
Carcharhinidae	*Triaenodon obesus*	2
Dasyatidae	*Pastinachus atrus*	8
Dasyatidae	*Urogymnus asperrimus*	4
Rhinobatidae	*Glaucostegus typus*	10

Table 3. Summary of acoustic tag detections at Mangrove Bay between December 2007 and May 2009 showing number of receivers detecting individual tags and total number of detections. The date animals were tagged the date they were last recorded by any receiver within the array are also shown. Only individuals with greater than 1000 detections (n = 114) are shown.

TAG_ID	**Species**	**Fork length (cm)**	**Number of receivers**	**Total detections**	**Date tagged**	**Date of last detection**
8077	*Lethrinus nebulosus*	45.0	3	247691	27-May-08	25-May-09
8075	*Lethrinus nebulosus*	46.5	5	223980	03-Dec-07	22-May-09
8170	*Lethrinus nebulosus*	45.0	11	141179	05-Dec-07	22-May-09
8067	*Kyphosus sydneyanus*	57.0	1	117478	16-Oct-08	22-May-09
8069	*Kyphosus sydneyanus*	58.0	25	92506	16-Oct-08	22-May-09
8070	*Kyphosus sydneyanus*	55.0	20	69246	16-Oct-08	24-May-09
8076	*Carangoides fulvoguttatus*	80.0	38	49990	03-Dec-07	02-Nov-08
8153	*Lethrinus nebulosus*	53.0	18	42857	30-Nov-07	21-May-09
8057	*Kyphosus sydneyanus*	56.0	15	40484	16-Oct-08	22-May-09
8062	*Lethrinus nebulosus*	51.5	6	36725	20-Oct-08	18-May-09
8208	*Carcharhinus melanopeterus*	97.0	20	32587	22-Jan-09	24-May-09
8068	*Kyphosus sydneyanus*	66.0	19	30499	16-Oct-08	24-May-09
8071	*Kyphosus sydneyanus*	56.0	18	29076	16-Oct-08	25-May-09
8074	*Lethrinus nebulosus*	48.0	11	25603	04-Dec-07	23-May-09
8230	*Carcharhinus amblyrhynchos*	150.0	33	25334	25-Feb-08	25-May-09
53317	*Carangoides fulvoguttatus*	62.0	12	24484	24-Jan-09	22-May-09
53313	*Coris aygula*	46.0	1	23749	22-Jan-09	22-May-09
8116	*Carangoides fulvoguttatus*	63.5	21	22020	15-Oct-08	22-May-09
8176	*Carcharhinus melanopterus*	104.0	21	20545	02-Jun-08	03-Mar-09
8215	*Carcharhinus cautus*	117.0	16	19568	25-Feb-08	17-Apr-09
53260	*Lethrinus atkinsoni*	30.0	1	19254	23-Jan-09	23-May-09
8229	*Carcharhinus amblyrhynchos*	146.0	33	18764	25-Feb-08	24-May-09
53314	*Coris aygula*	45.0	2	17633	22-Jan-09	22-May-09
8063	*Kyphosus sydneyanus*	55.0	21	16877	19-Oct-08	17-Apr-09
8246	*Negaprion acutidens*	730.0	5	16651	26-Feb-08	08-May-09
8217	*Carcharhinus melanopterus*	121.0	24	16199	25-Feb-08	15-Aug-08
8245	*Urogymnus asperrimus*	550.0	6	16192	28-Feb-08	08-May-09
53321	*Coris aygula*	47.0	2	16142	22-Jan-09	22-May-09
53312	*Coris aygula*	40.0	2	15193	22-Jan-09	22-May-09
8216	*Carcharhinus cautus*	104.5	14	14948	25-Feb-08	03-May-09
8201	*Carcharhinus melanopterus*	104.0	41	14875	02-Jun-08	23-May-09
8048	*Lethrinus nebulosus*	41.0	4	13978	03-Dec-07	08-Jan-09
53319	*Coris aygula*	45.0	1	13065	22-Jan-09	22-May-09
53239	*Lethrinus atkinsoni*	26.0	3	12942	21-Jan-09	16-May-09
53320	*Coris aygula*	49.0	1	11771	22-Jan-09	22-May-09
8125	*Aprion virscens*	58.0	16	11340	15-Oct-08	06-Apr-09
8234	*Carcharhinus melanopterus*	130.0	29	10930	25-Feb-08	15-Apr-09
8341	*Carcharhinus cautus*	77.0	10	10117	22-Feb-08	22-May-09
8253	*Pastinachus sephen*	45.8	18	10072	24-Feb-08	27-Sep-08
8132	*Coris aygula*	46.0	8	10030	01-Jun-08	04-May-09
8218	*Carcharhinus melanopterus*	134.0	29	9997	25-Feb-08	24-May-09
8064	*Kyphosus sydneyanus*	51.0	21	9969	19-Oct-08	24-May-09
8262	*Urogymnus asperrimus*	53.7	12	9960	28-Feb-08	03-Aug-08
8209	*Plectropomus leopardus*	72.0	9	9889	28-May-08	15-Feb-09
8028	*Lethrinus nebulosus*	28.0	4	9666	04-Dec-07	18-Feb-08

TAG_ID	Species	Fork length (cm)	Number of receivers	Total detections	Date tagged	Date of last detection
8169	*Lethrinus nebulosus*	46.0	10	9563	05-Dec-07	21-May-09
8241	*Urogymnus asperrimus*	74.5	5	9305	26-Feb-08	10-Feb-09
8049	*Lethrinus nebulosus*	38.0	1	9152	03-Dec-07	12-Aug-08
8096	*Coris aygula*	50.0	6	8196	01-Dec-07	20-Aug-08
8159	*Lethrinus nebulosus*	47.0	10	7954	04-Dec-07	19-Jan-09
8171	*Lethrinus nebulosus*	56.0	18	7895	06-Dec-07	20-May-09
8065	*Kyphosus sydneyanus*	54.0	23	7875	19-Oct-08	24-May-09
8342	*Negaprion acutidens*	82.0	6	7294	28-Feb-08	20-May-09
8026	*Lethrinus nebulosus*	39.5	9	7148	03-Dec-07	27-Jul-08
8027	*Lethrinus nebulosus*	26.5	4	6986	05-Dec-07	18-Feb-08
8235	*Galocerdo cuvier*	396.0	55	6777	25-Feb-08	17-Jul-08
8173	*Lethrinus nebulosus*	49.5	7	6572	03-Dec-07	20-Feb-09
8212	*Carcharhinus cautus*	110.0	8	6384	25-Feb-08	01-May-08
53245	*Lethrinus atkinsoni*	25.5	2	6210	23-Jan-09	02-May-09
8178	*Carcharhinus amblyrhynchos*	122.0	16	6044	19-Oct-08	21-Jan-09
8355	*Pastinachus sephen*	81.0	6	5976	28-Feb-08	21-May-09
8047	*Lethrinus nebulosus*	41.0	4	5940	03-Dec-07	30-Jan-09
8261	*Urogymnus asperrimus*	58.5	14	5796	24-Feb-08	22-Feb-09
53234	*Lethrinus atkinsoni*	26.5	1	5637	21-Jan-09	03-Mar-09
53262	*Lethrinus atkinsoni*	26.0	1	5636	23-Jan-09	23-May-09
8022	*Lethrinus nebulosus*	37.0	11	5097	04-Dec-07	03-May-09
8264	*Pastinachus sephen*	55.0	16	4801	25-Feb-08	01-Aug-08
8251	*Rhinobatos typus*	97.8	8	4391	26-Feb-08	10-Sep-08
8031	*Lethrinus nebulosus*	26.5	4	4384	04-Dec-07	17-Feb-08
8030	*Lethrinus nebulosus*	27.0	3	4342	04-Dec-07	18-Feb-08
53339	*Carangoides fulvoguttatus*	73.0	23	4311	24-Jan-09	20-Apr-09
8177	*Carcharhinus melanopterus*	106.0	24	4127	01-Jun-08	24-May-09
8243	*Rhinobatos typus*	85.2	14	3842	28-Feb-08	26-Apr-09
53337	*Coris aygula*	44.0	2	3482	23-Jan-09	23-May-09
8054	*Lethrinus nebulosus*	34.0	6	3427	03-Dec-07	27-Jan-09
8112	*Triaenodon obesus*	93.0	6	3259	24-Jan-09	22-May-09
53299	*Lethrinus atkinsoni*	26.0	2	3230	22-Oct-08	18-Apr-09
8255	*Carcharhinus melanopterus*	100.0	31	3125	28-Feb-08	22-May-09
8118	*Epinephelus multinotatus*	35.0	8	2960	21-Oct-08	24-May-09
8256	*Carcharhinus melanopterus*	78.0	12	2947	28-Feb-08	04-Jul-08
8056	*Lethrinus nebulosus*	33.0	5	2873	03-Dec-07	19-Feb-08
8033	*Lethrinus nebulosus*	37.0	3	2751	06-Dec-07	28-Jun-08
53310	*Kyphosus sydneyanus*	54.0	10	2740	22-Jan-09	23-Apr-09
8130	*Coris aygula*	51.0	2	2726	01-Jun-08	21-May-09
53227	*Coris aygula*	36.0	1	2649	22-Oct-08	22-Jan-09
8045	*Lethrinus nebulosus*	39.0	4	2647	01-Dec-07	23-Oct-08
8046	*Lethrinus nebulosus*	40.0	10	2541	02-Dec-07	19-Oct-08
53256	*Coris aygula*	38.0	1	2523	22-Jan-09	22-May-09
53236	*Scarus rivulatus*	34.0	2	2487	23-Jan-09	22-May-09
53257	*Coris aygula*	37.0	1	2389	22-Jan-09	22-May-09
8034	*Lethrinus nebulosus*	32.5	4	2381	06-Dec-07	13-Jul-08
53223	*Naso unicornis*	39.0	1	2320	22-Oct-08	23-May-09
8119	*Aprion viriscens*	54.0	13	2237	21-Jan-09	02-May-09
53263	*Lethrinus atkinsoni*	26.0	1	2232	23-Jan-09	07-May-09
53301	*Lethrinus atkinsoni*	24.0	1	2136	22-Oct-08	22-Dec-08
53341	*Lethrinus nebulosus*	42.5	5	2090	23-Jan-09	04-Mar-09

TAG_ID	Species	Fork length (cm)	Number of receivers	Total detections	Date tagged	Date of last detection
8052	*Lethrinus nebulosus*	37.0	6	1901	03-Dec-07	12-May-09
53300	*Lethrinus atkinsoni*	26.0	1	1896	22-Oct-08	12-Nov-08
8161	*Epinephelus multinotatus*	77.0	9	1803	27-May-08	22-May-09
8252	*Carcharhinus melanopterus*	90.1	14	1777	23-Feb-08	21-May-09
53261	*Epinephilus rivulatus*	34.0	2	1689	23-Jan-09	24-Feb-09
53297	*Lethrinus atkinsoni*	27.0	1	1666	22-Oct-08	29-Jan-09
8179	*Carcharhinus melanopterus*	112.0	15	1657	16-Oct-08	16-Jan-09
53298	*Lethrinus atkinsoni*	26.5	4	1632	22-Oct-08	05-May-09
8039	*Lethrinus nebulosus*	38.5	7	1630	29-May-08	06-Jan-09
53229	*Chlorurus sordidus*	29.5	1	1592	22-Oct-08	23-May-09
8131	*Coris aygula*	51.0	12	1520	01-Jun-08	26-Dec-08
53311	*Kyphosus sydneyanus*	49.0	4	1376	21-Jan-09	26-Jan-09
8044	*Lethrinus nebulosus*	32.0	2	1360	01-Dec-07	18-Feb-08
53253	*Lethrinus atkinsoni*	25.0	3	1273	22-Oct-08	30-Jan-09
8124	*Variola louti*	49.0	1	1251	02-Jun-08	22-Apr-09
8196	*Triaenodon obesus*	116.0	4	1164	24-Jan-09	01-Mar-09
8051	*Lethrinus nebulosus*	36.0	2	1045	02-Dec-07	18-Feb-08
53228	*Coris aygula*	35.0	2	1008	22-Oct-08	07-May-09

Population level analysis

For four species, *Lethrinus nebulosus, Carangoides fulvoguttatus, Coris aygula* and *Kyphosus sydneyanus* we have accumulated enough data to make it feasible to summarise movement behaviour at a population level. There is also sufficient information to draw conclusions about habitat utilization and movement of serranid fishes as well as some preliminary findings about relative movement patterns of more abundant members of this family, *Epinephelus tauvina, E. multinotatus, E. rivulatus, Plectropomus leopardus* and *Variola louti*.

Lethrinus nebulosus

A total of 79 *L. nebulosus* were tagged within the array between November 2007 – May 2009. Of these, three animals are thought to have been eaten by sharks, resulting in the tag falling out close to a receiver resulting in more than 100,000 detections throughout the tag life by only one receiver. Of the animals tagged prior to the last download, eight tags were not detected at all suggesting that animals either left the area immediately or more likely, that the tags were not functioning. Of the 60 animals that were detected at least once, sufficient data were available to determine the 50 and 95% kernel areas for 40 individuals (Table 3).

The behaviour of each fish as summarised by calculating fixed kernel distribution, condensed the sum of its behaviour during the tracking period into several statistics that were then compiled for the overall population of tagged fish. Representative examples of such kernels for *L. nebulosus* 8173, 8074 and 8154 (Fig. 3) show that these fish had a similar sized activity centres which were centred around the tagging location. Although these three fish had a similar sized activity centres, the small size of the Mangrove Bay Sanctuary resulted in fish 8154 spending up to 50% of it's time outside the marine park boundary, 8173 spending almost of it's time inside the marine park and 8074 almost all of it's time outside the boundary. Fish 8171 was tagged during the spawning period at a suspected spawning aggregation on the reef slope.

Approximately two weeks after tagging, this fish moved into the lagoon where it remained for the next 10 months until the spawning period in 2008. In October 2008 it again moved offshore to the location where it was tagged before moving back inside the lagoon in Mid December 2008. While inside the lagoon, this fish spent approximately 50% of it's time within the marine park boundary (Figure 3A).

Of the 40 individuals that were detected sufficient times by multiple receivers, 90% had a 50% kernel area of less than 3 km^2 (Fig. 4) with a modal size of between 2 and 3 km^2. The remaining 10% had 50% kernel areas of between 3 and 10 km^2. Using a 95% kernel area, the modal size was much larger, between 5 and 10 km^2 and some individuals ranging over as much as 25km^2 (Fig. 4). Given the linear nature of the fringing reef ecosystem at Ningaloo, it is useful to translate these areas into linear dimensions representing the diameter of activity centres, which are 1.6 to 2 km and 2.5 to 3.5 km for the 50% and 95% kernels respectively. Assuming that the additional 23 animals that were initially detected and then not detected have moved outside the array, 32% of all tagged animals have moved undetermined distances outside the array. The current design of acoustic array does not enable this distance to be accurately estimated, however it is likely that distances greater than the radius of the array (~4km). This conclusion is based on measurements of the distances between capture locations and their calculated activity centres, most of which were less than 0.5km (Fig. 5).

It is unlikely that individuals with activity centres outside the array happened to be captured inside the array since few of them were tagged near the edge of the sanctuary, although some may have a similar sized home range that is outside the area of the array. Only one *L. nebulosus* has been recorded on the Tantabiddi cross shelf line (Figure 1) approximately 6 km north of the Mangrove Bay. This animal was recorded on the Tantabiddi line 25 days after it was tagged and was only recorded twice within a 30 min period and has not been record on any receiver since then. Unfortunately, the Tantabiddi line of receivers does not extend inside the lagoon so any northward movements inside the lagoon would go undetected.

There does not appear to be any pattern in movement related to size, with kernel size remaining remarkably similar in fish ranging from 25 – 60 cm FL (Fig. 6). For all animals where kernel density was calculated, the distance from the tagging location to the centre of the home range (centre of the 50% kernel) was less than 2.5 km, (Fig. 7) indicative of the limited home range for the animals where home range was calculated.

Data from tagged spangled emperor have also shown that animals show seasonal movements associated with spawning. In December 2007, several fish were tagged on the reef slope adjacent to the northern side of South Passage. These were large fish, one of which was a running-ripe male. None of these remained in the area of capture, though one remained in the array, returning to lagoon and mangrove habitats within the Mangrove Sanctuary zone. Four of these tagged fish returned to reef slope habitats adjacent to South Passage during the same lunar phase approximately one year later in October 2008. It is not known where the other fish spent the intervening year, though they did not transit through the lagoon when leaving the array were likely to have spent this time at offshore locations.

Movements of *L. nebulosus* varied among key habitats and animals tagged in reef slope and shoreline habitats displayed greater and more variable distances moved between capture location and activity centre (Fig. 8). Mean Kernel Area (50%) also varied significantly among habitats (Fig. 9, F=12.5, p=0.0001).

Another more dynamic way of examining behaviour is to calculate the probability of movement from one location to the next. This is the approach depicted in Figure 9 where the width and density of lines between receiver locations indicates the likelihood of movement from one location directly to the other. It is clear from this analysis that certain sites are closely linked with high probabilities of movement from one area to the next and vice versa. The most strongly linked sites are those within Mangrove Bay proper, and the shoreline reefs immediately to its west. There are also strong movements to shoreline reefs to the south of Mangrove Bay adjacent to south passage, but northward shoreline movements appear to be much less common. A second frequent though much less common set of movements took place between shoreline reefs and adjacent lagoon and reef passage locations, though all other movements were relatively infrequent, especially those from lagoon to reef slope, with the possible exception of some movement through South Passage (Fig. 10).

Examples of a variety of behavioural patterns exhibited by individual fish can be examined in Appendix 1. One prominent pattern is diurnal variation in activity centres, where commonly fish tend to be found in deeper areas of the lagoon during the day and move to adjacent shallower areas either along the shoreline or on the reef flat at night. Movements of larger fish during November, presumably for spawning, are also common. At this point it has not been possible to pinpoint a spawning location, but it does seem that this is likely to take place outside the array, possibly in deeper water to the north. Other transient offshore movements were also seen in several fish, and it is not clear what the reason for these movements may be. Abrupt changes in the location of activity centres were also seen in some fish.

Table 3. *Lethrinus nebulosus* tagging summary. 50 and 95% kernel area and distance from centre of 50% kernel to tag location were only calculated for animals where sufficient data were available to compute kernel distribution. * denote animals that have died and the tag has fallen out close to a receiver resulting in continuous detection over time.

Species	FL cm	Tag ID	Date tagged	Habitat tagged in	Number of receivers	Total detections	Tag date to date last detected	Days detected	Proportion of days in array	Area of 50% kernel	Area of 95% kernel	Distance from 50% kernel centre to tag location
L. nebulosus	53	8153	30-Nov-07	lagoon bommies	18	42857	533	458	86.0	2.35	10.3	0.15
L. nebulosus	31.5	8043	01-Dec-07	reef pass	2	6	250	2	0.8			
L. nebulosus	32	8044	01-Dec-07	lagoon bommies	2	1360	78	63	80.8	2.15	7.97	0.19
L. nebulosus	39	8045	01-Dec-07	lagoon bommies	4	2647	327	180	55.0	2.15	7.97	0.18
L. nebulosus	48	8156	01-Dec-07	lagoon bommies	0	0						
L. nebulosus	56	8078	01-Dec-07	lagoon bommies	5	966	347	7	2.0	1.81	7.34	0.33
L. nebulosus	40	8046	02-Dec-07	lagoon bommies	10	2541	322	97	30.1	2.16	6.6	0.36
L. nebulosus	36	8051	02-Dec-07	reef pass	2	1045	78	72	92.3	2.39	9.42	0.3
L. nebulosus	34	8054	03-Dec-07	lagoon bommies	6	3427	421	356	84.6	1.77	7.28	0.35
L. nebulosus	49	8158	03-Dec-07	shoreline pavement	1	10	4	2	50.0			
L. nebulosus	49.5	8173	03-Dec-07	shoreline pavement	7	6572	445	110	24.7	1.77	5.81	0.13
L. nebulosus	46.5	8075	03-Dec-07	shoreline pavement	5	223980*						
L. nebulosus	53	8103	03-Dec-07	shoreline pavement	1	41	57	10	17.5			
L. nebulosus	38	8049	03-Dec-07	lagoon bommies	1	9152	253	245	96.8	2.51	7.78	0.16
L. nebulosus	44	8154	03-Dec-07	reef pass	5	52	5	6	120.0			
L. nebulosus	38	8055	03-Dec-07	lagoon bommies	5	572	376	146	38.8	2.41	9.5	0.45
L. nebulosus	39.5	8026	03-Dec-07	shoreline pavement	9	7148	220	203	92.3	1.77	5.43	0.48
L. nebulosus	35.5	8053	03-Dec-07	lagoon bommies	4	920	424	196	46.2	2.34	9.44	0.51
L. nebulosus	37	8052	03-Dec-07	lagoon bommies	6	1901	525	291	55.4	2.25	9.07	0.31
L. nebulosus	34	8050	03-Dec-07	reef pass	6	15	248	10	4.0	3.27	19.05	0.62
L. nebulosus	41	8048	03-Dec-07	lagoon bommies	4	13978	402	173	43.0	2.14	7.25	0.15

Species	FL cm	Tag ID	Date tagged	Habitat tagged in	Number of receivers	Total detections	Tag date to date last detected	Days detected	Proportion of days in array	Area of 50% kernel	Area of 95% kernel	Distance from 50% kernel centre to tag location
L. nebulosus	41	8047	03-Dec-07	lagoon bommies	4	5940	424	353	83.3	2.06	7.79	0.17
L. nebulosus	33	8056	03-Dec-07	lagoon bommies	5	2873	78	78	100.0	2.15	6.33	0.15
L. nebulosus	48	8074	04-Dec-07	shoreline pavement	11	25603	536	513	95.7	2.63	8.91	0.68
L. nebulosus	47	8159	04-Dec-07	shoreline pavement	10	7954	412	162	39.3	1.54	7	0.15
L. nebulosus	26.5	8031	04-Dec-07	lagoon bommies	4	4384	75	70	93.3	2.08	7.79	0.15
L. nebulosus	27	8030	04-Dec-07	lagoon bommies	3	4342	76	75	98.7	2.32	10.3	0.14
L. nebulosus	28	8028	04-Dec-07	lagoon bommies	4	9666	76	75	98.7	2.2	7.68	0.53
L. nebulosus	41	8025	04-Dec-07	shoreline pavement	2	223	107	10	9.3	2.56	9.48	1.39
L. nebulosus	34	8024	04-Dec-07	shoreline pavement	7	42	6	6	100.0	3.03	11.27	1.55
L. nebulosus	28.5	8023	04-Dec-07	shoreline pavement	3	11	523	6	1.1	2.32	9.15	0.33
L. nebulosus	37	8022	04-Dec-07	shoreline pavement	11	5097	516	129	25.0	1.73	7.54	2.17
L. nebulosus	34	8036	05-Dec-07	shoreline pavement	24	344	11	11	100.0	4.71	16.52	0.35
L. nebulosus	43	8157	05-Dec-07	shoreline pavement	1	1	1	1	100.0			
L. nebulosus	46	8169	05-Dec-07	shoreline pavement	10	9563	532	454	85.3	1.86	6.18	0.73
L. nebulosus	45	8170	05-Dec-07	lagoon bommies	11	141179*	531	504	94.9			
L. nebulosus	26.5	8027	05-Dec-07	lagoon bommies	4	6986	75	75	100.0	1.7	7.23	0.13
L. nebulosus	56	8166	06-Dec-07	reef slope	11	21	361	5	1.4			
L. nebulosus	56	8171	06-Dec-07	reef slope	18	7895	531	422	79.5	2.82	9.81	2.38
L. nebulosus	37	8033	06-Dec-07	reef slope	3	2751	205	145	70.7	2.15	7.97	0.15
L. nebulosus	59	8095	06-Dec-07	reef slope	15	48	361	6	1.7	6.59	23.8	2.01
L. nebulosus	57	8168	06-Dec-07	reef slope	22	141	373	9	2.4			
L. nebulosus	51	8164	06-Dec-07	reef slope	11	87	341	4	1.2			
L. nebulosus	57	8163	06-Dec-07	reef slope	5	44	5	3	60.0			
L. nebulosus	56	8160	06-Dec-07	reef slope	5	8	1	1	100.0			
L. nebulosus	54	8165	06-Dec-07	reef slope	10	52	409	3	0.7			

Species	FL cm	Tag ID	Date tagged	Habitat tagged in	Number of receivers	Total detections	Tag date to date last detected	Days detected	Proportion of days in array	Area of 50% kernel	Area of 95% kernel	Distance from 50% kernel centre to tag location
L. nebulosus	67	8162	06-Dec-07	reef slope	6	8	1	2	200.0			
L. nebulosus	32.5	8034	06-Dec-07	lagoon bommies	4	2381	217	82	37.8	2.18	8.1	0.13
L. nebulosus	56	8167	06-Dec-07	reef slope	3	90	1	1	100.0			
L. nebulosus	56.5	8094	25-May-08	reef slope	4	134	60	11	18.3	2.24	9.38	0.72
L. nebulosus	34	8041	25-May-08	reef slope	7	716	214	132	61.7	2.37	10.46	0.71
L. nebulosus	37	8038	26-May-08	reef slope	1	1	0					
L. nebulosus	43	8155	27-May-08	reef slope	3	38	46	5	10.9			
L. nebulosus	45	8077	27-May-08	reef slope	3	247691*	363	255	70.2			
L. nebulosus	38.5	8072	27-May-08	reef slope	1	2	1	1	100.0			
L. nebulosus	37	8032	27-May-08	reef slope	4	297	15	14	93.3	2.14	9.63	0.7
L. nebulosus	48	8088	27-May-08	reef slope	0	0						
L. nebulosus	51	8090	28-May-08	reef slope	2	37	352	34	9.7			
L. nebulosus	38.5	8039	29-May-08	reef slope	7	1630	222	181	81.5	2.12	9.8	1.09
L. nebulosus	67	8199	30-May-08	reef slope	11	171	31	6	19.4			
L. nebulosus	58.5	8198	30-May-08	reef slope	4	319	7	7	100.0			
L. nebulosus	55	8200	02-Jun-08	reef flat	0	0						
L. nebulosus	51.5	8062	20-Oct-08	shoreline pavement	6	36725	210	171	81.4	1.39	4.94	0.54
L. nebulosus	55	8059	20-Oct-08	reef flat	0	0						
L. nebulosus	47.5	8120	23-Jan-09	shoreline pavement	0	0						
L. nebulosus	27	53238	23-Jan-09	reef flat	1	166	108	32	29.6	2.2	9.27	0.06
L. nebulosus	42.5	53341	23-Jan-09	reef flat	5	2090	40	30	75.0	2.38	9.42	0.44
L. nebulosus	26	53270	23-Jan-09	reef flat	3	627	15	15	100.0	2.21	10.07	0.17
L. nebulosus	46	53340	23-Jan-09	reef flat	0	0						
L. nebulosus	50	8122	23-Jan-09	shoreline pavement	0	0						
L. nebulosus	52	8123	23-Jan-09	shoreline pavement	0	0						

Species	FL cm	Tag ID	Date tagged	Habitat tagged in	Number of receivers	Total detections	Tag date to date last detected	Days detected	Proportion of days in array	Area of 50% kernel	Area of 95% kernel	Distance from 50% kernel centre to tag location
L. nebulosus	61	8105	23-May-09	shoreline pavement	0	0						
L. nebulosus	55	8111	23-May-09	shoreline pavement	0	0						
L. nebulosus	56	8114	23-May-09	shoreline pavement	0	0						
L. nebulosus	26	53280	23-May-09	shoreline pavement	0	0						
L. nebulosus	55	8113	23-May-09	shoreline pavement	0	0						
L. nebulosus	45	53332	23-May-09	shoreline pavement	0	0						
L. nebulosus	53	8061	23-May-09	shoreline pavement	0	0						
L. nebulosus	53	8126	23-May-09	shoreline pavement	0	0						

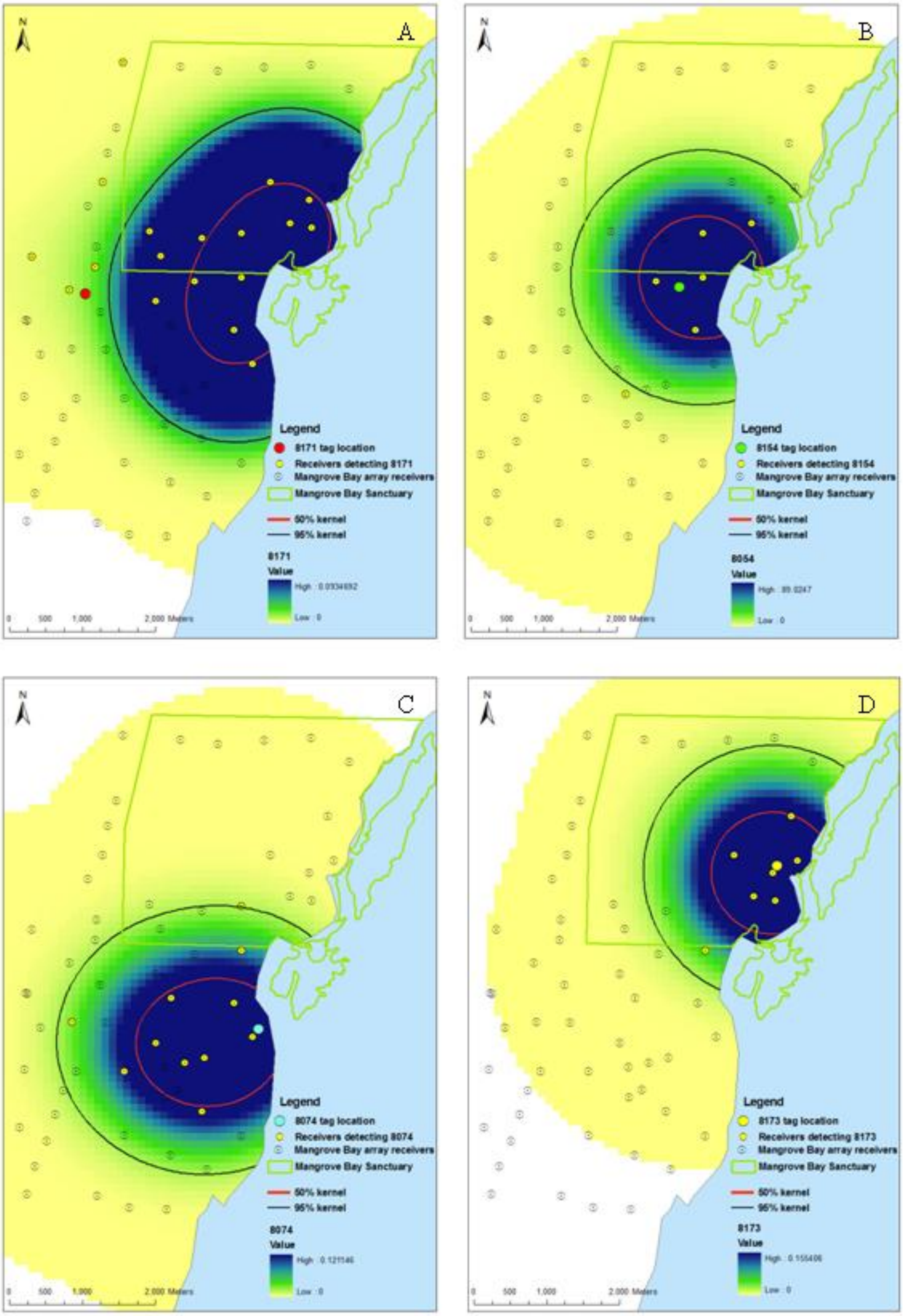
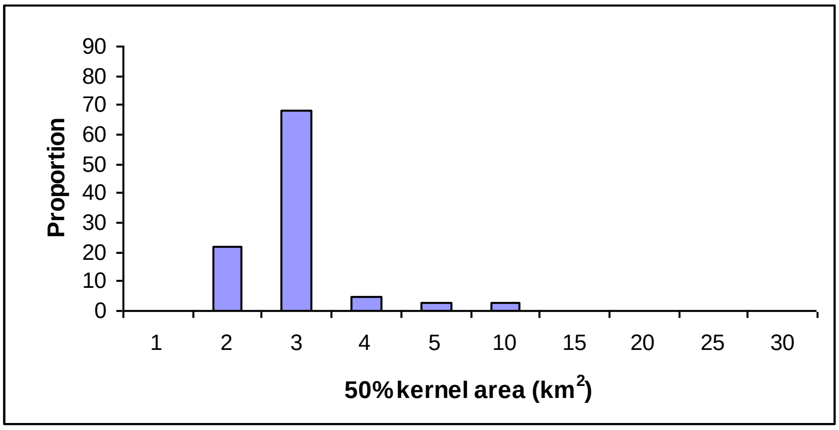


Figure 3. Map showing the fixed kernel density of four *L. nebulosus* (tag number 8171 (A), 8154 (B), 8074 (C) and 8173 (D). The tagging location, sanctuary boundary and receivers detecting the fish along with all receivers within the array are shown. The 50 and 95% kernel densities and fixed kernel density are also shown.



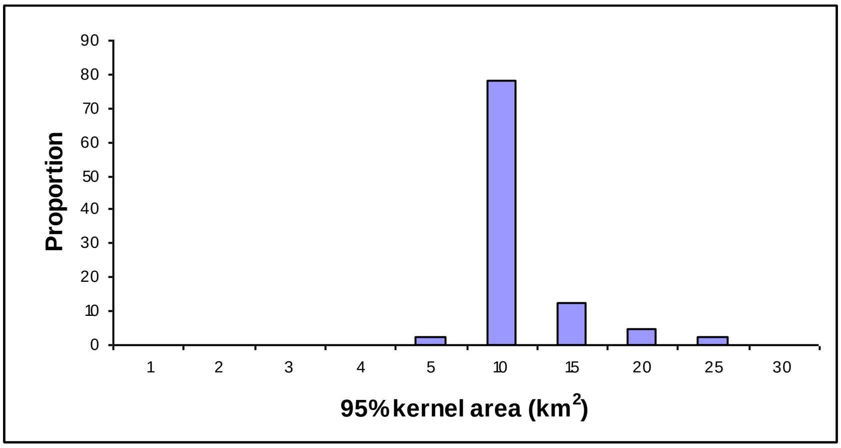


Figure 4. Cumulative proportion of 50% and 95% kernel area for 40 *L. nebulosus*.

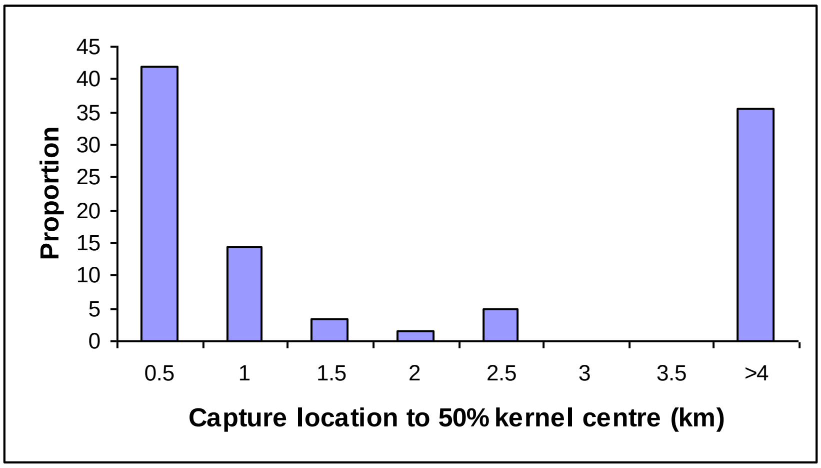


Figure 5. Distance between capture location and activity centre. For those animals where kernel size was not calculated due to insufficient data, the 50% kernel centre was assumed to be greater than 4 km from the tagging location based on the size of the array and the ability of the array to detect fish.

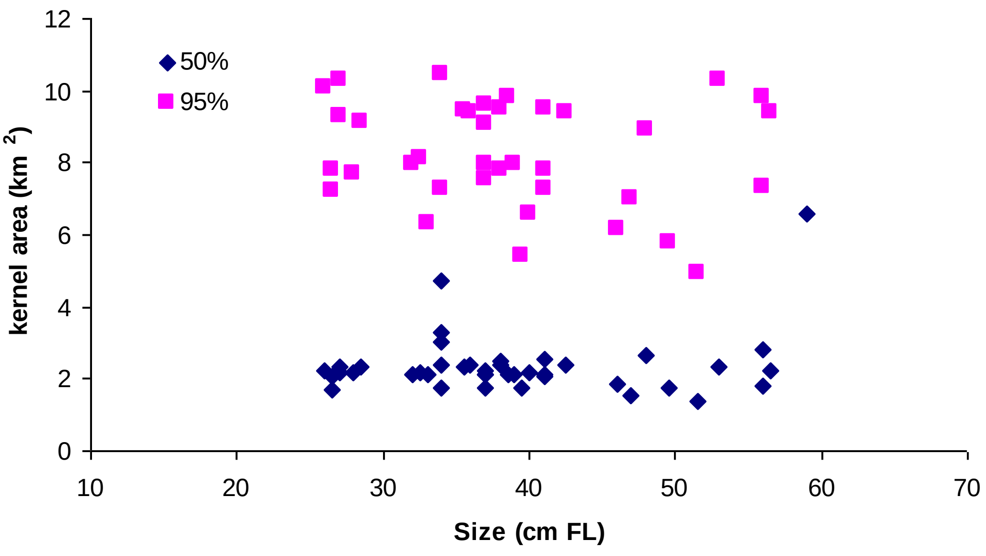


Figure 6. Plot of the 50 and 95% kernel area (km2) against *L. nebulosus* size (n = 41)

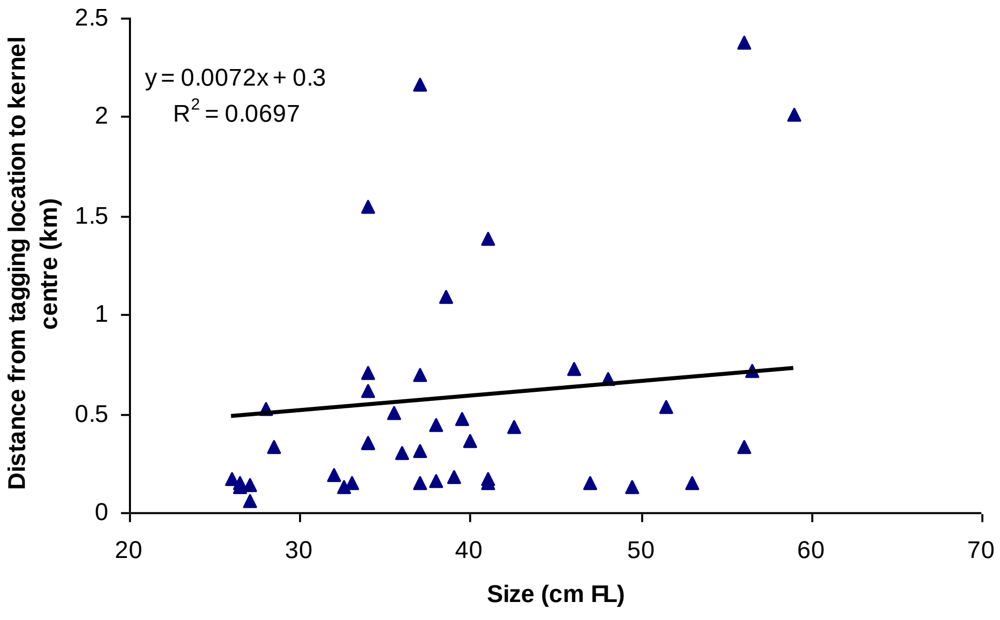


Figure 7. Plot of *L. nebulosus* size against the distance (km) from the tagging location to the centre of the 50% kernel for each individual

Figure 8. Habitat related variation in movement. Data are for distances between 50% kernel centres and capture locations.

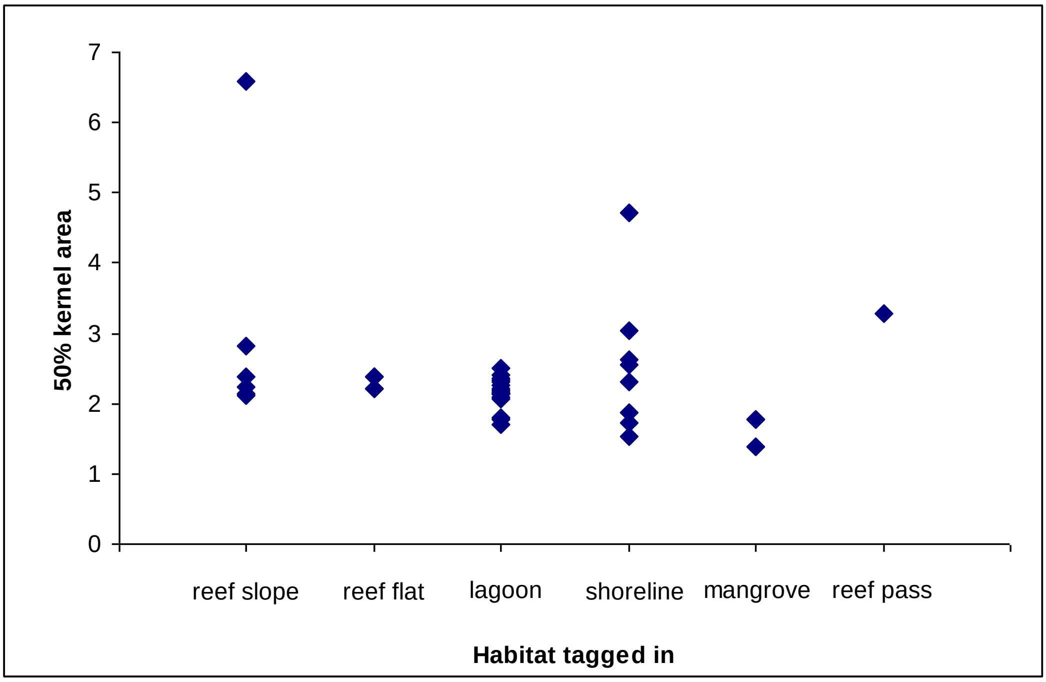


Figure 9. Habitat related variation in kernel area.

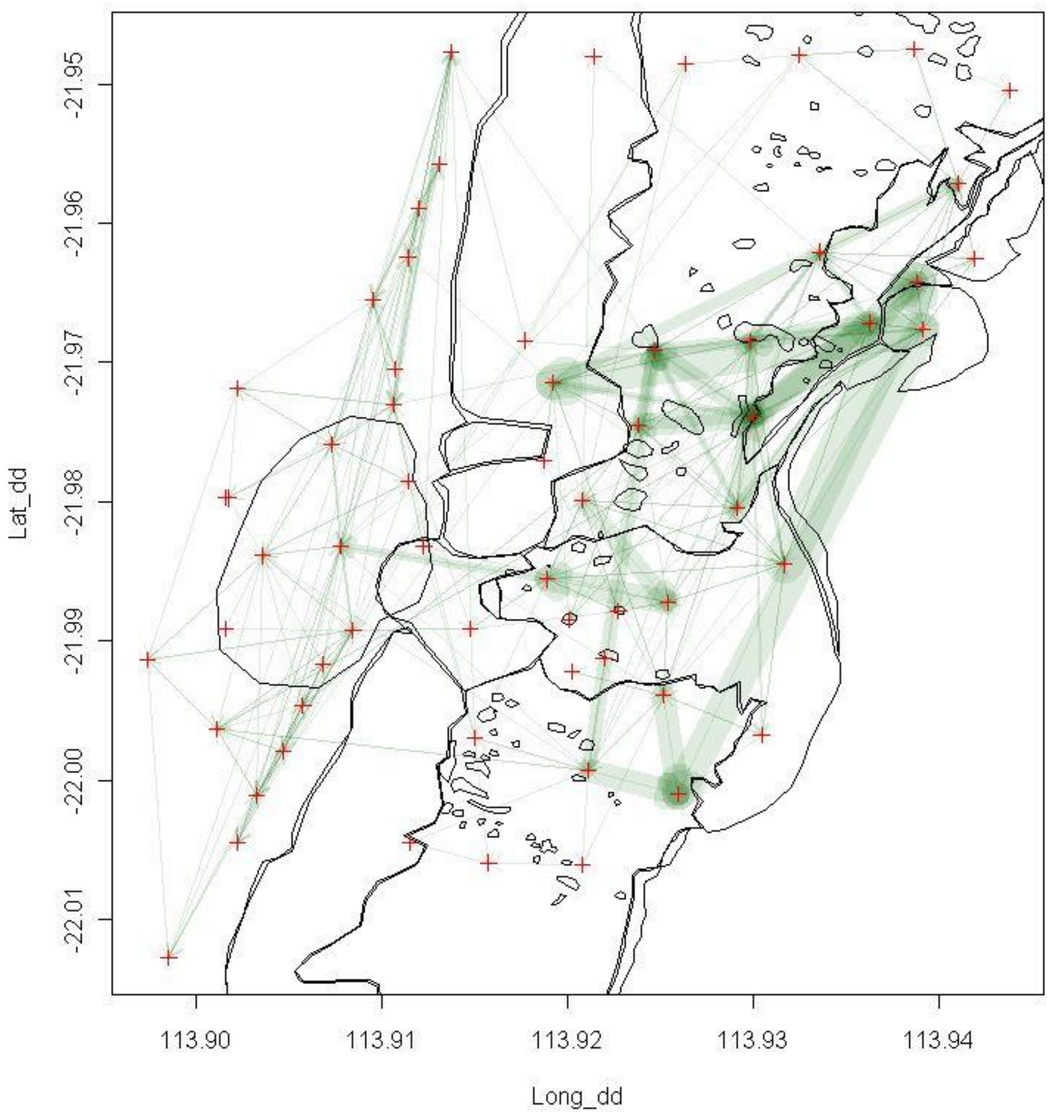


Figure 10. *Lethrinus nebulosus* movement pathways for all tagged animals. The thickness of the arrow is proportional to the number of movements from one receiver to another.

Carangoides fulvoguttatus

Gold Spot Trevally *Carangoides fulvoguttatus* are a highly active pelagic trevally species. Of the 15 animals tagged to date, six individuals have remained within or very close to the array throughout their time at liberty and have been detected regularly by receivers (Table 4). The activity centres of these individuals were relatively limited with activity kernels centred around the tagging location (Fig. 11). One of the individuals tagged on the reef slope (53306) displayed a more linear activity pattern moving parallel to the reef front (Fig. 11). The modal size of 50% activity kernels was between 2 and 3 km^2, or areas with a linear diameter of between 1.6 and 2 km (Fig. 12). 95% activity kernels were larger with modal sizes between 10 and 15 km^2, however no activity centres were larger than 25km^2 or approximately 5.6 km in diameter. Modal distance between capture location and 50% kernel centres was

0.5 to 1km (Fig. 13), adding further support to the conclusion that activity centres in *C. fulvoguttatus* are not large.

There was no apparent influence of individual size on the size of activity centre (Fig. 14) and no significant relationship between size and the distance between capture location and the centre of the 50% activity kernel (Fig. 15).

There was no significant variation in the distance from capture location to kernel centre (Fig. 16), or in kernel size (Fig. 17). Interesting patterns in behaviour were nevertheless evident with distinct diurnal variations in behaviour (Appendix 1) and particularly high levels of site fidelity at night to either to lagoon or reef slope sites. Main areas of activity were either inside the lagoon or outside the reef with relatively little movement from one area to the other (Fig. 18). Similarly there seemed to be little movement north-south across south passage (Fig. 18). Correspondingly the most frequent movements are between locations within the lagoon, and these are mainly east-west, rather than north south across south passage (Fig. 19). The next most common class of movements was along the reef slope.

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Table 4. *Carangoides fulvoguttatus* tagging summary. 50 and 95% kernel area and distance from centre of 50% kernel to tag location were only calculated for animals where sufficient data were available to compute kernel distribution. Kernel density was only calculated for animals that were detected for more than 20 days and detected at least 100 times during this period. * denote animals that have died and the tag has fallen out close to a receiver resulting in continuous detection over time.

Species	FL cm	Tag ID	Date tagged	Habitat tagged	Number of receivers	Total detections	Tag date to date last detected	Days detected	Proportion days in array	Area 50% kernel	Area 95% kernel	Distance tag to 50% centre
C. fulvoguttatus	53	8151	01-Dec-07	lagoon bommies	27	807	372	99	26.6	4.2	22.1	0.4
C. fulvoguttatus	53	8152	01-Dec-07	reef pass	9	51	3	3	100.0			
C. fulvoguttatus	70	8172	01-Dec-07	reef pass	5	124	26	13	50.0	2.7	11.3	0.9
C. fulvoguttatus	80	8076	03-Dec-07	lagoon bommies	38	49990	335	333	99.4	2.8	11.3	0.8
C. fulvoguttatus	50	8035	06-Dec-07	reef slope	17	100	217	29	13.4	6.8	24.7	2.4
C. fulvoguttatus	86.5	8237	31-May-08	reef slope	18	319	63	20	31.7	3.1	17.6	0.5
C. fulvoguttatus	63.5	8116	15-Oct-08	lagoon bommies	21	22020	219	201	91.8	2.4	9.9	0.2
C. fulvoguttatus	67	53306	21-Oct-08	reef slope	18	939	212	108	50.9	4.4	17.4	0.9
C. fulvoguttatus	61	53305	22-Oct-08	reef pass	11	801	209	29	13.9	2.4	10.7	0.7
C. fulvoguttatus	62	53317	24-Jan-09	reef pass	12	24484	118	118	100.0	2.2	10.9	1.4
C. fulvoguttatus	70	53338	24-Jan-09	lagoon bommies	9	67	3	3	100.0			
C. fulvoguttatus	73	53339	24-Jan-09	reef slope	23	4311	86	86	100.0	2.7	10.7	1.2
C. fulvoguttatus	66	53327	24-May-09	reef pass	0	0	0	0	0			
C. fulvoguttatus	63	8093	27-May-08	reef slope	0	0	0	0	0			
C. fulvoguttatus	75	53318	24-Jan-09	reef pass	0	0	0	0	0			

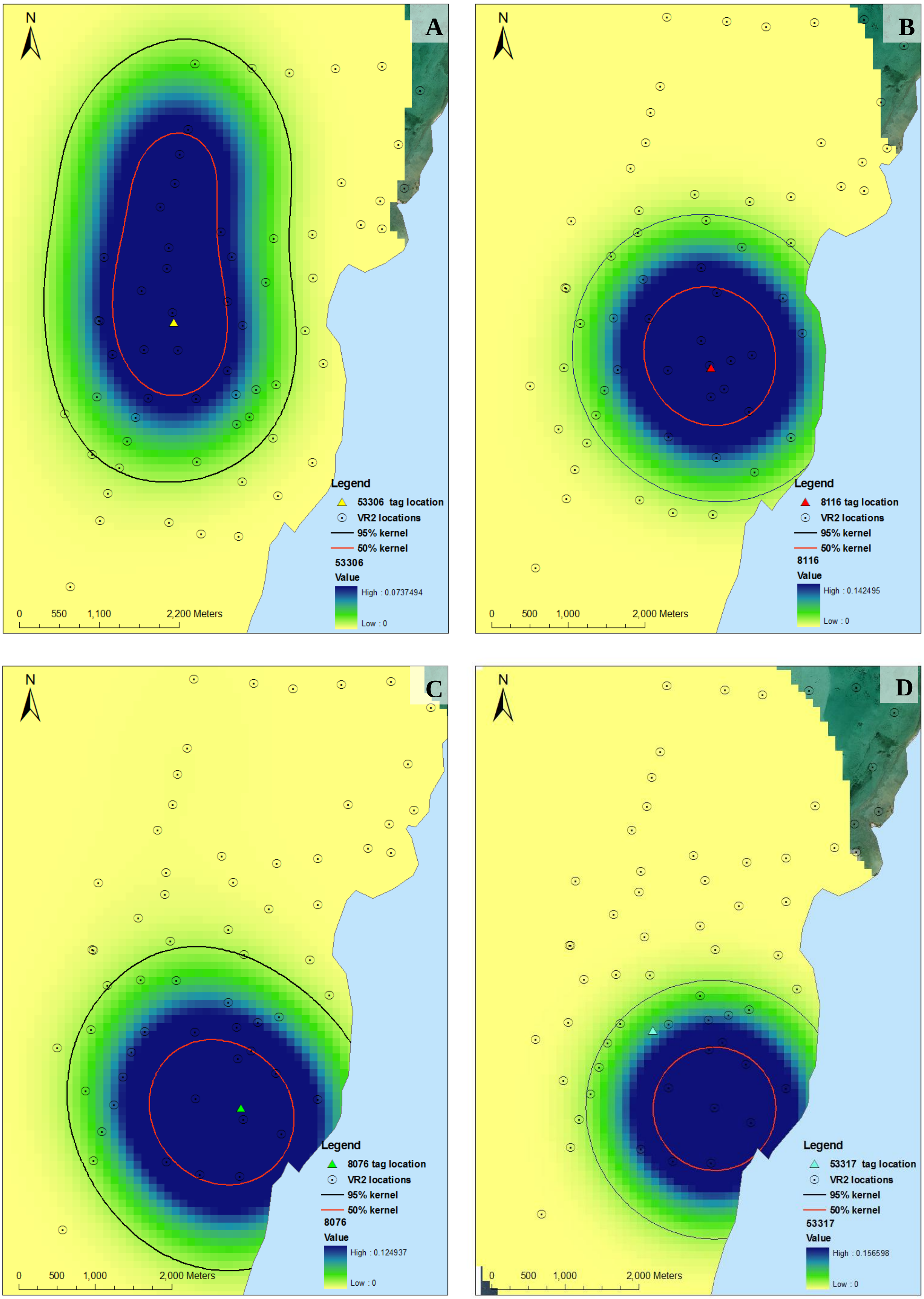
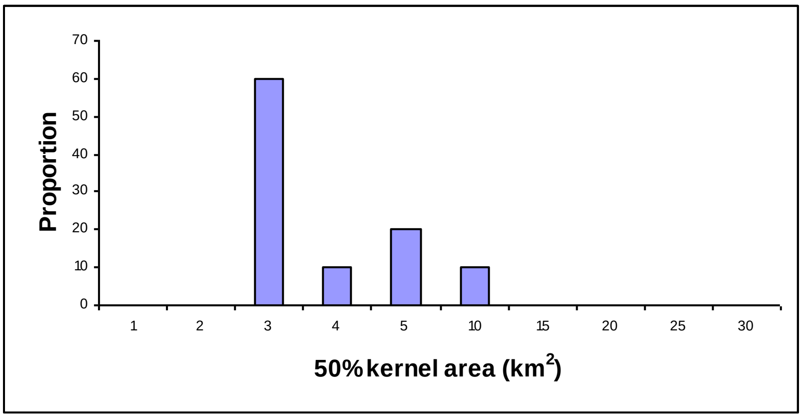


Figure 11 A-D. Map showing the fixed kernel density and 50 and 95% kernel densities of four *C. fulvoguttatus* (tag number 53315 (A), 8116(B), 8076 (C) and 53317(D). The tagging location and all receivers within the array are shown.



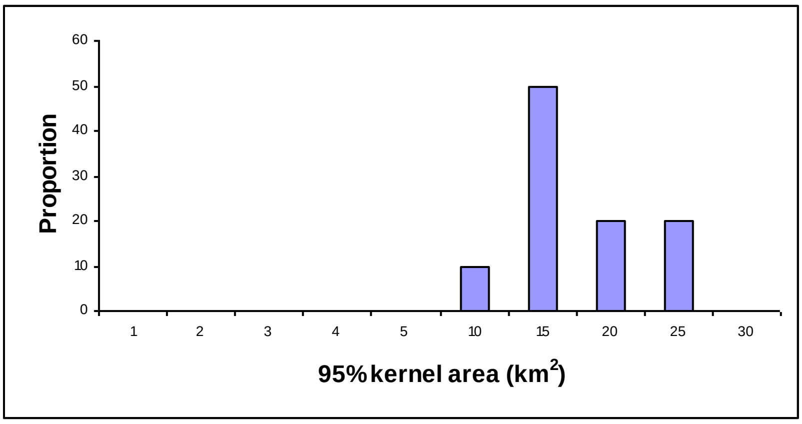


Figure 12. Size frequency distribution of 50% and 95% kernel areas for 40 *C. fulvoguttatus*. For those animals that moved outside of the array, the area was assumed to be greater than 10 km^2.

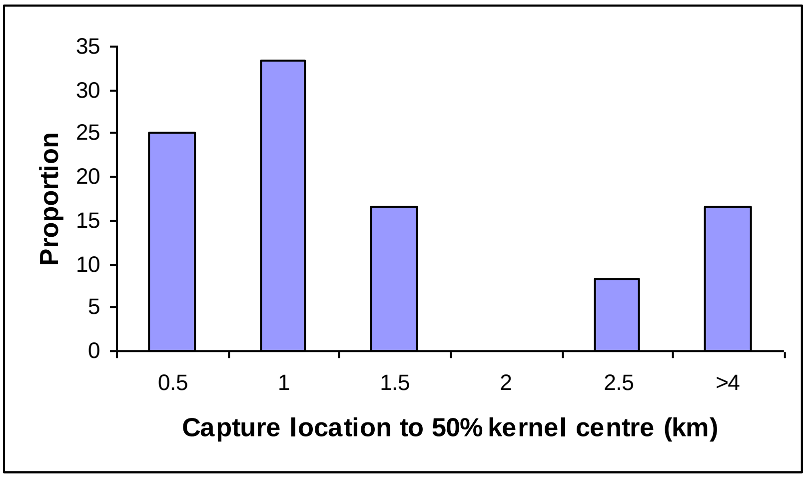


Figure 13. Distance between capture location and activity centre for *C. fulvoguttatus*. For those animals where kernel size was not calculated due to insufficient data, the

50% kernel centre was assumed to be greater than 4 km from the tagging location based on the size of the array and the ability of the array to detect fish.

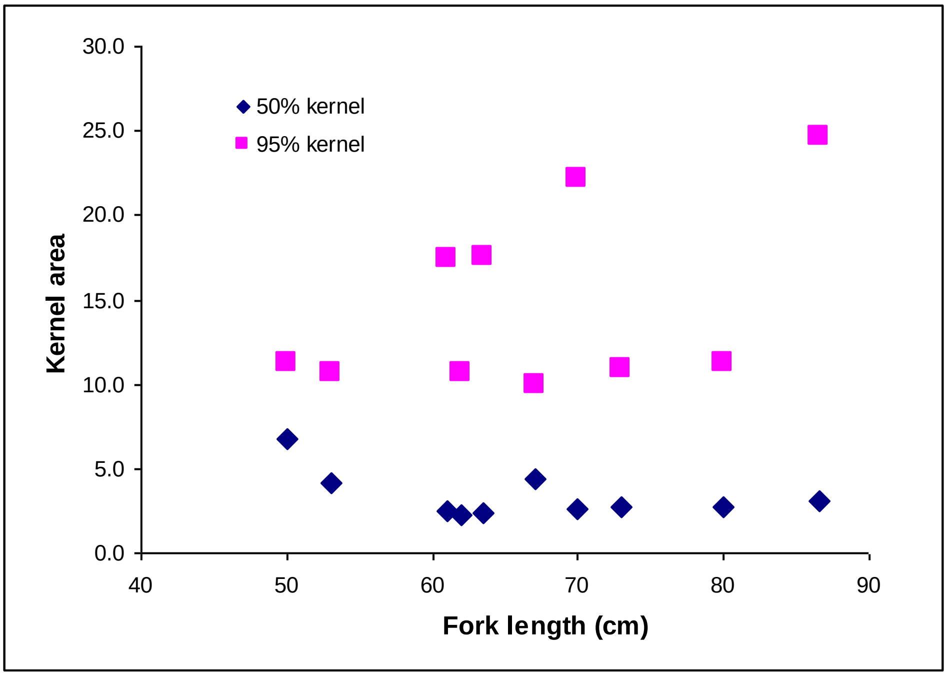


Fig. 14. Plot of the 50 and 95% kernel area (km^2) against *C. fulvoguttatus* size (n = 15)

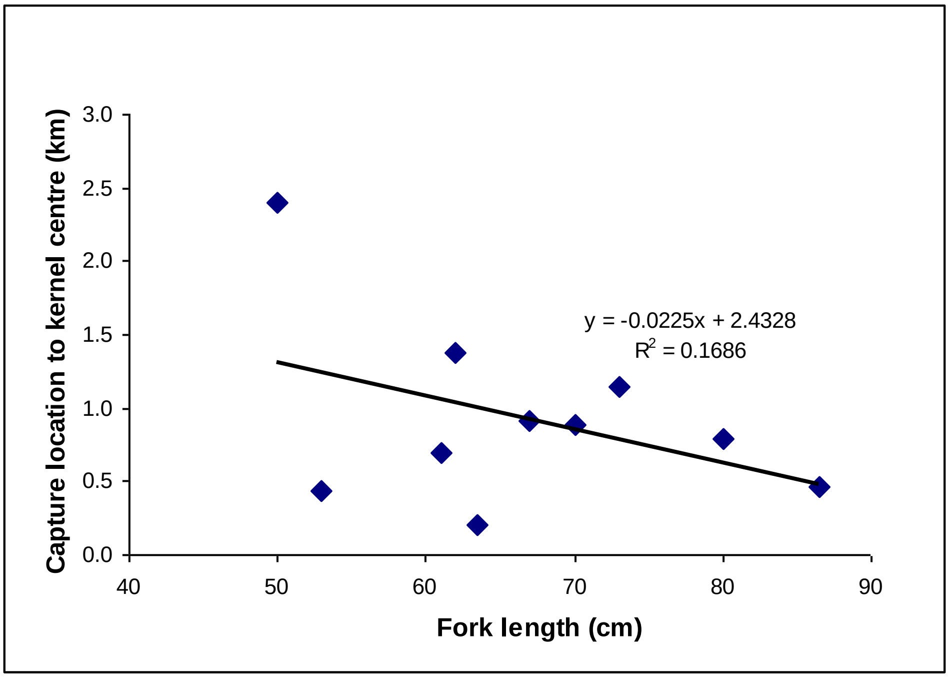


Figure 15. Plot of *C. fulvoguttatus* size against the distance (km) from the tagging location to the centre of the 50% kernel for each individual

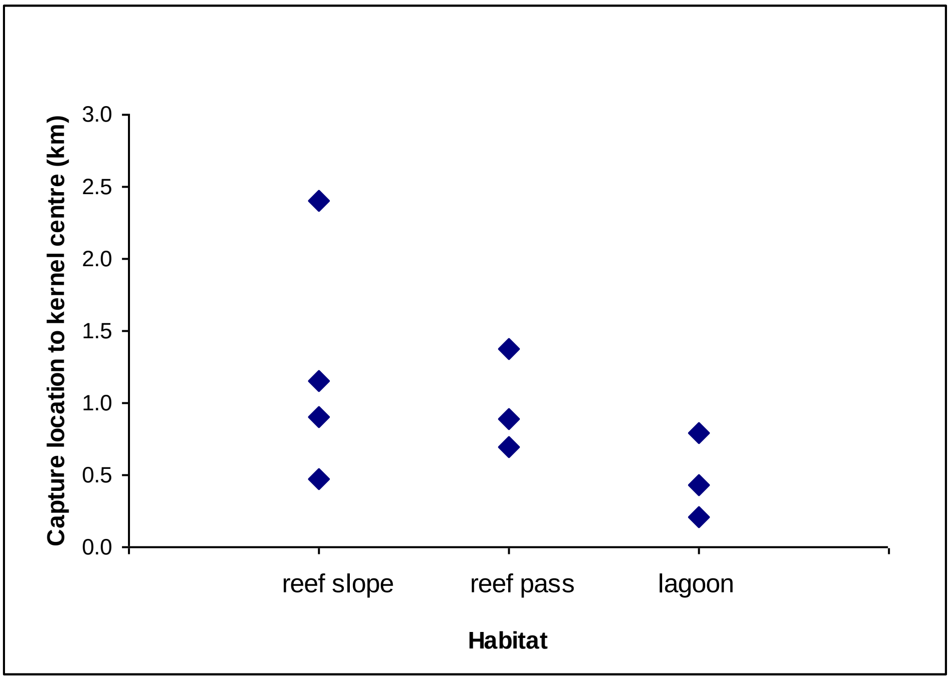


Figure 16. Habitat related variation in movement *C. fulvoguttatus*. Data are for distances between 50% kernel centres and capture locations.

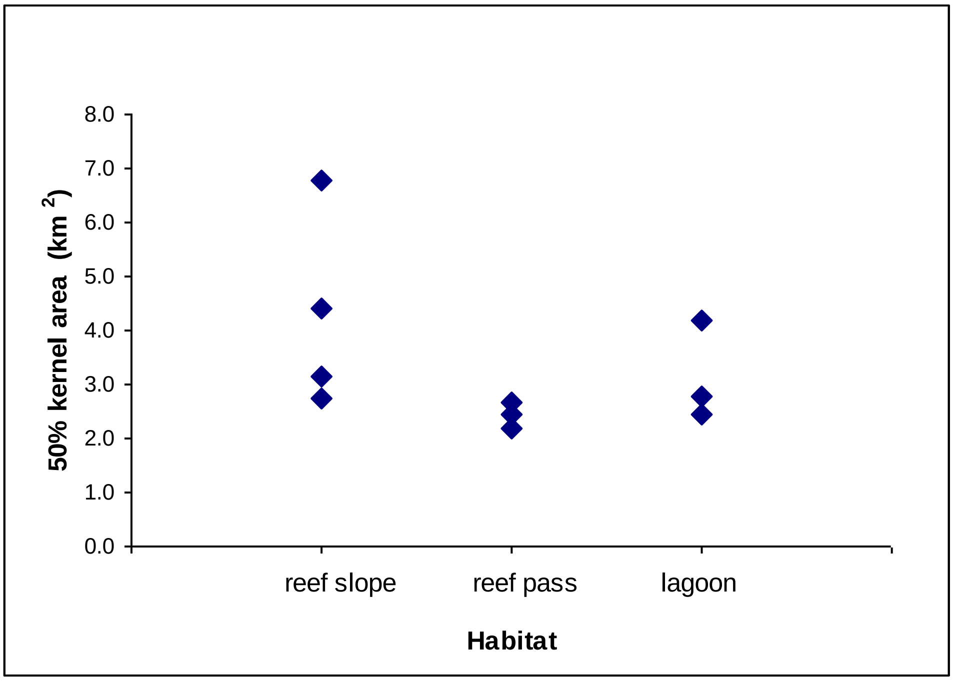


Figure 17. Habitat related variation in kernel area *C. fulvoguttatus*.

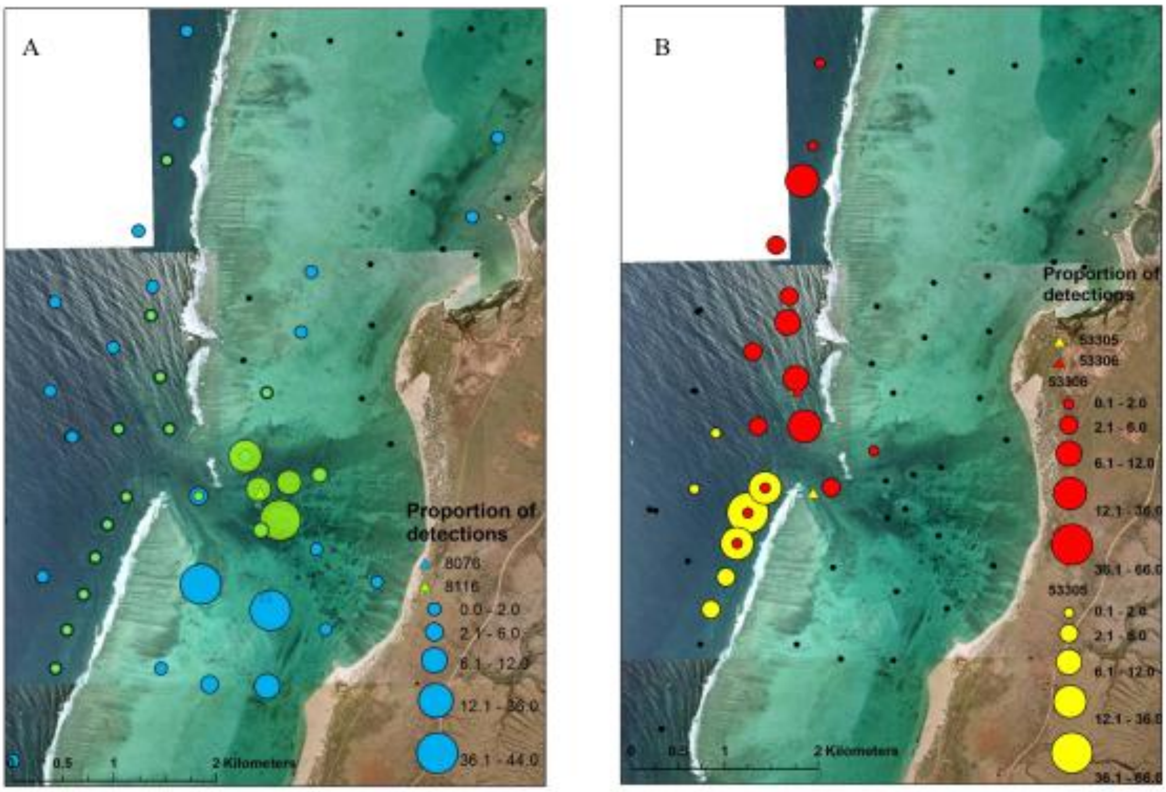


Figure 18. A - Plot of the proportion of total detections for two *C. fulvoguttatus* tagged in the lagoon (8076, 49990 detections over 12 months, 8116,22020 detections over 7 months). B - Plot of the proportion of total detections for two *C. fulvoguttatus* tagged in the reef pass and reef slope (53306, 1000 detections over 7 months; 53305, 800 detections over 7 months. Triangles represent tagging location, circles correspond to the proportion of detections on each receiver. Black circles represent no detections.

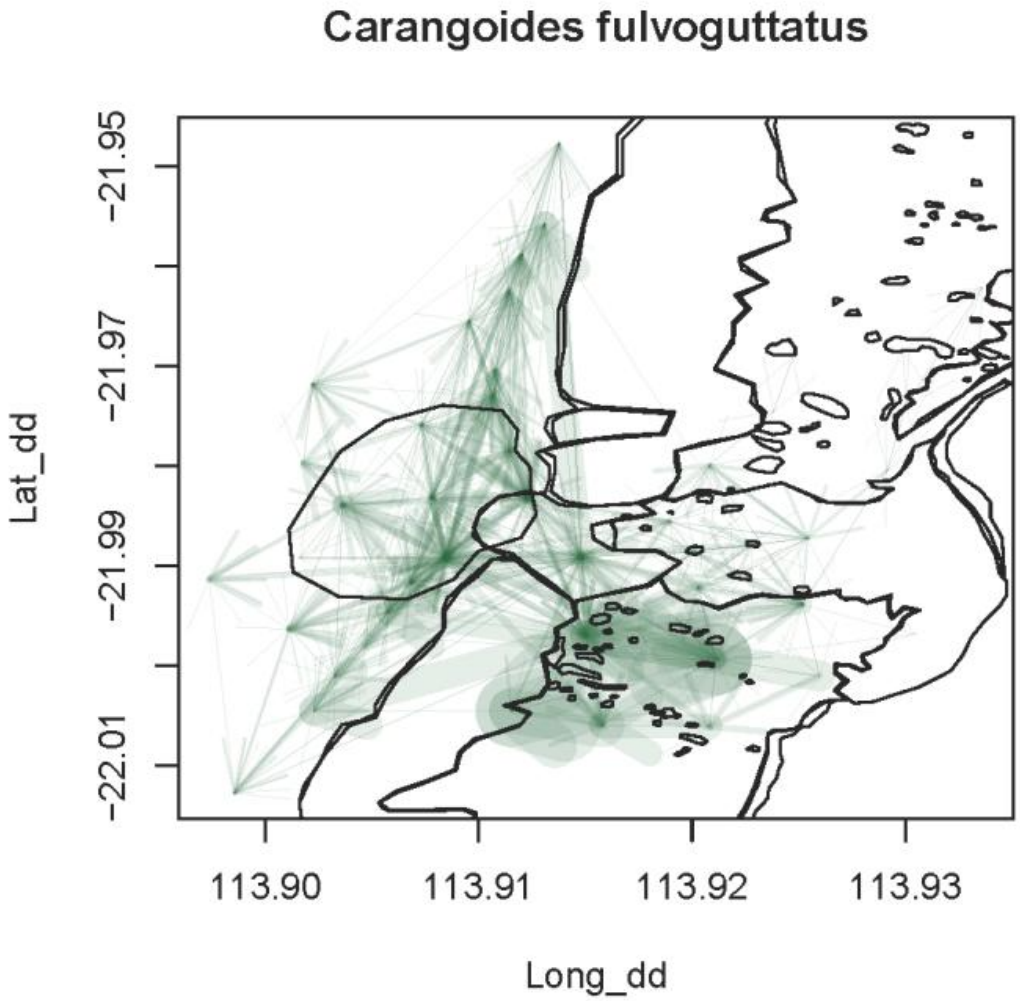


Figure 19. *Carangoides fulvoguttatus* movement pathways for all tagged animals. The thickness of the arrow is proportional to the number of movements from one receiver to another.

Coris aygula

Black Wrasse *Coris aygula* are a medium sized wrasse that are most abundant within the lagoon and reef flat and feed primarily on gastropods and echinoderms. The data from 20 tagged animals clearly show that this species have a restricted movement pattern with the majority of detections occurring very close to the where the animals were tagged (Figs. 20, 21). Modal 50% kernel area was between 2 and 3 km^2, or areas 1.6-2 km in diameter (Fig. 22), and while 95% kernel areas were larger, (5-10km^2) modal size, none were larger than 15km^2 or 3.5 km in diameter. In line with these estimates, the modal distance between capture location and 50% kernel centres were less than 500m (Fig. 23).

There was no significant variation in kernel area (Fig. 24) or distance from capture to activity kernel centre (Fig. 25) for fish ranging in size from 34 – 53 cm FL.

Distance from capture to activity kernel centre was significantly larger for fish tagged in reef flat habitats that for those tagged in the lagoon (Fig. 26, $F_{1,17} = 6.6$, $p=0.0202$). In one case, a fish tagged on the reef flat moved out onto the reef slope (Fig. 20C) while lagoon tagged fish were rarely captured more than 100 m from their activity centres. There was no significant difference in kernel size however for fish tagged in these habitats (Fig. 27).

Behaviour was diurnal with little activity detected at night (Appendix 1). On several occasions individuals shifted their activity centre quite abruptly from one centre of activity to another, non adjacent location. As it happens these movements were from areas inside the sanctuary zone to other areas outside the sanctuary. Another interesting observation was that two individuals, both tagged on the same bommie at the same time, spent the next several weeks at or near the tagging location, then were not detected or rarely detected for a period of over a month. Both reappeared at a location some 2 km to the north within a week of each other for very brief period, then both returned to the bommie where they were tagged and did not move again.

Table 5. Size, tag ID, date and habitat *Coris aygula* were tagged in as well a detection summary and 50 and 95% kernel area and distance from centre of 50% kernel to tag location for animals were sufficient data were available to compute kernel distribution. * denote animals that have died and the tag has fallen out close to a receiver resulting in continuous detection over time.

Species	FL cm	Tag ID	Date tagged	Habitat tagged	Number of receivers	Total detections	Tag date to date last detected	Days detected	Proportion days in array	Area 50% kernel	Area 95% kernel	Distance tag to 50% centre
Coris aygula	50	8096	01-Dec-07	lagoon	6	8196	263	255	97.0	2.39	9.15	0.33
Coris aygula	51	8130	01-Jun-08	reef flat	2	2726	354	320	90.4	2.16	9.2	0.34
Coris aygula	51	8131	01-Jun-08	reef flat	12	1520	207	133	64.3	2.62	11.67	0.9
Coris aygula	46	8132	01-Jun-08	lagoon	8	10030	337	320	95.0	2.38	10.6	0.14
Coris aygula	38	8238	01-Jun-08	reef flat	1	95	255	56	22.0	2.3	9.27	0.38
Coris aygula	38	8240	01-Jun-08	reef flat	2	123	186	60	32.3	2.3	9.47	0.44
Coris aygula	36	53227	22-Oct-08	reef flat	1	2649	92	71	77.2	2.3	9.3	0.06
Coris aygula	35	53228	22-Oct-08	reef flat	2	1008	197	58	29.4	2.19	9.3	0.19
Coris aygula	39	53231	21-Jan-09	lagoon	3	147	123	11	8.9	3.42	11.8	0.07
Coris aygula	38	53256	22-Jan-09	lagoon	1	2523	120	120	100.0	2.2	8.9	0.05
Coris aygula	37	53257	22-Jan-09	lagoon	1	2389	120	119	99.2	2.25	9	0.05
Coris aygula	44	53309	21-Jan-09	lagoon	4	292	121	40	33.1	3.88	11.5	0.4
Coris aygula	40	53312	22-Jan-09	lagoon	2	15193	120	120	100.0	2.28	8.9	0.04
Coris aygula	46	53313	22-Jan-09	lagoon	1	23749	120	120	100.0	2.25	9.02	0.02
Coris aygula	45	53314	22-Jan-09	lagoon	2	17633	120	120	100.0	2.28	8.9	0.02
Coris aygula	45	53319	22-Jan-09	lagoon	1	13065	120	120	100.0	2.28	9	0.02
Coris aygula	49	53320	22-Jan-09	lagoon	1	11771	120	120	100.0	2.28	9	0.02
Coris aygula	47	53321	22-Jan-09	lagoon	2	16142	120	120	100.0	2.26	8.98	0.01
Coris aygula	44	53337	23-Jan-09	reef flat	2	3482	120	120	100.0	2.14	9.33	0.08
Coris aygula	50	8096	01-Dec-07	lagoon	6	8196	263	255	97.0	2.39	9.15	0.33

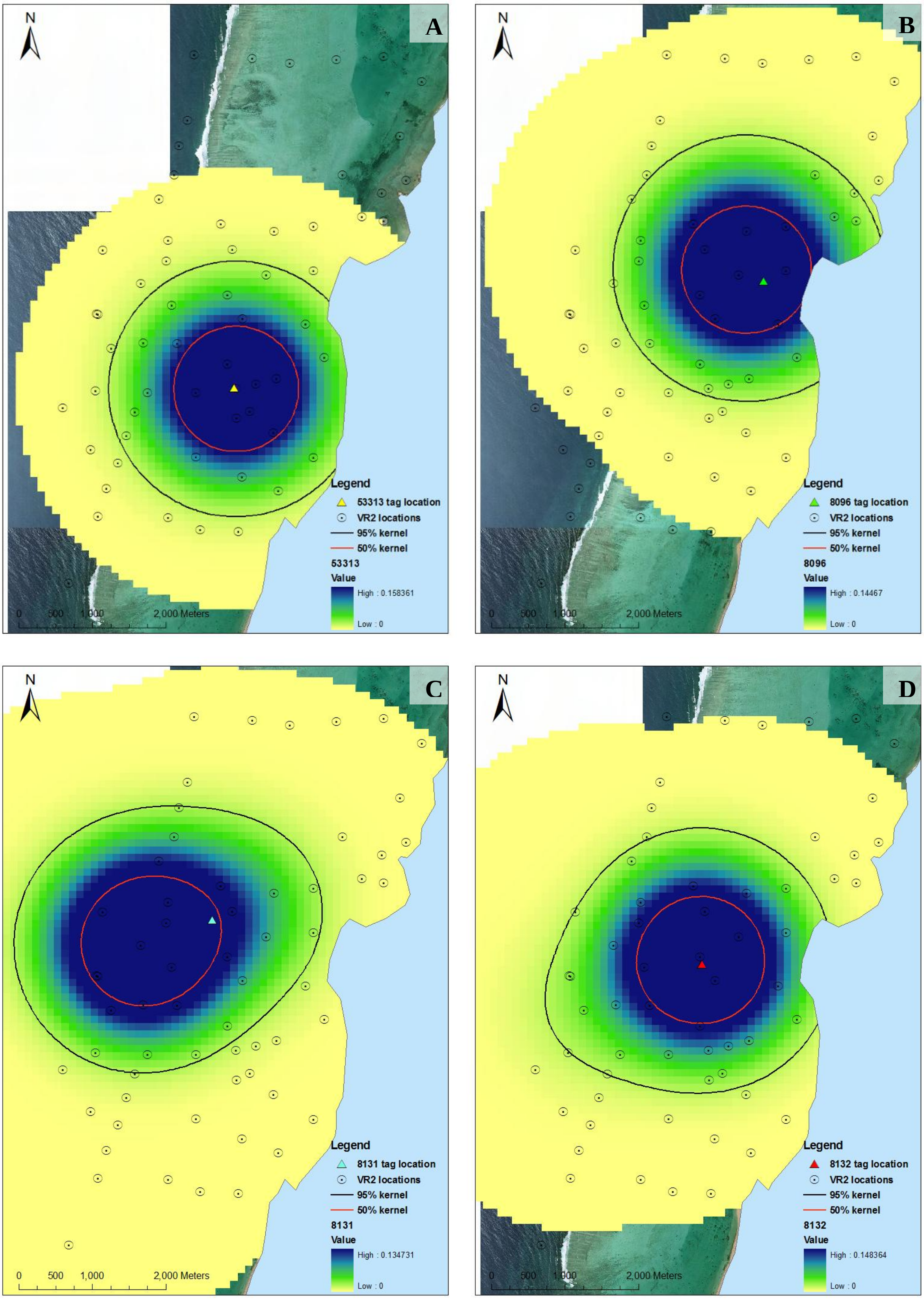


Figure 20 A-D. Map showing the fixed kernel density and 50 and 95% kernel densities of four *C. aygula* (tag number 53313 (A), 8096(B), 8131 (C) and 8132 (D). The tagging location and all receivers within the array are shown.

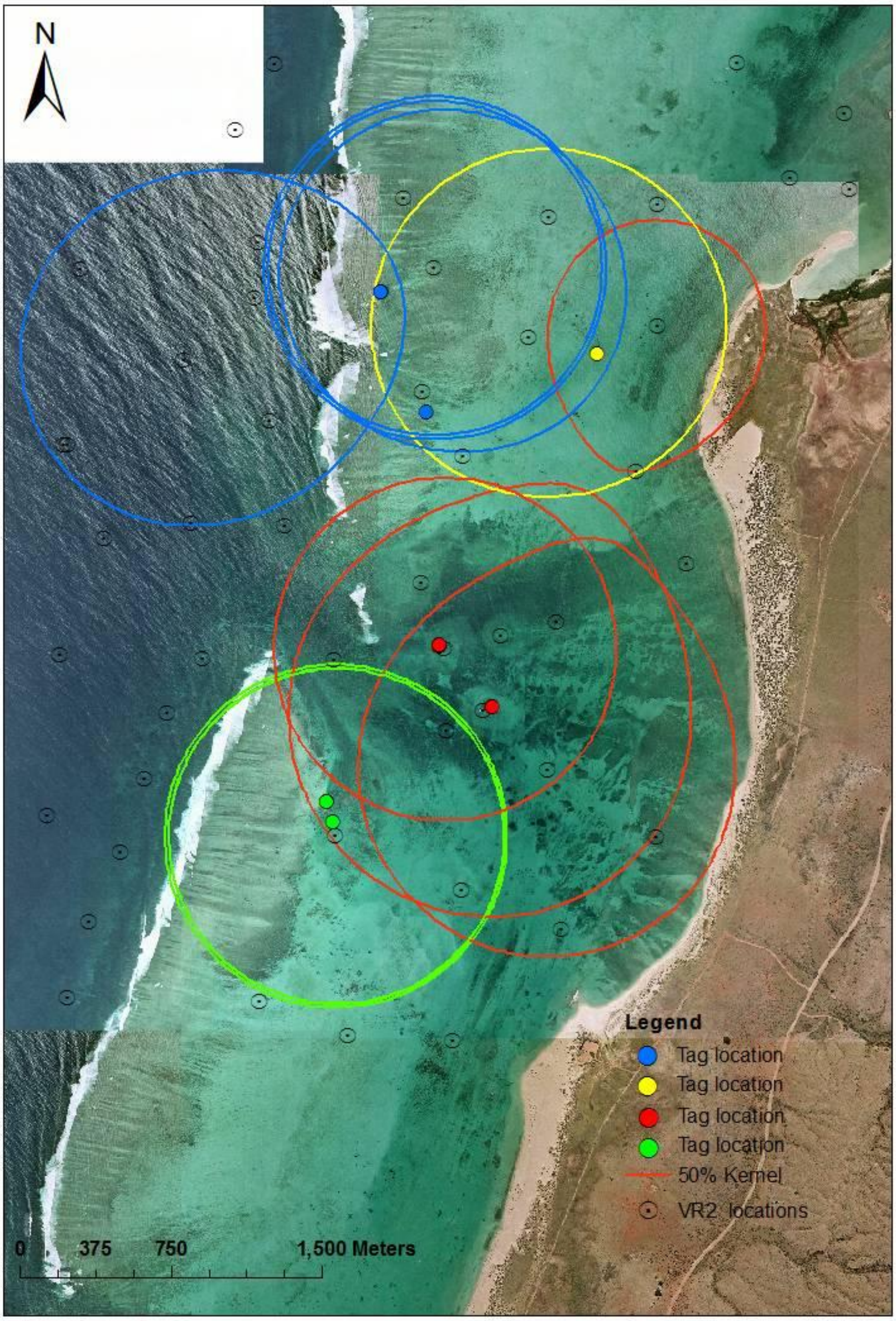
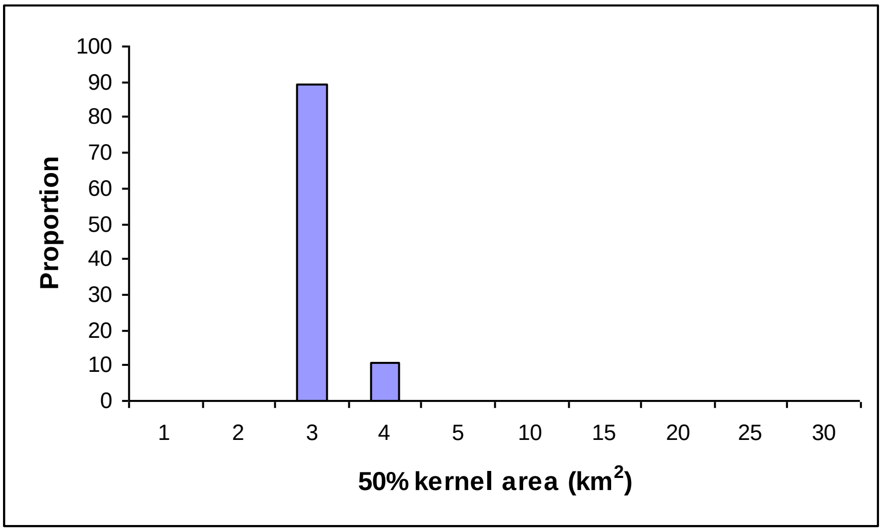


Figure 22. Map showing the tag location of four groups of *C. aygula* tagged within the array and the 50% kernel of individual animal within each group. Colour of 50% kernel matches colour of circles denoting the tag location of each group of fish. Blue = 8130, 9131, 8238, 8240; Yellow = 8096; Red = 53231, 53256, 53257, 53309, 53312, 53313, 53314, 53319, 53320, 53321; Green = 53221, 53227, 53228, 53337.



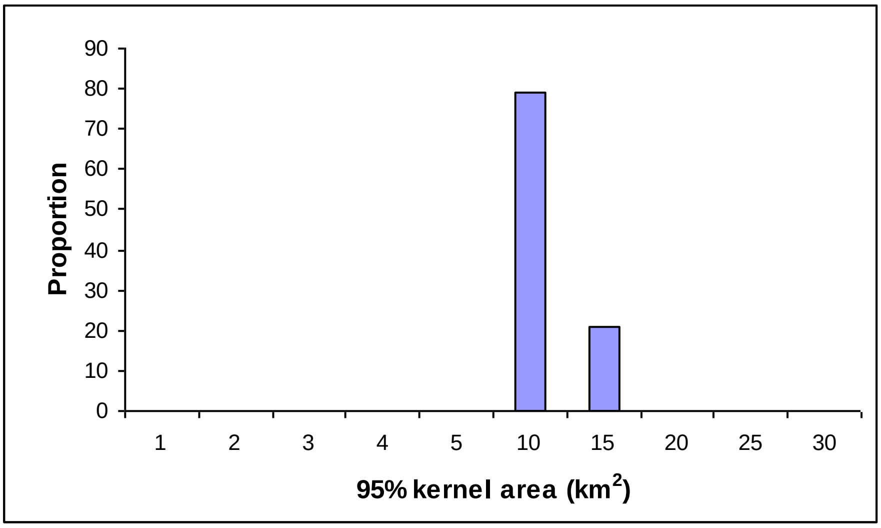


Figure 22. Cumulative proportion of 50% and 95% kernel area for 20 *Coris aygula* .

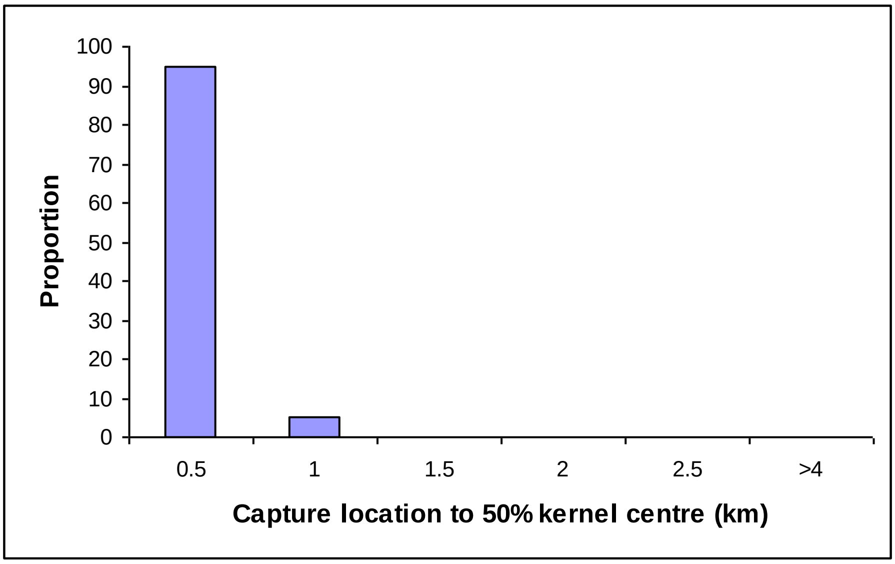


Figure 23. Distance between capture location and activity centre for *Coris aygula*. For those animals where kernel size was not calculated due to insufficient data, the 50% kernel centre was assumed to be greater than 4 km from the tagging location based on the size of the array and the ability of the array to detect fish.

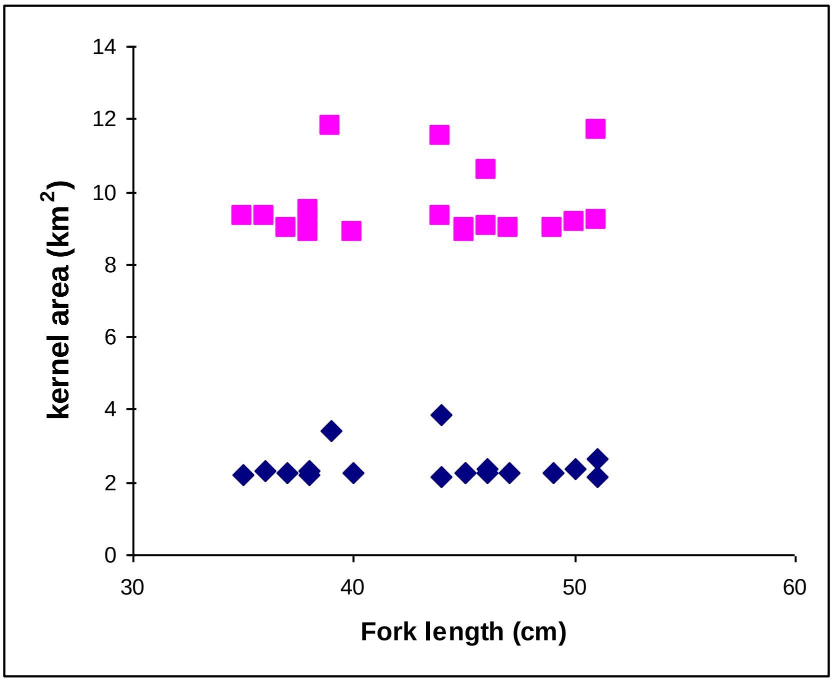


Fig. 24. Plot of the 50 and 95% kernel area (km2) against *Coris aygula* size (n = 19)

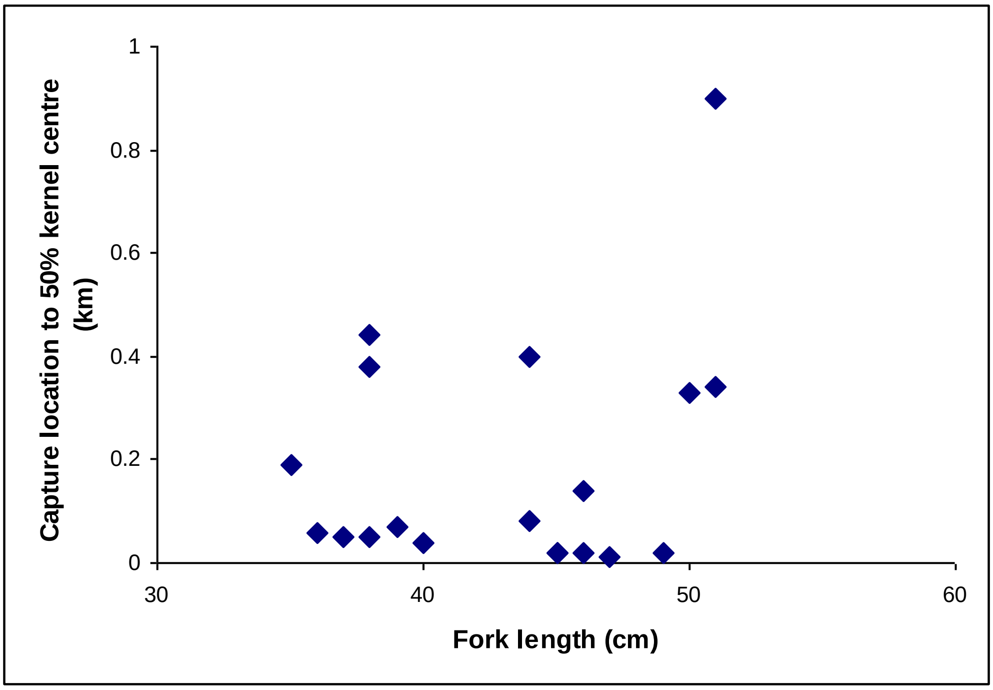


Figure 25. Plot of *Coris aygula* size against the distance (km) from the tagging location to the centre of the 50% kernel for each individual

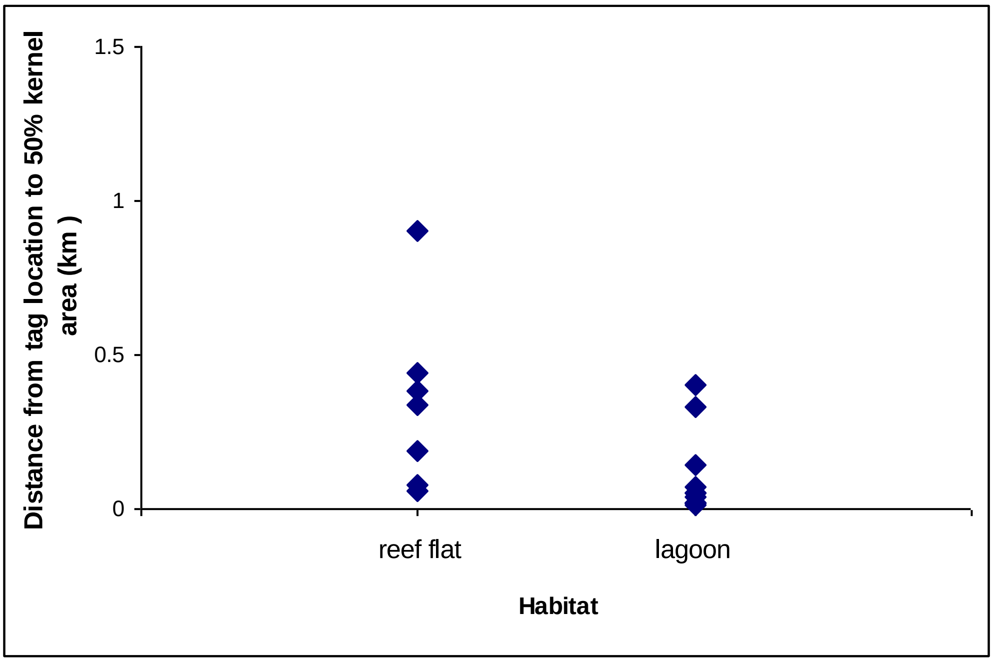


Figure 26. Habitat related variation in movement *Coris aygula* tagged on the reef flat and lagoon bommies. Data are for distances between 50% kernel centres and capture locations.

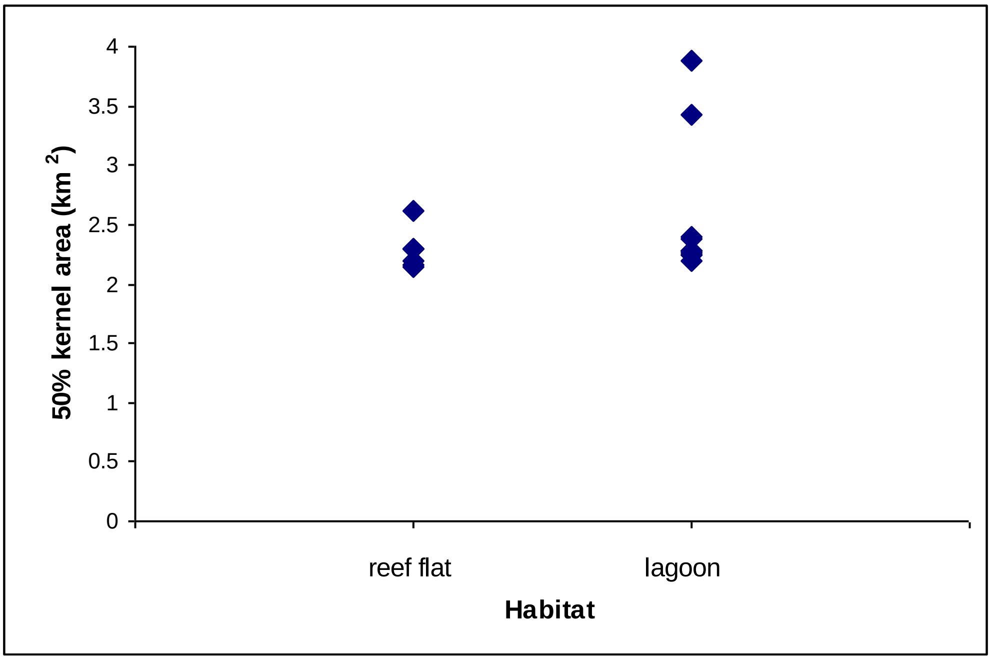


Figure 27. Habitat related variation in kernel area *Coris aygula*

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Table 6. Size, tag ID, date and habitat *Kyphosus sydneyanus* were tagged in as well a detection summary and 50 and 95% kernel area and distance from centre of 50% kernel to tag location for animals were sufficient data were available to compute kernel distribution. * denote animals that have died and the tag has fallen out close to a receiver resulting in continuous detection over time.

Species	FL cm	Tag ID	Date tagged	Habitat tagged	Number of receivers	Total detections	Tag date to date last detected	Days detected	Proportion days in array	Area 50% kernel	Area 95% kernel	Distance tag to 50% centre
Kyphosus sydneyanus	56	8057	16-Oct-08	Lagoon bommies	15	40484	218	214	98.2	2.23	8.48	0.12
Kyphosus sydneyanus	56	8071	16-Oct-08	Lagoon bommies	18	29076	221	216	97.7	2.35	8.70	0.12
Kyphosus sydneyanus	66	8068	16-Oct-08	Lagoon bommies	19	30499	220	214	97.3	2.32	9.09	0.08
Kyphosus sydneyanus	58	8069	16-Oct-08	Lagoon bommies	25	92506	216	212	98.1	2.2	9.17	0.15
Kyphosus sydneyanus	55	8070	16-Oct-08	Lagoon bommies	20	69246	218	213	97.7	2.2	9.15	0.15
Kyphosus sydneyanus*	57	8067	16-Oct-08	Lagoon bommies	1	117478 *	214	205	95.8			
Kyphosus sydneyanus	54	8065	19-Oct-08	Lagoon bommies	23	7875	217	184	84.8	3.45	16.60	0.15
Kyphosus sydneyanus	51	8064	19-Oct-08	Lagoon bommies	21	9969	217	164	75.6	2.61	11.80	0.12
Kyphosus sydneyanus	55	8063	19-Oct-08	Lagoon bommies	21	16877	180	135	75.0	2.47	12.15	0.14
Kyphosus sydneyanus	61	53304	21-Jan-09	Lagoon bommies	7	270	92	10	10.9	2.26	9.81	0.45
Kyphosus sydneyanus	57	53303	21-Jan-09	Lagoon bommies	1	2	1	1	100.0			
Kyphosus sydneyanus	63	53302	21-Jan-09	Lagoon bommies	9	73	6	4	66.7			
Kyphosus sydneyanus	49	53311	21-Jan-09	Lagoon bommies	4	1376	5	5	100.0	2.15	8.30	0.40
Kyphosus sydneyanus	57	53307	21-Jan-09	Lagoon bommies	9	85	12	7	58.3	3.76	14.30	2.76
Kyphosus sydneyanus	57	53308	21-Jan-09	Lagoon bommies	11	484	15	15	100.0	2.72	11.60	0.90
Kyphosus sydneyanus	54	53310	22-Jan-09	Lagoon bommies	10	2740	91	65	71.4	2.28	9.46	0.10
Kyphosus sydneyanus	54	53316	22-Jan-09	Lagoon bommies	4	34	16	6	37.5			
Kyphosus sydneyanus	59	53331	22-Jan-09	Lagoon bommies	10	572	10	10	100.0			
Kyphosus sydneyanus	57	53315	22-Jan-09	Lagoon bommies	7	63	3	3	100.0			

Kyphosus sydneyanus

Silver Drummer *Kyphosus sydneyanus* are a large, schooling, herbivorous species that feed predominantly on brown algae. This species was only tagged around large *Porites* bommies within the lagoon where large schools were observed (Fig. 28). The data clearly show that these animals have a restricted movement pattern (Fig. 29) with the majority of detections occurring within the array and fewer detection on receivers on the edges of the array (Fig. 30). Modal 50% kernel area was between 2 and 3 km^2, or areas 1.6-2 km in diameter (Fig. 31), and while 95% kernel areas were larger, (5-10km^2 modal size), none were larger than 20 km^2 or 5 km diameter. In line with these estimates, the modal distance between capture location and 50% kernel centres were less than 500m (Fig. 32).

The size of *K. sydneyanus* activity centres did not vary significantly with fish size (49-66 cm FL), nor did the distance from capture location to activity kernel centre (Figs. 33, 34).

Kyphosus sydneyanus were tagged in groups of 3-5 individuals on five different days/locations (Figs. 28, 30). Behaviour was clearly diurnal with the majority of individuals resident around lagoon bommies at night (Appendix 1). Each group of fish displayed a unique behaviour with individuals from each group being detected with other animals within that group but not individuals from other groups. Two of the groups (13 of 19 tagged animals) have remained within the array for most of the time since tagging, whereas the other three have spent long periods of time outside the array. There was no significant variation in activity kernel area among the groups (Fig. 35) however this species is clearly displaying quite complicated behaviour. The movement of all individuals from receiver to receiver (Fig. 36) clearly demonstrates that this species occurs primarily in the reef pass and reef slope with very few movements towards the shoreline. Other locations also appeared to be of particular importance for *K. sydneyanus*, in particular the area around receiver 6595 on the reef slope south of South Passage (Appendix 1). The characteristics of this location and why it appears to be attractive or important is less obvious than for sites of transit or shelter such as reef passages and lagoon bommies.

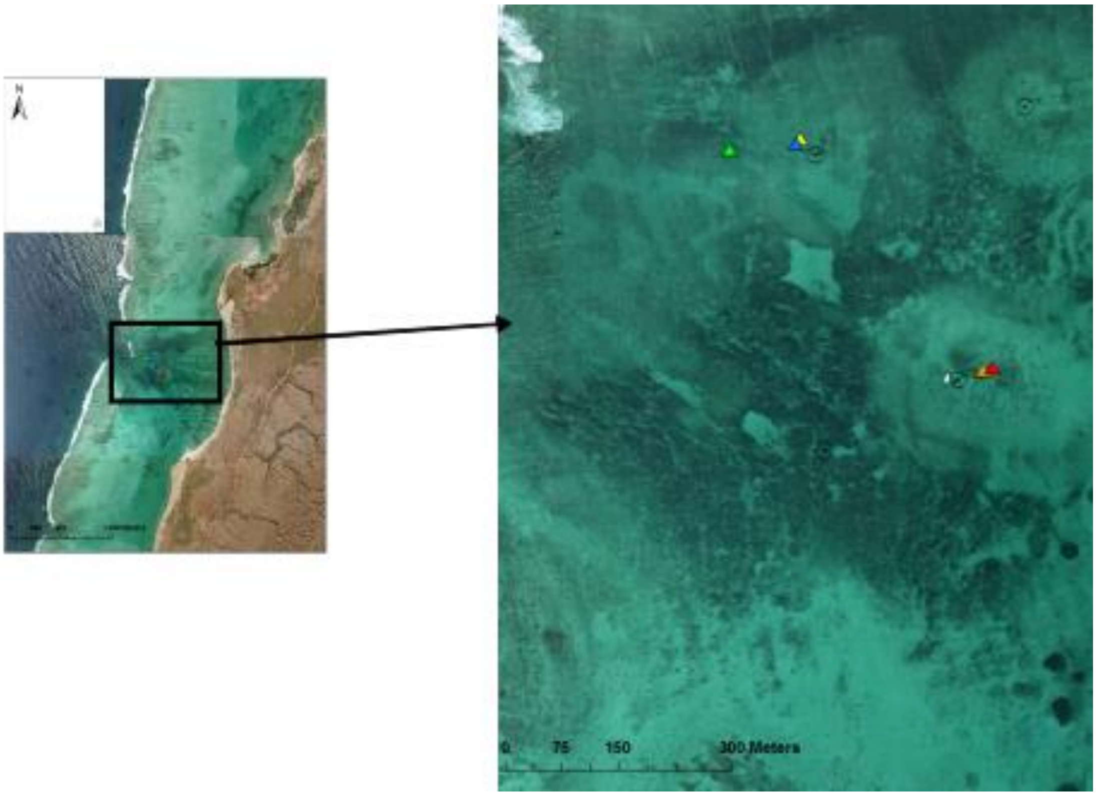

Figure 28. Map showing the locations were *K. sydneyanus* were tagged. Different coloured rectangles denoted distinct tagging events and locations. Rectangle colours correspond to bubble plot colours in Figure 30A - F

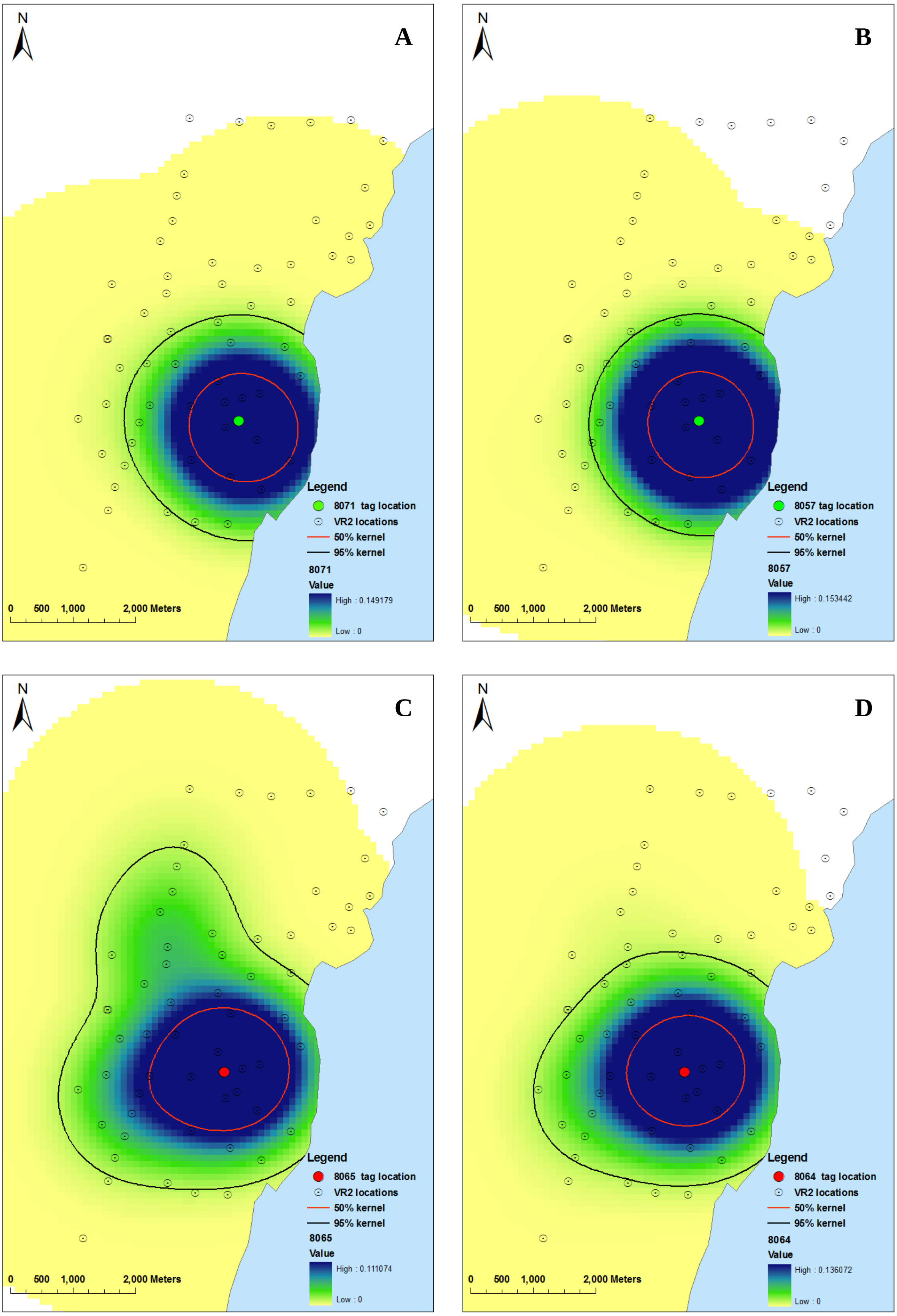

Figure 29 A-D. Map showing the fixed kernel density and 50 and 95% kernel densities of four *Kyphosis sydneyanus* (tag number 8071 (A), 8067 (B), 8065 (C) and 8064(D). The tagging location and all receivers within the array are shown.

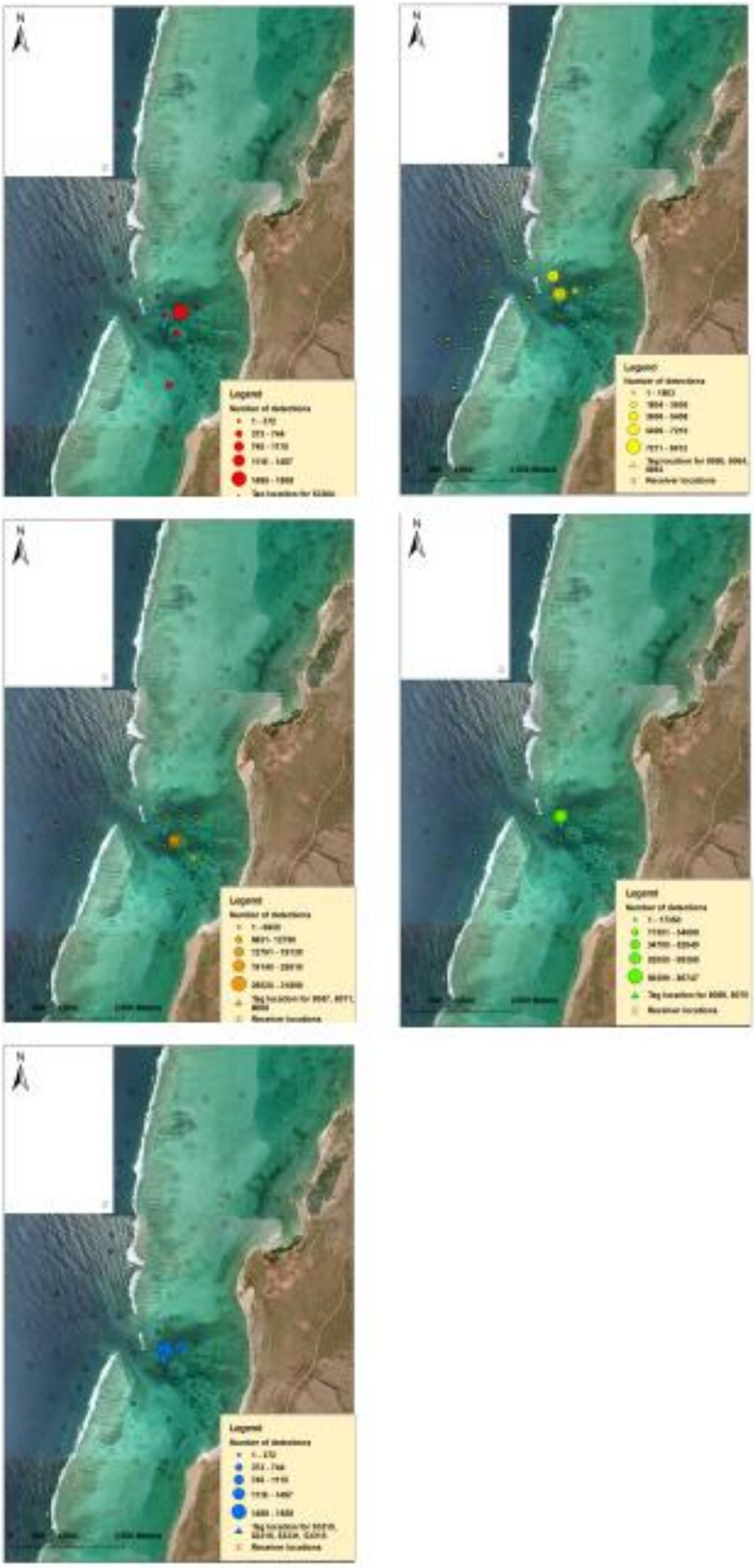

Figure 30 A – E. Bubble plot of number of times each group of *K. sydneyanus* was detected on each receiver for five groups of fish tagged in different locations and on different days. Triangles show tagging location for each group of fish with the colours corresponding to triangles in Figure 28. Scale of bubble plots varies for each figure.

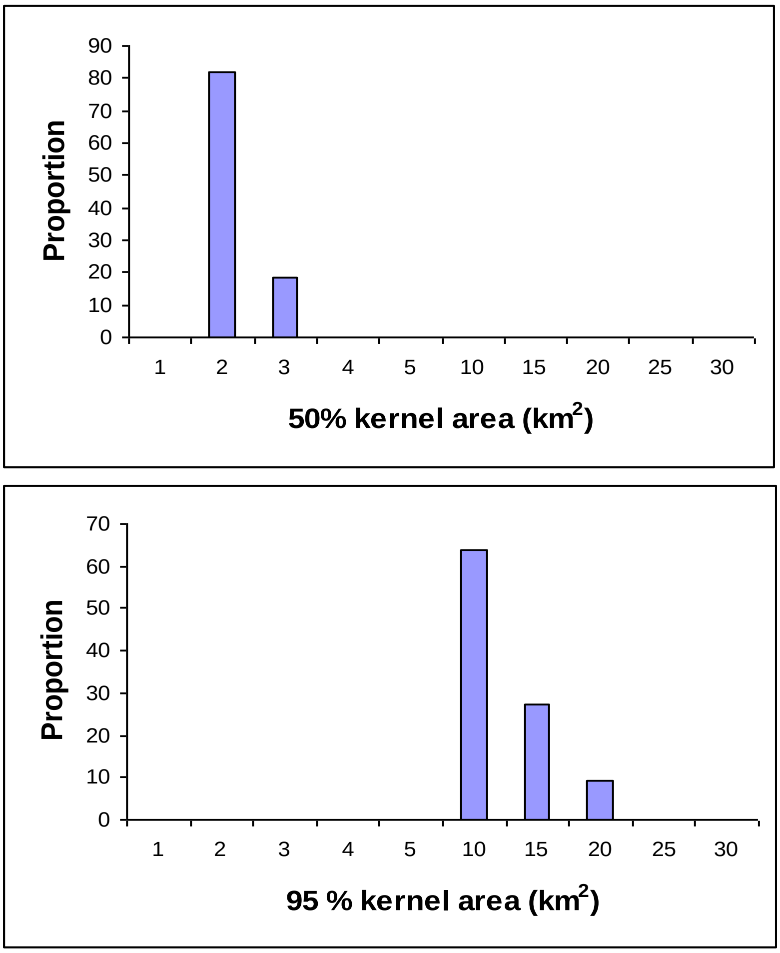

Figure 31. Cumulative proportion of 50% and 95% kernel area for 11 *Kyphosus sydneyanus*.

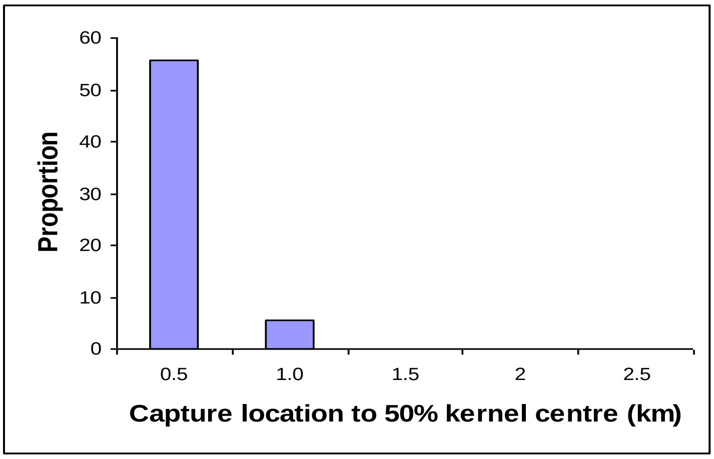

Figure 32. Distance between capture location and activity centre. *Kyphosus sydneyanus*. For those animals where kernel size was not calculated due to insufficient data, the 50% kernel centre was assumed to be greater than 4 km from the tagging location based on the size of the array and the ability of the array to detect fish.

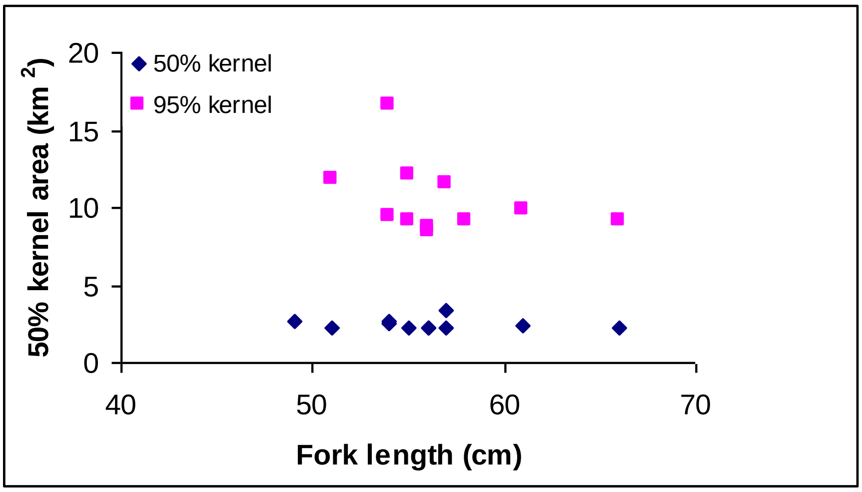

Figure 33. Plot of the 50 and 95% kernel area (km2) against *Kyphosus sydneyanus* size (n = 11)

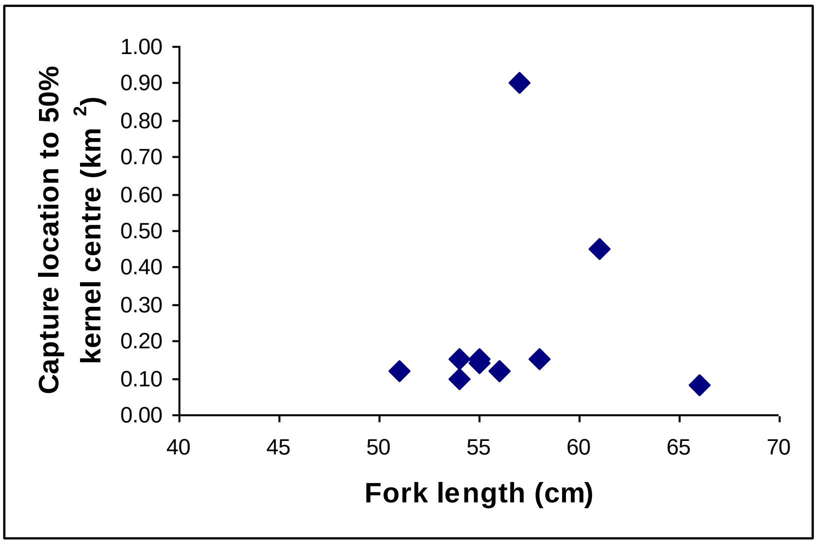

Figure 34. Plot of *Kyphosus sydneyanus* size against the distance (km) from the tagging location to the centre of the 50% kernel for each individual

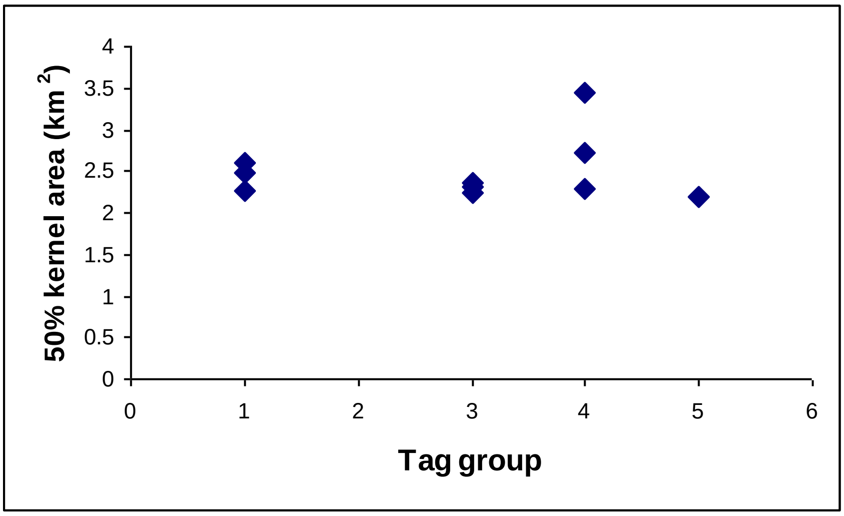

Figure 35. Tagging group variation in kernel area *Kyphosus sydneyanus*

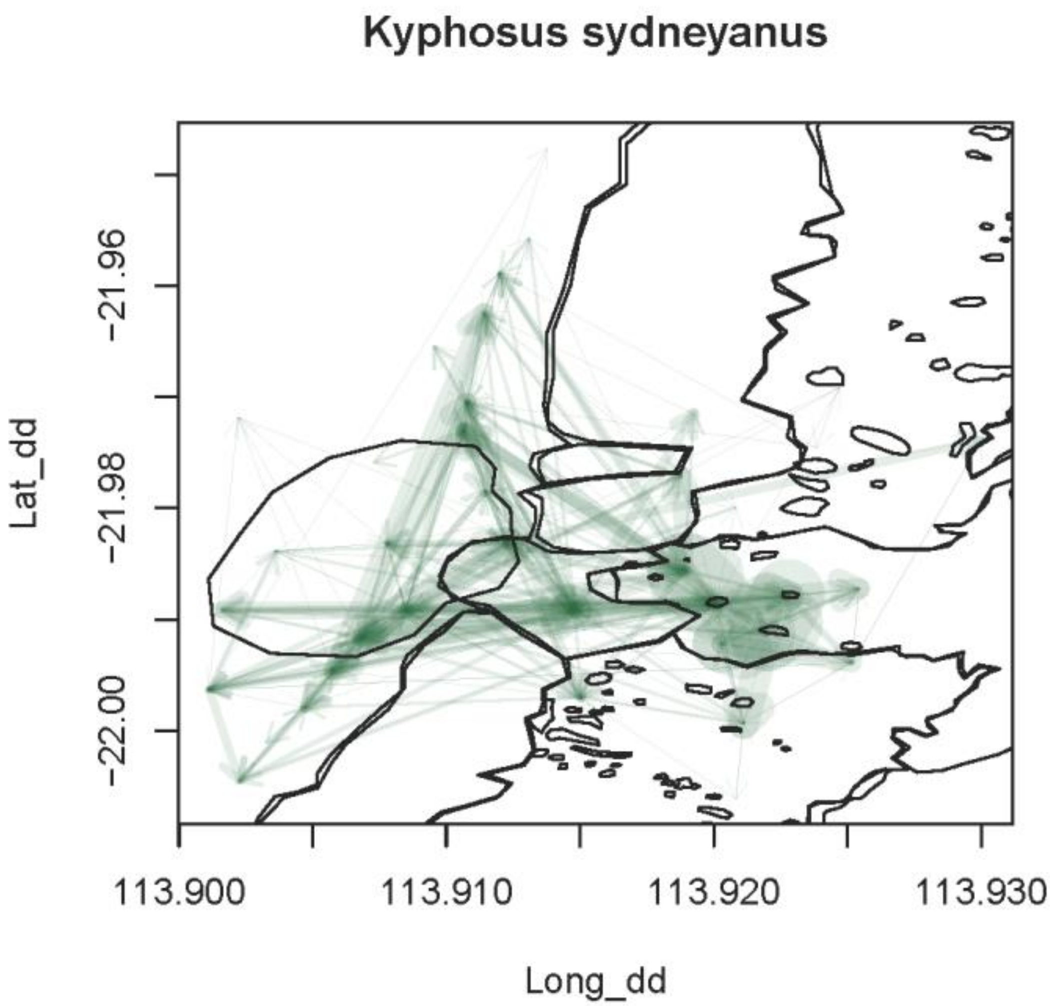

Figure 36. *Kyphosus sydneyanus* movement pathways for all tagged animals. The thickness of the arrow is proportional to the number of movements from one receiver to another.

Serranidae

There were 51041 detections from the 30 tagged serranids (Table 7). Seven fish were not detected after release, and another 7 were detected for less than a week after release. The remaining 16 fish were detected for up to 2 years (719 days) after they were released providing good long-term movement information (Figure 37).

Table 7 - Release and detection details of tagged Serranids released at Mangrove Bay, Ningaloo.

Spp	FL	Release	Last Detect	Count	Receivers	Days detected	Liberty	Detect rate (%)
Epinephelus multinotatus								
8203	70.5	3/06/2008		0	0	0	0	0
8161	77	27/05/2008	12/05/2010	14032	9	666	716	93.02
8085	57	28/05/2008	28/05/2008	2	1	1	1	100
8089	47.5	28/05/2008	30/05/2008	6	1	3	3	100
8092	64.5	26/05/2008	10/01/2010	358	8	21	595	3.53
8118	35	21/10/2008	14/05/2010	11710	8	556	571	97.37
8060	52.5	21/10/2008		0	0	0	0	0
Epinephelus rivulatus								
8029	28.5	14/12/2007	12/06/2008	115	1	19	182	10.44
8042	34	1/12/2007	2/01/2008	1	1	1	33	3.03
53261	34	23/01/2009	24/02/2009	1689	2	33	33	100
53265	37	24/01/2009	25/06/2009	2	1	2	153	1.31
53267	28	24/01/2009	31/10/2009	88	1	47	281	16.73
Epinephelus tauvina								
8091	56	25/05/2008		0	0	0	0	0
8109	53	30/05/2008	15/06/2008	334	2	11	17	64.71
8066	48	19/10/2008	8/05/2010	1255	1	250	567	44.09
8115	49	17/10/2008	4/12/2008	107	5	6	49	12.24
8184	51			0	0	0	0	0
8110	52	31/05/2008	8/06/2008	94	13	8	9	88.89
8210	48	28/05/2008	22/07/2008	215	4	19	56	33.93
Plectropomus leopardus								
8209	72	28/05/2008	15/02/2009	10429	9	261	264	98.86
Plectropomus maculates								
8083	60	29/05/2008		0	0	0	0	0
Variola louti								
8040	36	28/05/2008	3/06/2008	12	3	5	7	71.43
8079	48	30/05/2008	1/02/2010	11	2	10	613	1.63
8081	61	30/05/2008	21/02/2009	310	3	154	268	57.46
8082	38	29/05/2008	14/11/2009	1717	3	377	535	70.47
8084	50	30/05/2008	3/06/2008	6	2	3	5	60
8086	48	29/05/2008	1/02/2010	235	2	132	614	21.5
8087	53	29/05/2008		0	0	0	0	0
8124	49	2/06/2008	21/01/2010	8166	1	144	599	24.04
8117	57	18/10/2008	24/10/2008	147	6	7	7	100

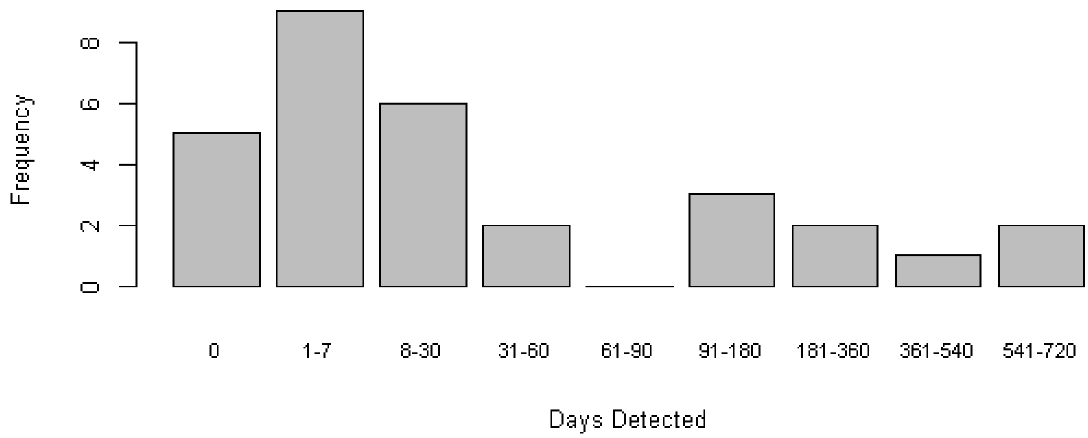

Figure 37. Length of tracking period for Serranid fishes. Number of fish detected up to and including the number of days.

For those fish that were detected within the array (n=23), over half were detected on one or two receivers, with all species, with the exception of *P.* leopardus, detected on only one receiver. For those that were detected on three or more receivers, *V. louti* and *E. tauvina* were detected on less than 7 receivers, with *E. multinotatus* and *P. leopardus* were detected on eight and nine receivers respectively. The one notable outlier was an *E. tauvina* which was detected on 13 receivers (Figure 38).

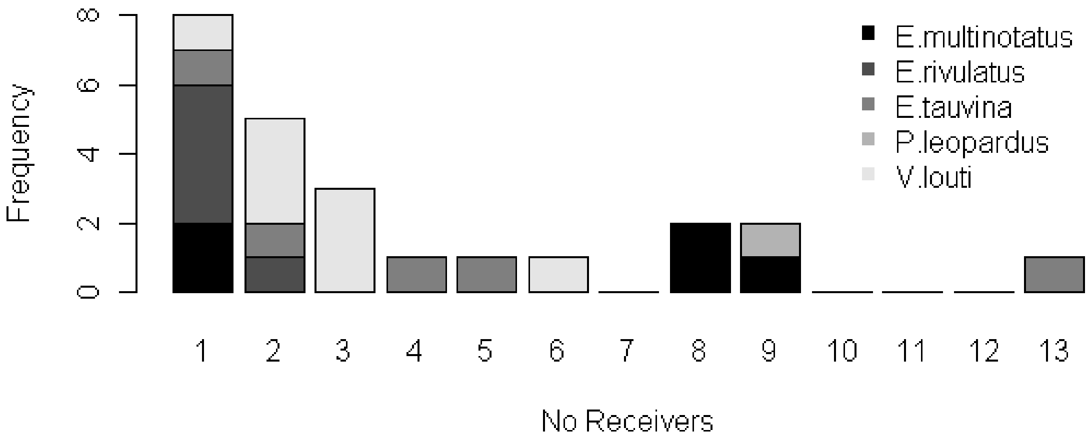

Figure 38. Frequency of detected fish by the number of receivers on which they were detected

Epinephelus rivulatus

The four *E. rivulatus* detected within the array were all detected within the lagoonal part of the array (Figure 4). Three of the four fish were detected on only one receiver, with the dominant receiver in all four fish being the one closest to the point of capture and release. Only one *E. rivulatus* (53261) was detected on two receivers, with the receiver further form the point of capture only having 2 detections at the end of its detection period.

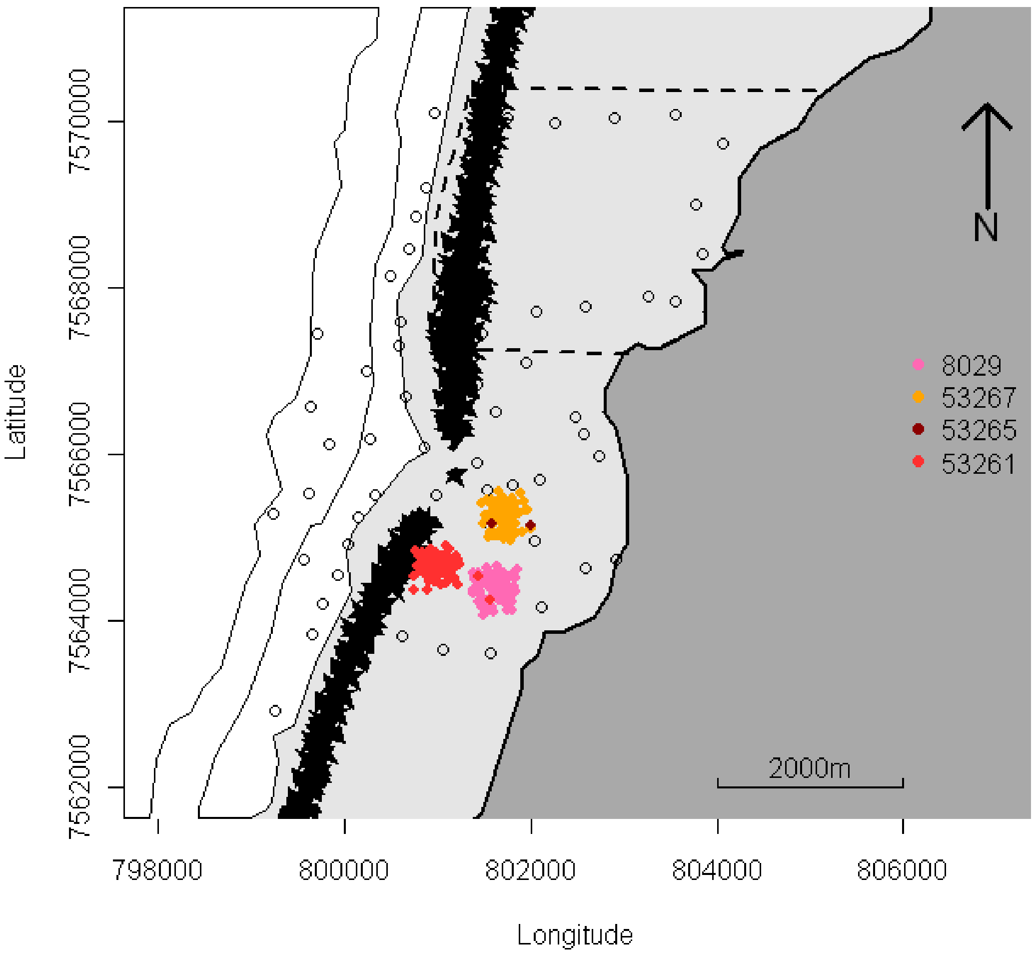

Figure 39. Capture / release location (black circle) and a diagrammatic representation (randomised distance from the receiver for illustrative purposes only) of location of detections for the four *E. rivulatus.* Fish. Other symbols as per Figure 37.

The time at liberty for *E. rivulatus* was variable ranging from one to nine months (Table 1). Despite this, the number of detections for each fish was low, resulting in an intermittent detection profile throughout the tracking period. Two *E. rivulatus*, 53265 and 53267, had a significant period of time from capture to first detection (151 and 128 days respectively). The notable exception to this was *E. rivulatus* (53261), which was detected on every day for the 33 days it was at liberty.

Epinephelus multinotatus

Of the seven *E. multinotatus* that were tagged, two were not detected, and a further two were only detected on one receiver less than 10 times for no more than three days (Table 7). The remaining three *E. multinotatus* that had over 350 detections with two detected over 14000 and 11700 times for 716 and 571 respectively, providing robust home range estimates. The home range estimates for both fish were quite similar being 0.19 and 0.23 km^2 for the core area (50% kernel) and 1.22 and 1.40 km^2 for the 95% kernel area respectively despite their considerable size difference of 77 and 35 cm FL (Fig. 40). Both remained exclusively on the south side of the channel opening moving around the reef slope and associated offshore areas. The smaller *E. multinotatus* (8118) had a core movement area which was split over both deep and shallow water (Fig. 40). The larger *E. multinotatus* (8161), while being detected on the reef slope, had a smaller core area focused in deeper water (Fig. 40).

The third *E. multinotatus* (8092) showed a very interesting detection and movement pattern. During an initial 10 day period in late May 2008 it made a number of movements to and from the reef slope and lagoon. This is reflected in its home range, which spans both reef slope and lagoon, with core areas in both habitats. On each occasion, movements didn't cross the channel opening, with movements to and from the southern reef slope and southern lagoon presumably over the reef flat. Almost a year to the day that it was last detected, were a series of single detections on an offshore receiver, with more detections six months later in January 2010. These detections were at a receiver adjacent to the point of capture and release.

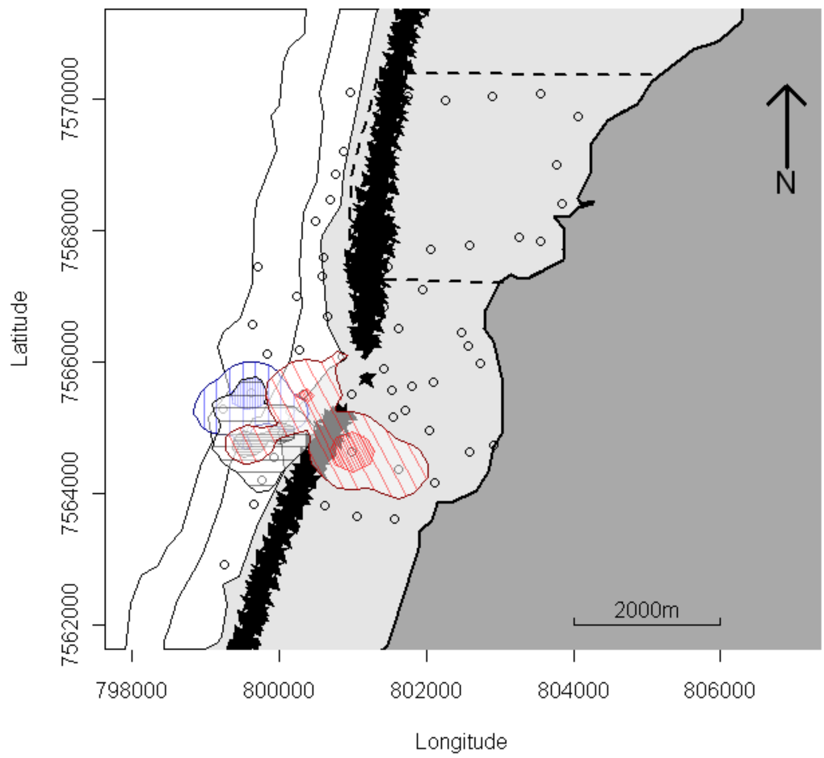

Figure 40. Core area (50% kernel; heavy shading) and home ranges (95% kernel; light shading) for three *E. multinotatus*, fish 8092 (diagonal), fish 8161 (vertical) and fish 8118 (horizontal). Other symbols as per Fig. 37.

Epinephelus tauvina

Five of the seven tagged *E. tauvina* were detected from 94 to 1255 times, with times at liberty over 18 months (Table 7). This species was detected in a diverse range of habitats encompassing the reef slope, offshore reefs and channel opening.

One highly mobile individual was detected on 13 receivers over a nine-day period, traversing the extremes receivers on the reef slope a number of times before detections ceased. This was quite an uncharacteristic movement patterns for this species and other members of the family tracked, and is more characteristic of a more mobile species that may utilise the reef slope. The short retention time is similar to that found for a species which may have been acoustically tagged through voluntary gastric insertion (Winger et al 2002, How unpublished data), where transmitters are retained for around 1-2 weeks. Therefore, the more vagile movement pattern and tracking period similar to that of a gastricly ingested transmitter suggests that this movement may relate to that of a predator, rather the *E.tauvina*. As such it has been removed from all subsequent analysis.

There was little movement exhibited by the remaining four *E. tauvina*. Two individuals were detected on one or two receivers only, with one of these detected over 1255 times for 567 days on one receiver. The other was detected over 300 times on two receivers either side of it capture location (Fig. 41).

Kernel estimates were possible for two individuals which were detected on 4 and 5 receivers and these yielded similar core area estimates (50% kernel) of 0.38 and 0.20 km^2 and home ranges (95% kernel estimates) of 1.80 and 1.42 km^2 respectively (Figure 41). However, the habitats occupied by these two fish differed, with one fish detected predominantly on two offshore receivers in around 30m depth, with several detections on the reef slope. In contrast, the other fish was detected around the mouth of the channel opening, and a few surrounding receivers. There were a few detections on the reef slope, on a receiver directly outside the channel opening with no movement up either side of the channel (Fig. 41).

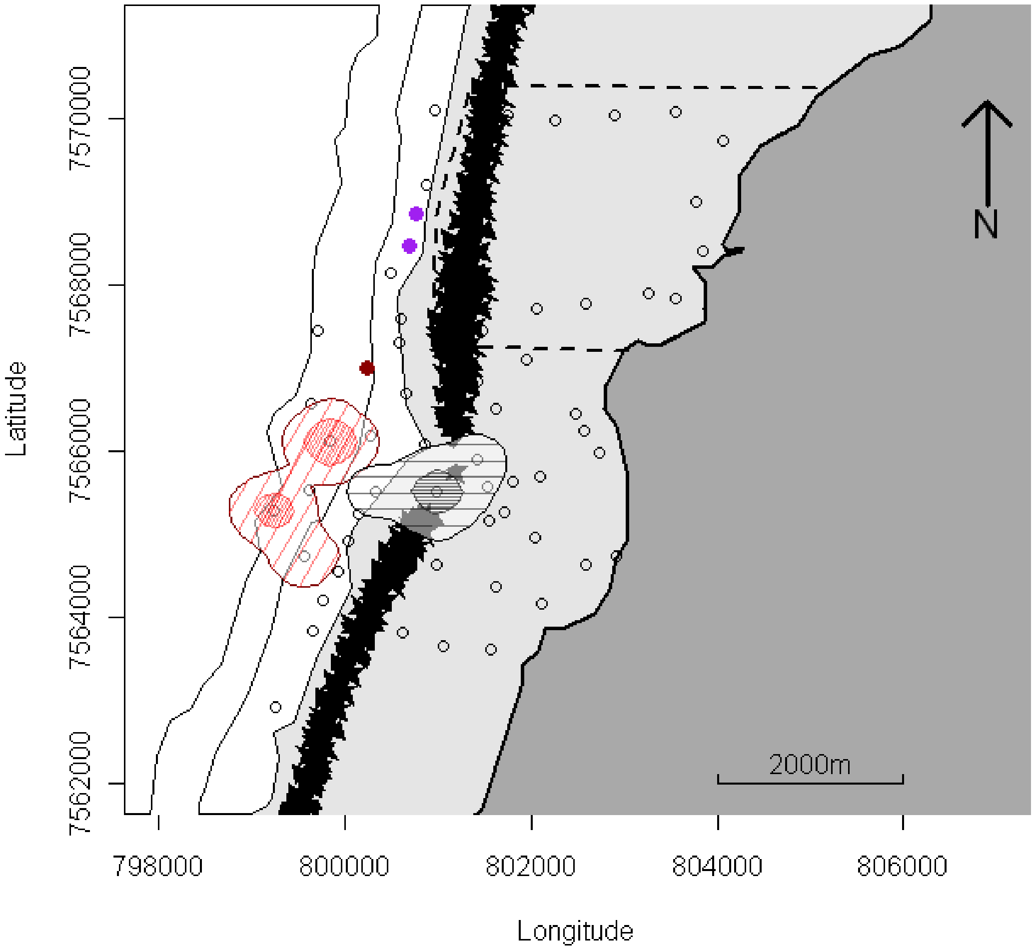

Figure 41. Core area (50% kernel; heavy shading) and home ranges (95% kernel; light shading) for two *E. tauvina*, detected on multiple receivers. Filled symbols for fish that were detected on less than 3 receivers. Other symbols as per Fig. 37.

Plectropomus leopardus

Only one *P. leopardus* was tagged but was detected every day (except 3) for the 264 days it was at liberty yielding a total of 10429 detections (Table 7). Detections were concentrated on the reef slope and around the mouth of the reef channel with two major receivers within the 50% kernel, a shallow water and a deeper offshore receiver (Fig. 42). There was no obvious shift within this region through time with the area being utilised

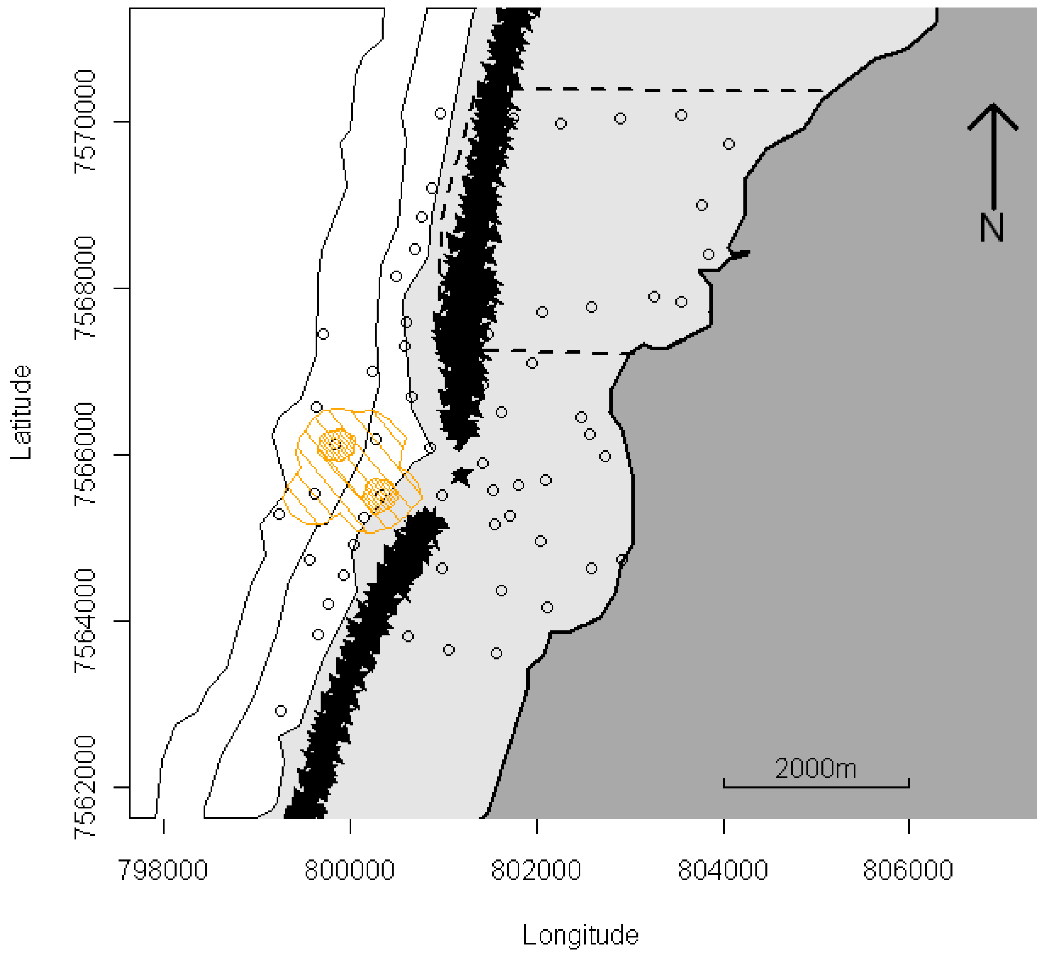

Figure 42. Core area (50% kernel; heavy shading) and home range (95% kernel; light shading) of tagged *P.leopardus*. Other symbols as per Fig. 37.

Variola louti

Several *V. louti* were detected on less than three receivers, with one individual being detected more than 8000 times for almost 600 days on a single receiver (Table 7). This was the only Serranid of the six species tracked that was detected on either side of the reef channel (Figure 8). However, these detections were adjacent to their capture locations with no individual detected traversing the reef slope across the channel (Figure 43). One fish was detected several times at the mouth of the reef slope, but wasn't detected on the other side reef channel.

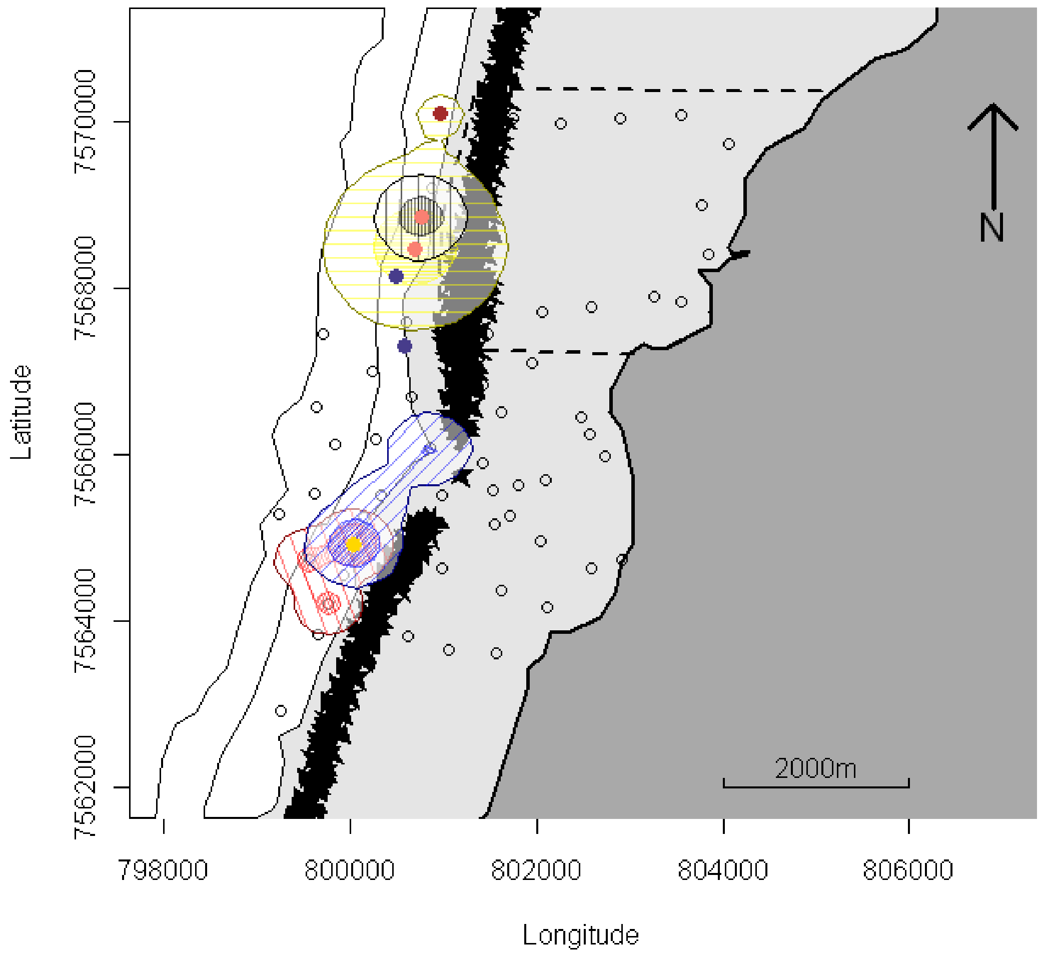

Figure 43. Core area (50% kernel; heavy shading) and home ranges (95% kernel; light shading) for four *V. louti*, detected on multiple receivers. Filled symbols for fish that were detected on less than 3 receivers. Other symbols as per Fig. 37.

Species comparison

The location of serranid detections for all species shows the clear habitat preference of this family. The vast majority of detections were on the reef slope and adjacent offshore areas. There was some utilisation of the lagoonal habitat, predominantly by *E. rivulatus*, and areas within the reef channel (Fig. 44). However, it is notable that there were no detections that spanned either side of the reef channel (Fig. 44). There was also similarity in the home range estimates and core areas for all species that were detected on more than two receivers (Figure 45). There was no significant difference in either core area ($p>0.1$) or home range area ($p>0.1$) between species.

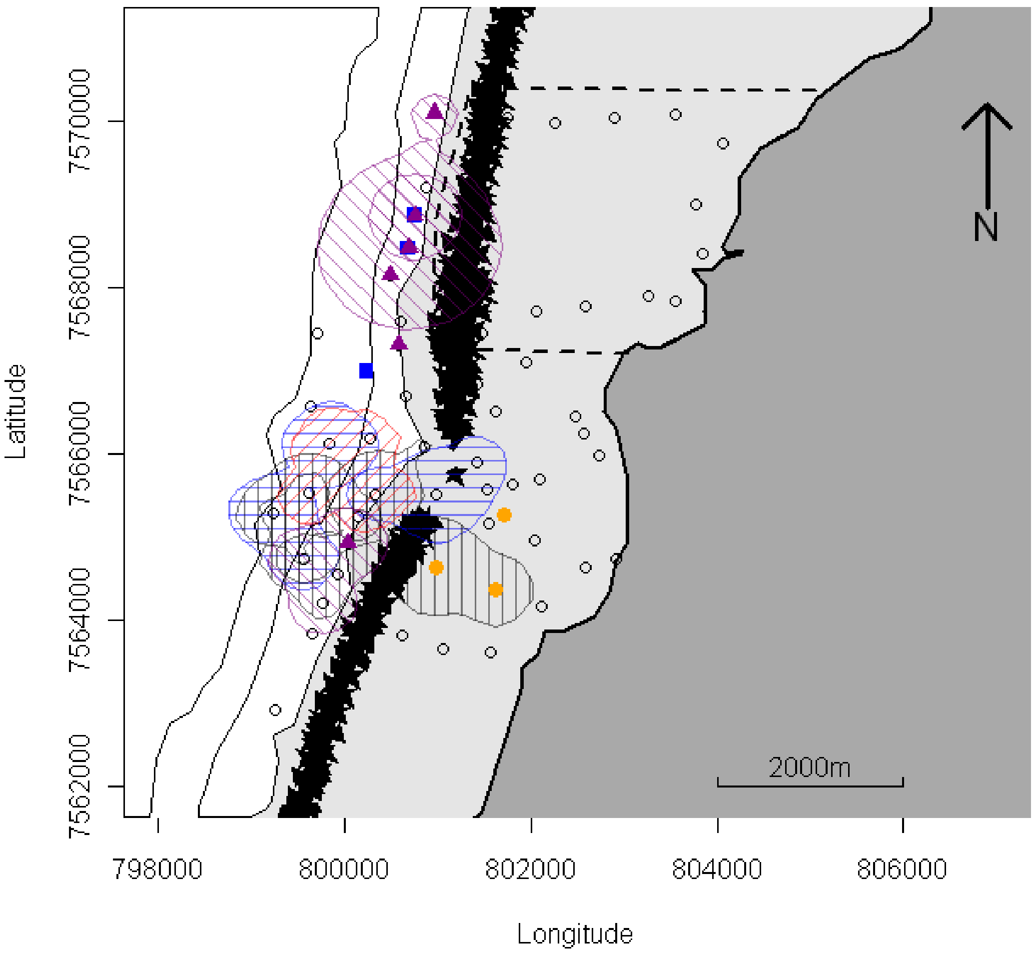

Figure 44. Home ranges (95% kernel; light shading) of all Serranids (*E. tauvina* – horizontal; *E. multinotatus* – vertical; *V. louti* – (backward diagonals) and *P. leopardus* (forward diagonals) detected on multiple receivers. Filled symbols: (*E. rivulatus* – circles; *E. tauvia* – square; *V. louti* – triangle) for fish that were detected on less than 3 receivers. Other symbols as per Fig. 37.

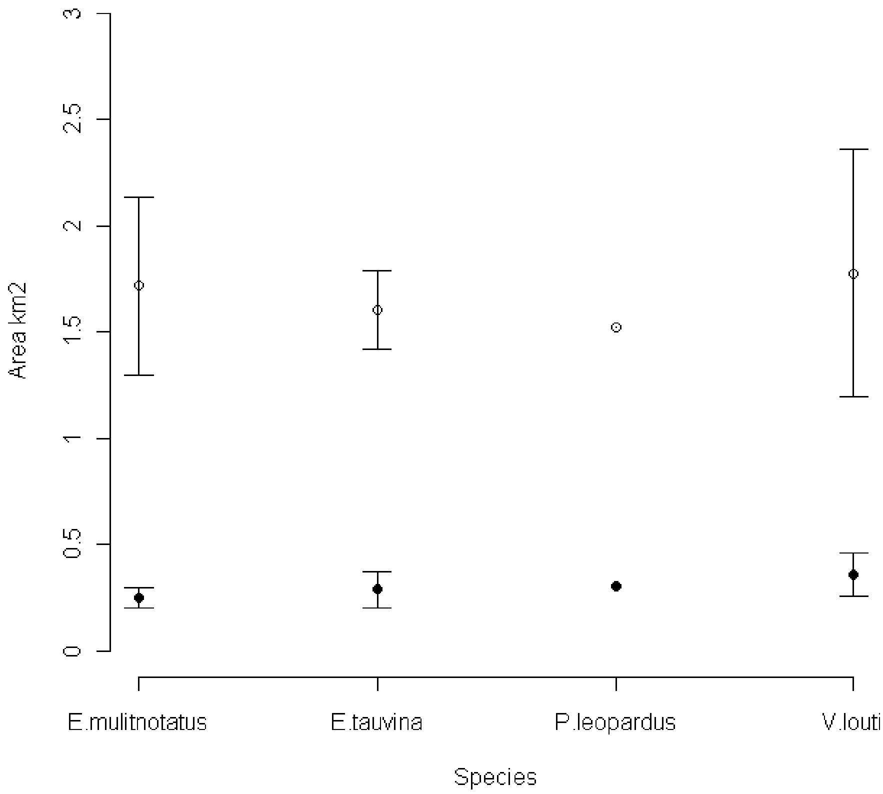

Figure 45. Serranid home ranges. Mean home range (open circle) and mean core areas (filled circle) ± SE by species.

3.4. Discussion

Lethrinus nebulosus

Most spangled emperor *Lethrinus nebulosus* were found to have surprisingly small activity ranges, with diameters of 2.5 to 3.5 km for 95% activity kernels. This is an even more restricted range than suggested for the majority of *L. nebulosus* by Moran et al (1993) who were restricted to 6 nm accuracy of standard fishery reporting. That study, which was a conventional mark-recapture study based mainly at Ningaloo, reported approximately 60% of all recaptured fish were returned from the same 6 nm statistical area in which they were tagged. The proportion of fish which we found to remain near the point of capture was 68%, remarkably similar to that reported by Moran et al. (1993). Because the majority of individuals appear to use areas of reef that are small in relation to the size of most sanctuary areas in the Ningaloo Marine Park, it seems likely that the reserves are of an adequate size to protect substantial proportions of the population. That said there are important caveats that must be placed on this conclusion.

Our data span 12 months to two years, for each individual. The conclusion of adequacy is dependent on individuals retaining their resident behaviour for large proportions of their life span. Since these are long lived fish (Moran et al 1993) surviving up to at least 30 yrs, and we have no proof that behaviour does not change, each individual may be protected for relatively short periods of time, with the potential for adequacy to be reduced. In fact we should remember that approximately on third of spangled emperor did not remain in the vicinity of the areas where they were tagged and that many fish, while originally resident, subsequently undertook movements of at least 5-10 km outside the tracking array. Adequacy and the degree of protection afforded at a population level will be sensitive to variation in this behaviour and to the proportion of the population that displays non-resident behaviour.

Other aspects of the behaviour of *L. nebulosus* at Ningaloo may influence the adequacy of the current zoning system in the marine park. There was significant variation among habitats in both kernel size and the distance between capture location and kernel centre. Shoreline and reef slope habitats have the highest values for kernel areas and for distance to kernel centre. Movement analysis in particular suggests that there are high levels of movement between shoreline areas. With the activities of fish apparently focused on these shoreline (spangled emperor) and reef slope (serranids) habitats they may be particularly exposed to the effects of fishing. While the recent re-zoning of the marine park has achieved a much higher level of protection for reef slope habitats, there remain significant areas of shoreline habitat within sanctuary zones reserved for fishing as Special Purpose (Shore Based Activities) Zones (Table 8). Such zones may present a disproportionate threat to the adequacy of zones due to the importance of shoreline habitats for *L. nebulosus* at Ningaloo, not only because of the behaviour of the species but also because approximately 40% of the shoreline within sanctuary zones is actually open to shore based angling.

Table 8. Length of shoreline (km) in the Ningaloo Marine Park protected by sanctuary zones and available for fishing as recreational zone or special purpose shore-based activities zone (spsbaz).

shoreline region	Recreation zone	Sanctuary zone	spsbaz
Turtles	6.35	4.313	
Gnaraloo	9.17	3.45	
Farquahar	6.17	4.75	
Pelican	16.7	14.1	
Pelican	17.1	7.9	9.02
Maud	14.4	4.06	3.3
Maud	7.7	3.6	
Cloates	15.6	16.4	20.9
Cloates	13.4	9.5	
Winderabandi	7.1		16.8
Yardie	7.2	6.8	6.14
Mandu	3.93	10.9	
Milyering	7.88	0.4	
Mangrove	9.55	4.67	
Jurabbi	12.5		4.6
Lighthouse			4.9
Navy	3.95	4.4	
Bundegi		2.5	
Total	158.7	97.743	65.66

Spawning aggregations are another important behaviour that may affect the success of sanctuary zones. Tracking of *L. nebulosus* at Mangrove Bay suggests seasonal spawning activity with a potential semi-lunar periodicity occurs somewhere outside the tracking array between October and December. Anecdotal reports from local fishers suggest locations of aggregations (likely spawning aggregations given the timing of observations) are adjacent to the Tantabiddi passage, adjacent the passage at the north end of the main Tantabiddi reef line (south of Jurabbi Sanctuary) and off Helby Banks. There are suggestions from tage detections on the norther cross shelf line at Tantabiddi that fish which left the array in the spawning season were detected closer to these areas. Other such potential spawning sites must exist, but it should be pointed out that all of these locations are located outside sanctuary zones. Should the timing and location of spawning aggregations become common knowledge there could be serious impacts on the spangled emperor population of the region. *Lethrinus erythropterus,* a Pacific emperor species, is known to spawn adjacent or in reef passages (Hamilton 2005). While Westera and Hyndes (2001) did note the likelihood that spawning locations of transient spawners are adjacent deep water (i.e. on the reef slope) they did not include any detail on the spawning of lethrinids in their review. Our data suggest that it would be wise to re-assess the zoning of the reef slope areas in relation to major reef passes to ensure inclusion of an adequate proportion of these habitats.

The full implications of individual behaviour and habitat utilization for the adequacy of marine park zoning at Ningaloo requires the calculation of numerous trade-offs may play out in the context of a dynamic population. Such implications are best addressed by means of a spatially explicit numerical population model. This work will directly provide data to one such study which has recently commenced a project to model spangled emperor *Lethrinus nebulosus* populations using ELFSim (Little et al 2007) as part of joint WA-CSIRO funding under the Ningaloo Research Program. While this model does not include individual adult behaviours, other models being constructed as part of the Ningaloo Collaboration Cluster (e.g. In Vitro) have the capacity to do this if required.

Carangoides fulvoguttatus

Despite the fact that trevallies are pelagic fishes, there is increasing evidence that they are strongly linked to reef structures in terms of their behaviour. For example marke recapture studies of the blue trevally *Caranx melampyga* have shown that it spends most of its time within 500m of the site of capture, while active tracking revealed these fish to mainly travel along reef walls rather than out in open water (Holland et al 1996) with movement distances averaging 4.6km. Movements by the white trevally (*Pseudocaranx dentex*) have been shown using acoustic tracking to be larger (average maximum excursion 9.7km) than those of *P. melampygus,* but nevertheless to be restricted to certain areas of coast or to particular high relief bathymetric features (Afonso et al 2009). The scale of habitat use by *C. fulvoguttatus* is 5.6 km probably similar to the blue trevally, considering the tracking periods of *C. melampyga* were much shorter than for our study. The scale of these movements is sufficiently small that some degree of protection should be afforded to *C. fulvoguttatus* populations by most of the sanctuary zones in the Ningaloo Marine Park, although clearly there would be reduced levels of protection for individuals within a range of 2-3 km of the reserve boundaries.

The behaviour of trevallies such as the *P. dentex* has been shown to be unexpectedly diverse, with different behaviours shown by individuals in different habitats (Afonso et al 2009). Similar complexity is evident in *C. fulvoguttatus*. Although the reef passage was a focus of activity there was relatively little movement of animals from lagoon to reef slope or vice-versa, and activity kernel centres were either inside or outside the reef. Similarly, there were apparently relatively limited movements across reef passages from north to south. It is important to ensure that reef pass habitats are adequately represented in the Marine park zoning in order to ensure protection of key habitats for this species.

Coris aygula

Black Wrasse *Coris aygula* are a medium sized wrasse that are most abundant within the lagoon and reef flat and feed primarily on gastropods and echinoderms. (At Ningaloo they are an important predator on the urchin *Echinometra matthaei* (MV, RB, personal observations). Lagoon tagged fish were rarely captured more than 100 m from their activity centres, suggesting a limited activity area, however modal 50% kernel area was between 2 and 3 km^2, or areas 1.6-2 km in diameter and 95% kernel areas were larger, (5-10km^2) modal size. These kernel sizes are much larger than those for the only other wrasse for which equivalent tracking data exists. The California Sheephead *Semicossyphus pulcher* was found to spend 90% of its time within areas 600m in diameter (Topping et al 2006).

Larger scale movements were occasionally recorded, for example in the case of some individuals tagged on the reef flat, which moved offshore. These movements out of the tagging area may be similar to those reported for Napoleon wrasse *Cheilinus undulatus*, which was tracked for short periods in New Caledonia. The fish moved out of the small array after approximately 25 days, potentially to undertake spawning activity in another part of the reef (Chateau and Wantiez 2007).

Kyphosus sydneyanus

Silver Drummer *Kyphosus sydneyanus* displayed relatively limited movement centred around the tagging location with evidence of discreet groups of individuals moving around together, but separately from other groups tagged at different locations or at the same location on different days.

Kyphosus sectatrix tracked in the Caribbean had home sizes of 30 – 40 000 m^2 (Eristhee and Oxenford, 2001) which is significantly smaller than estimates of habitat use by *K. sydneyanus* at Ningaloo Reef where 50% kernel area was between 45,000,000 – 12,000,000 m^2. These large discrepancies may be due to the length of time animals were tracked for (mean = 150, SE = 24 days in our study and mean = 21-22, SE = 3 - 8 days in Eristhee and Oxenford (2001)). An additional source of discrepancy may also have been the method used to determine home range as Eristhee and Oxenford (2001) used the maximum convex polygon method which is far more simplistic than our method and likely to underestimate home range. The location were *K. sydneyanus* were tagged is characterised by large areas of suitable habitat and is open to the reef slope where most fish were recorded. It is possible that there is more available habitat within Ningaloo Reef, resulting in this species moving further than kyphosids in the Caribbean. Species specific differences in habitat utilisation and home range are likely to occur and can not be excluded as the cause of the large difference in home range between these species.

Kyphosus sectatrix showed significant differences in the shape of home range between groups of fish tagged in different locations which is consistent with movement pattern of *K. syneyanus* at Ningaloo. Eristhee and Oxenford (2001) attributed these differences to the shape of available reef, whereas our study suggests groups of animals use the available habitat in different ways. As in Kyphosids at Ningaloo, the home range of Individual Caribbean Kyphosids overlapped strongly with individuals tagged at the same site. Eristhee and Oxenford (2001) showed that certain locations were used at certain times of the day and were shared among individuals. *Kyphosus sectatrix* demonstrated high site fidelity to a single sleeping shelter at day and night and did not display diel migrations. *Kyphosus sectatrix* showed a strong preference for a few sites within their home range and these sites were associated with schooling behaviour. Similar patterns were observed at Ningaloo where *K. sydneyanus* are frequently observed schooling around selected bommies within the lagoon, and tagged individuals returning to particular areas at night over protracted periods of time or even over the entire record of activity.

At Ningaloo, these schooling/resting sites are associated with high degree of rugosity and have much lower algal cover than surrounding areas attributed to increased grazing by herbivorous fish using the area of high rugosity as a shelter from predators and primarily feeding in an area around the central shelter (see Milestone 3.2.2.33). In the Caribbean, schooling sites were characterised by high rugosity but had higher algal cover than surrounding areas.

Serranidae

A long term examination of the movement patterns of a suite of serranid species demonstrated a consistent sedentary nature throughout the family. This was typified by the fact that over half of all fish tracked, including individuals from the four major species tracked, were detected on one or two receivers throughout the tracking period, with these often being adjacent to the point of capture and release. For individuals where kernel utilisation distributions were possible, there was no significant difference between either core (50%) or home range (95%) areas for *E. mulitnotatus, E. tauvina* or *V. louti* which ranged from core areas of 0.2 – 0.3 km^2, and home range areas of 1.5 - 2 km^2. While utilisation kernels for *P. leopardus* were unable to be statistically examined, they were also within the range of the aforementioned species kernels.

Home range estimates of con-specifics tracked at other locations were smaller than those at Ningaloo. Estimates of *P. leopardus* on the Great Barrier Reef (Zeller 1997) and *E. tauvina* in Kenya (Kaunda-Arara & Rose 2004), were both based on minimum convex polygon estimates from manual acoustic tracking data. These resulted in estimates of 0.344 (±0.23) and 0.02 (±0.001) km^2 respectively (Zeller 1997, Kaunda-Arara and Rose 2004) which are considerably smaller than the estimates of individuals at Ningaloo, especially for *P. leopardus*, where the home range estimate was several orders of magnitude larger. The *P. leopardus* tracked at Ningaloo was likely to be a male (How et al. 2011), and was located on patch reefs. Both of these factors which both have been shown to result in a larger home range estimates (Zeller 1997). However, this doesn’t appear to account for the large difference in home range estimate between the GBR and Ningaloo. While home range area couldn’t be compared, dimensions of *P. leopardus* from another Western Australian population were also considerably larger than its GBR conspecific (How et al. 2010). This population at the Abrolhos Islands did have a longer linear dimension than the Ningaloo fish, however due to habitat differences they were of markedly different shape with the overall areas of movement likely to be similar.

Estimates of home range sizes were not possible for *E. rivulatus* as they were not detected on more than two receivers. This led to the conclusion that they were highly sedentary. It does concur with an earlier mark – resighting project on *E. rivulatus* at Mangrove Bay, Ningaloo, where estimates of home range were in the order of 94-200 m^2 (Mackie 1998), which would be easily be within the range of a single receiver. Serranids movement more generally, have been addressed through a variety of techniques including tag recapture–resighting (Sheaves 1993, Chapman and Kramer 2000), release–resighting (freeze-branding) (Samoilys 1997), manual acoustic tracking (Zeller 1997, Kaunda-Arara and Rose 2004), passive acoustic tracking (How et al 2010) or a combination of techniques (Zeller and Russ 1998). Despite differences in methodology, the ultimate conclusion of a highly sedentary nature is consistent throughout. Therefore, the resultant highly sedentary nature for the suite of Serranids tracked at Ningaloo is consistent with previous research on this highly exploited Teleosts family. However, where direct comparisons of con-specifics were possible, Ningaloo Serranids occupied larger home ranges than con-specifics at other locations (Zeller 1997, Kaunda-Arara and Rose 2004), though consistent with more local studies (Mackie 1998 and How et al. 2010). Difference may be due to a number of factors relating to tracking technique, duration of study, or even habitat or population differences. It does however highlight significant variation in conspecifics movement patterns between location, and the need for utilise local information in the effective planning of local closures.

The advantages to such a long tracking dataset, especially for highly sedentary species allows for greater duration in which to detection transmissions. Two *E. rivualatus* were not detected for four to five months after release, before one individual was detected 88 times. A shorter study potentially would not have detected these fish, missing potentially valuable movement information. Long term tracking provided sufficient data for a robust estimate of home range with several fish detected over 8000 times for periods up to 18 months. This provided good estimates of their home range allowing for any potential deviation in the home range over time to be assessed. The longevity of the study provided a robust assessment of movement patterns enhanced by the extensive coverage of the array, and the simultaneous assessment of multiple species within the same location.

Reef fish fisheries are often multi-species fisheries, requiring an understanding of the movement patterns of a number of exploited species to increase the likelihood that a marine reserve will protect the suite of targeted species. The amount of protection afforded is dependent on the amount of time the individual is located outside the area protected (Kramer and Chapman 1999). In the case of Serranids, small core areas would require a relatively small area to be protected, though this would only afforded protection for around 50% of the time. With considerable overlap in species utilisation distributions, the protection of areas of several square kilometres would provide protection for the majority (95%)of detections, for a number of species simultaneously.

While the size of the reserve is of importance, the habitat that it encompasses and the location of boundaries can alter its effectiveness. Virtually all species of serranids (with the exception of the lagoon specialist *Epinephelus rivulatus*) showed a strong habitat preference for reef slope sites. The sedentary nature of the species tracked resulted in little movements between habitats with in the array at Ningaloo. While not common, inter-habitat movements did occur, and were mainly to and from the reef slope and deeper offshore areas. There was a clear demarcation of detection for the Serranids tracked in this study, with very few detection in the lagoon, except for *E. rivulatus*. This is consistent with underwater visual surveys of the fish fauna in Ningaloo, which saw reef slope communities being most distinct from other habitats, with species such as *V. louti* not being recorded anywhere but on the reef slope (Babcock et al 2008). However, the current sanctuary zone at Mangrove Bay doesn't encompass the reef slope or deeper offshore areas, with the outer edge of the sanctuary zone on the reef flats, resulting in little or no protection of these vital Serranid habitats. The northern areas of the park, where there are relatively low levels of protection for reef slope habitats (i.e. special purpose benthic habitat protection zone at Mandu Mandu), may need to be examined in order to assess whether they offer adequate protection for iconic, long lived serranid species.

The permeability of a marine reserve boundary to fish movement can be altered based on the habitat on which the boundary occurs. Previous studies have shown that expanses of rubble or sand may provide a natural barrier to fish movement (Barrett 1995, Lowe et al 2003, Popple and Hunte 2005), with movements between river banks not occurring possibly due to the channel associated with the river (Sheaves 1993). This can result in a reduced movement across a marine reserve boundary, which directly contrast to those reserves where boundaries are on contiguous habitat (Eristhee and Oxenford 2001).

The placement of marine reserve boundaries that incorporate such natural barriers may greatly increase the success of the reserve as the natural movement patterns of the fish are utilised to create an effective boundary edge as opposed to a boundary edge along continuous habitat, which can cause greater cross boundary movement (Barrett 1995). Some individuals in this study did utilise the reef channel area, though none of these moved across the channel. The few movements that did occur from the reef slope to the lagoon were from the southern reef slope, through the south of the channel opening into the southern side of the lagoon, and back again. There was no evidence of individuals crossing the reef channels, suggesting that the reef channel, despite the occurrence of a number of coral bommies within it, may provide a natural barrier to movement of fish.

Serranid species have demonstrated considerable movements of several hundred kilometres associated with migrations to spawning aggregation sites requiring movements between reefs, which are often separated by deep channels (Colin 1992, Luckhurst 1998, Bolden 2000, Nemeth et al 2007). Re-homing experiments have also demonstrated that Serranids do move across sand channels to return to their original home range (Kaunda-Arara & Rose 2004). Despite this ability to move across channels for spawning migrations or re-homing, none of the Serranids tracked as part of this study crossed these apparent natural barriers. One set of movements was detected for *E. multinotatus* (8092) which were potentially spawning related, and these movements appear to have been across the reef flat, rather than through the channel. While there is no published data on the spawning season of *E. multinotatus* on the west coast of Australia, other serranids including *Plectropomus leopardus* spawn in February - March at the Abrolhos Islands further south on the WA coast (How et al. 2010).

The long-term tracking employed in this study, coupled with simultaneous tracking of several species from an ecologically important family of fishes which are also significant fishing targets, enabled a robust assessment of the movement patterns and habitat uses. It also provided valuable information on natural barriers to fish movements, whose incorporation into marine reserve boundaries may naturally reduce flux rates across reserve boundaries. While this information is directly applicable to marine reserves at Ningaloo, with strong parallels to other Serranid movement studies, it adds strength to the existing knowledge of Serranid movements and how this may be considered in other marine closures.

3.5. Acknowledgements

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3.6. References

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4. Communication and Outputs

4.1. Communication Achievements

4.1.1. **Students Supported**

Jason How, PhD student, Edith Cowan University, Supervisor Glenn Hyndes. Tagging and analysis of grouper behaviour.

4.1.2. **PhD Theses and Dissertations and Student Placement**

(Jason How, expected completion July 2011, PhD, Edith Cowan University).

4.1.3. **Planned Publications**

Movement and home range of the spangled emperor *Lethrinus nebulosus* at Ningaloo Reef. Rich Pillans, Russ Babcock and Toby Patterson

Spawning behaviour of the spangled emperor *Lethrinus nebulosus* at Ningaloo Reef. Russ Babcock, Rich Pillans, Ross Marriott, and Toby Patterson

Habitat preferences of the spangled emperor *Lethrinus nebulosus* at Ningaloo Reef. Toby Patterson, Rich Pillans, Russ Babcock

Habitat use and movement range of the gold spot trevally *Carangoides fulvoguttatus* at Ningaloo Reef. Rich Pillans, Russ Babcock and Toby Patterson

Habitat use and foraging behaviour of the silver drummer *Kyphosus sydneyanus* at Ningaloo Reef Russ Babcock, Rich Pillans and Toby Patterson

Comparison of habitat use and movement range among a guild of groupers (Serranidae) at Ningaloo Reef. Jason How, Rich Pillans and Russ Babcock

Comparative habitat use and seasonal movements of reef sharks (*Carcharhinus melanopterus and C. amblyrhynchos*) and Ningaloo reef. Rich Pillans, Russ Babcock and Toby Patterson

The impact of fish tracking and fish behaviour on marine park zoning. Russ Babcock and Chris Simpson.

4.1.4. **Presentations**

Russ Babcock, Rich Pillans, Toby Patterson and Mark Bravington 2011. Including habitats in estimates of utilization distributions for reef fish International Conference on Biologging Hobart February 2011

Russ Babcock 2010. Ecosystem impacts of human usage and the effectiveness of zoning for biodiversity conservation. Ningaloo Synthesis Workshop, March 2010, Exmouth

Russ Babcock 2009. Integrating science into management strategies and actions to support marine conservation: the scientist's perspective. Ningaloo Research Symposium Exmouth, May 2009.

4.2. Project Outputs

Adequacy of zoning - CMAR/ECU receiver deployment/tagging progress report. Milestones 3.2.2.17a,b, November 2007

Adequacy of zoning – CMAR/ECU tagging progress report Milestones 3.2.2.24 a,b, May 2008

Adequacy of zoning – CMAR/ECU tagging progress report Milestones 3.2.2.30 a,b, November 2008

Adequacy of zoning - interim final report CMAR/ECU tagging progress report Milestones 3.2.2.35, May 2009

Adequacy of zoning - Analysis and interpretation report. CMAR/ECU tagging progress report Milestones 3.2.2.37, March 2011

4.3. Data Management

See below.

Project Metadata

	Project
What	
What is the title of the study? (e.g. what would like to be the title of the metadata record)	Adequacy of zoning in the Ningaloo Marine Park
What would be some key words for searching for this data?	Fish behaviour, fish movement, home range, habitat use
What constraints would you place on the data (e.g. legal, usage - purposes that shouldn't use the data)	Report authors should be consulted before use of data
what kind of data will/has been collected (e.g. sp richness, inventory, abundance, density etc)	Fish position data determined by acoustic tag detections
Who	
Who did the research? Please list names and the contact details.	Russ Babcock, Rich Pillans, Toby Patterson CSIRO Marine and Atmospheric Research Ecosciences Precinct, Dutton Park Q 4102 Glenn Hyndes, Jason How Centre for Marine Ecosystems Research, School of Natural Sciences, Edith Cowan University, Joondalup, Australia,
Who is point of contact in case of questions? Please list their contact details - is there a generic contact that could be used to ensure longevity?	Russ Babcock, Rich Pillans, Toby Patterson CSIRO Marine and Atmospheric Research Ecosciences Precinct, 41 Boggo Rd, Dutton Park Q 4102 GPO Box 2583 Brisbane, Qld 4001 Phone: +61 7 3833 5904 Mobile: 0408 944961 russ.babcock@csiro.au
Who else should be acknowledged? Any links to journal articles?	Australian Animal Tracking and Monitoring System, Australian Integrated Marine Observing System.
Why	
Why was the research done? This is the abstract - a brief summary of the content of the research is required including the research intentions include summary of aims and objectives and use	We assessed the adequacy of marine park zoning at Ningaloo by studying the movements of fish and asking asked the question whether sanctuary zones were large enough and in the right locations to protect targeted species of fish.

	Analysis has focused on four species, spangled emperor *Lethrinus nebulosus*, gold spot trevally *Carangoides fulvoguttatus*, black wrasse *Coris aygula* and drummer *Kyphosus sydneyanus* for which we have significant amounts of data. These species represent a range of target species as well as an important herbivorous species on the reef. An additional 300 fish and elasmobranchs from 23 species have also been tagged within the Mangrove Bay array. The behaviour of each fish from the four main species, spangled emperor *Lethrinus nebulosus*, gold spot trevally *Carangoides fulvoguttatus*, black wrasse *Coris aygula* and drummer *Kyphosus sydneyanus* was summarised by calculating fixed kernel distributions. This statistic summarises the probability of an individual being located within the perimeter of a given area with varying probabilities (we have used 50% and 95% probabilities). Estimates of kernel size were then compiled for the overall population of tagged fish. Most spangled emperor *Lethrinus nebulosus* were found to have surprisingly small activity ranges, with diameters of 2.5 to 3.5 km for 95% activity kernels. This is an even more restricted range than previously suggested for the majority of *L. nebulosus* by Moran et al (1993) who reported approximately 60% of all recaptured fish were returned from the same 6 nm statistical area in which they were tagged. The proportion of fish which we found to remain near the point of capture was 68%, remarkably similar to that reported by Moran et al. (1993). Because the majority of individuals appear to use areas of reef that are small in relation to the size of most sanctuary areas in the Ningaloo Marine Park, it seems likely that the reserves are of an adequate size to protect substantial proportions of the population. That said there are important caveats that must be placed on this conclusion. Our data span 12 months to two years, for each individual. The conclusion of adequacy is dependent on individuals retaining their resident behaviour for large proportions of their life span. Adequacy and the degree of protection afforded at

	a population level will be sensitive to variation in this behaviour and to the proportion of the population that displays non-resident behaviour. Our data suggest that some fish change their behavioural patterns leaving long term sites of residence for varying periods. Since these are long lived fish, living up to at least 30 yrs, each individual may be protected for relatively short periods of time, with the potential for adequacy to be reduced. A significant proportion of the population (36%) never appeared to establish residence in a particular area and may be nomadic. Other aspects of the behaviour of *L. nebulosus* at Ningaloo may influence the adequacy of the current zoning system in the marine park. There was significant variation among habitats in both kernel size and the distance between capture location and kernel centre. Shoreline and reef slope habitats had the highest values for kernel areas and for distance to kernel centre. Movement analysis in particular suggests that there are high levels of movement among shoreline areas. With the activities of fish apparently focused on these shoreline and reef slope habitats they may be particularly exposed to the effects of fishing. While the recent re-zoning of the marine park has achieved a much higher level of protection for reef slope habitats, there remain significant areas of shoreline habitat within sanctuary zones reserved for fishing as Special Purpose (Shore Based Activities) Zones. Such zones may present a disproportionate threat to the adequacy of zones due to the importance of shoreline habitats for *L. nebulosus* at Ningaloo. Spawning aggregations are another important behaviour that may affect the success of sanctuary zones. Tracking of *L. nebulosus* at Mangrove Bay suggests seasonal spawning activity occurs outside the array between October and December. Sites for spawning have not been located but may include sites adjacent to the Tantabiddi passage, adjacent the passage at the north end of the main Tantabiddi reef line (south of Jurabbi Sanctuary) and off Helby Banks. Other such potential spawning sites must exist, but data from the Mangrove Bay

	area suggest they are outside the lagoon and may be outside the immediate reef slope habitats. *Lethrinus erythropterus*, a Pacific emperor species, is known to spawn adjacent or in reef passages. Should the timing and location of spawning aggregations become common knowledge there could be serious impacts on the spangled emperor population of the region. The full implications of individual behaviour and habitat utilization for the adequacy of marine park zoning at Ningaloo requires the calculation of numerous trade-offs may play out in the context of a dynamic population. Such implications are best addressed by means of a spatially explicit numerical population model. While models currently being used to assist management of fish populations at Ningaloo do not include individual adult behaviours, it seems likely that the results of such modelling could be improved if fish behaviour were to be explicitly incorporated. Home range areas for the gold spot trevally *Carangoides fulvoguttatus* were surprisingly small. Despite the fact that trevallies are pelagic fishes, there is increasing evidence that they are strongly linked to reef structures in terms of their behaviour. For example mark-recapture studies of the blue trevally *Caranx melampyga* have shown that it spends most of its time within 500m of the site of capture, while active tracking revealed these fish to mainly travel along reef walls rather than out in open water with movement distances averaging 4.6km. Movements by the white trevally (*Pseudocaranx dentex*) have been shown using acoustic tracking to be larger (average maximum excursion 9.7km) than those of *P. melampygus*, but nevertheless to be restricted to certain areas of coast or to particular high relief bathymetric features. The scale of habitat use by *C. fulvoguttatus* is 5.6 km probably similar to the blue trevally, considering the tracking periods of C. *melampyga* were much shorter than for our study. The scale of these movements is sufficiently small that some degree of protection should be afforded to *C. fulvoguttatus* populations by most of the sanctuary zones in the Ningaloo Marine Park, although clearly there would be reduced levels of

	protection for individuals within a range of 2-3 km of the reserve boundaries. The behaviour of trevallies such as the *P. dentex* has been shown to be unexpectedly diverse, with different behaviours shown by individuals in different. Similar complexity is evident in *C. fulvoguttatus*. Although the reef passage was a focus of activity there was relatively little movement of animals from lagoon to reef slope or vice-versa, and activity kernel centres were either inside or outside the reef. Similarly, there were apparently relatively limited movements across reef passages from north to south. It is important to ensure that reef pass habitats are adequately represented in the Marine park zoning in order to ensure protection of key habitats for this species. Black wrasse *Coris aygula* are a medium sized wrasse that are most abundant within the lagoon and reef flat and feed primarily on gastropods and echinoderms. At Ningaloo they are an important predator on the urchin *Echinometra mathaei* and as such they may have an important role in trophic relationships across the reef. Lagoon tagged fish were rarely captured more than 100 m from their activity centres, suggesting a limited activity area, however modal 50% kernel area was between 2 and 3 km^2, or areas 1.6-2 km in diameter and 95% kernel areas were larger, (5-10km^2) modal size. These kernel sizes are much larger than those for the only other wrasse for which equivalent tracking data exists. The California Sheephead *Semicossyphus pulcher* was found to spend 90% of its time within areas 600m in diameter. Larger scale movements of *C. aygula* were occasionally recorded, for example in the case of some individuals tagged on the reef flat, which moved offshore. These movements out of the tagging area may be similar to those reported for Napoleon wrasse *Cheilinus undulatus*, which was tracked for short periods in New Caledonia. The fish moved out of the small array after approximately 25 days, potentially to undertake spawning activity in another part of the reef. *Kyphosus sydneyanus* displayed limited movement centred around the tagging

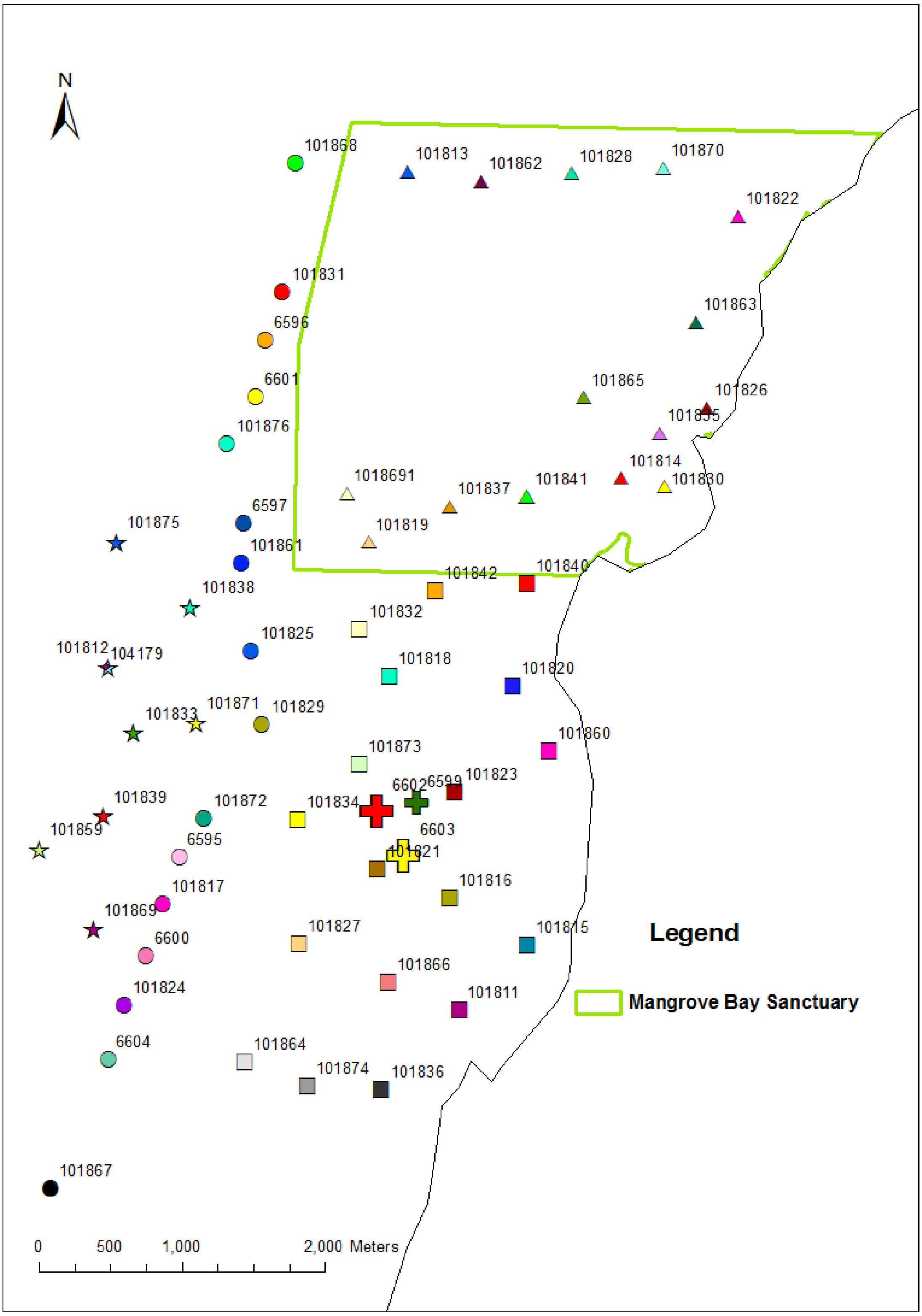
	location with evidence of discreet groups of individuals moving around together, but separately from other groups tagged at different locations or at the same location on different days. Kyphosids tracked in the Caribbean had home sizes of 30 – 40 000 m^2) which is significantly smaller than estimates of habitat use by *K. sydneyanus* at Ningaloo Reef where 50% kernel area was between 45,000,000 – 12,000,000 m^2. these differences may in part be due to differences in methodololgy, but it is more likely that there is more available habitat within Ningaloo Reef, resulting in this species moving further than kyphosids in the Caribbean. Species specific differences in habitat utilisation and home range are likely to occur and can not be excluded as the cause of the large difference in home range between these species. Tracking of drummers at Ningaloo suggests groups of animals use the available habitat in different ways. At Ningaloo where *K. sydneyanus* are frequently observed schooling around selected bommies within the lagoon. At Ningaloo, these schooling sites are associated with high large coral bommies and have much lower algal cover than surrounding areas attributed to increased grazing by herbivorous fish using the area of high rugosity as a shelter from predators and primarily feeding in an area around the central shelter. In the Caribbean, schooling sites were characterised by high rugosity but had higher algal cover than surrounding areas. Overall, the results of the analysis to date suggest that for spangled emperor *Lethrinus nebulosus*, black wrasse *Coris aygula* and drummer *Kyphosus sydneyanus* sanctuary zones are of sufficient size to offer adequate protection to populations of these species. For the more mobile gold spot trevally *Carangoides fulvoguttatus*, existing zones should still be large enough to offer some degree of protection. These conclusions require further examination in light of the details of habitat usage (e.g. for nearshore habitats or for spawning) and should be included in population modelling studies in order to reach firm

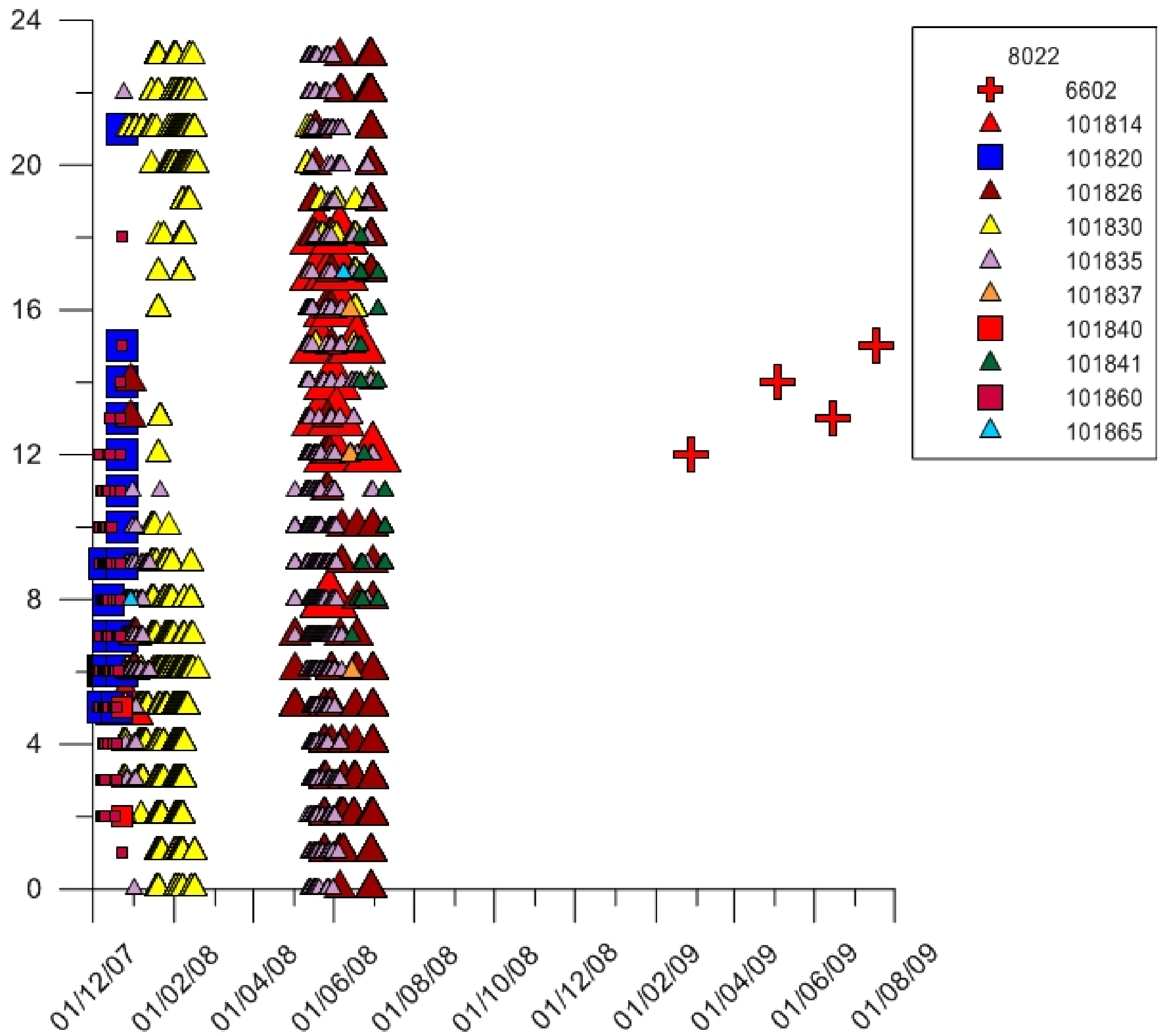
	conclusions on adequacy.
How	
How was the research done? (e.g. instrumentation, brief description of procedure)?	Data was collected by tagging fish with coded acoustic transmitters and using acoustic receivers to detect the tags, allowing us to build a picture of fish home range, movement patterns and habitat use.
How often were measurements taken? Were they aggregated into a specific unit of time (e.g. day, multi-day, week, month, multi-month, year, multi-year)? Change to an overview of sampling design with more detail - spatial and temporal parameters	Measurements have been taken continuously since November 2008
How is the data currently stored, that is what format is the data? (e.g. GIS shapefiles, compressed AVI etc.) Please provide as much information as possible.	The data is currently stored on the IMOS eMII portal at http://imos.org.au/emii_aatams.html
When	
When was the research carried out? When were the start and end dates?	1/11/2008 – 28/02/2011
Where	
Where was the research done? As a minimum please indicate the 'bounding box' in latitude/longitude (decimal degrees) (e.g. North bound latitude -22.00; West bound longitude 113.00; East bound longitude 114.00; South bound latitude -23.00)	Ningaloo Reef, between -21.6553 and 113.81312
Where are any other related publications/information about the research published - if any? (e.g. url)	n/a
Where in the vertical column of the ocean was the research undertaken? (e.g. minimum and maximum depth)	Maximum depth ~200m
site names and GPS coordinates	The data is currently stored on the IMOS eMII portal at http://imos.org.au/emii_aatams.html
ACCESS	
where is raw data stored (full name, file and location	The data is currently stored on the IMOS eMII portal at http://imos.org.au/emii_aatams.html

where are derived/processed data products stored (full name, file and location)	
where are any other related publications/info	n/a
what constraints/restrictions would you place on the data…	Must consult authors before use
Supplementary information - Please attach any further information you think would be useful for future researchers	n/a

Appendix 1:

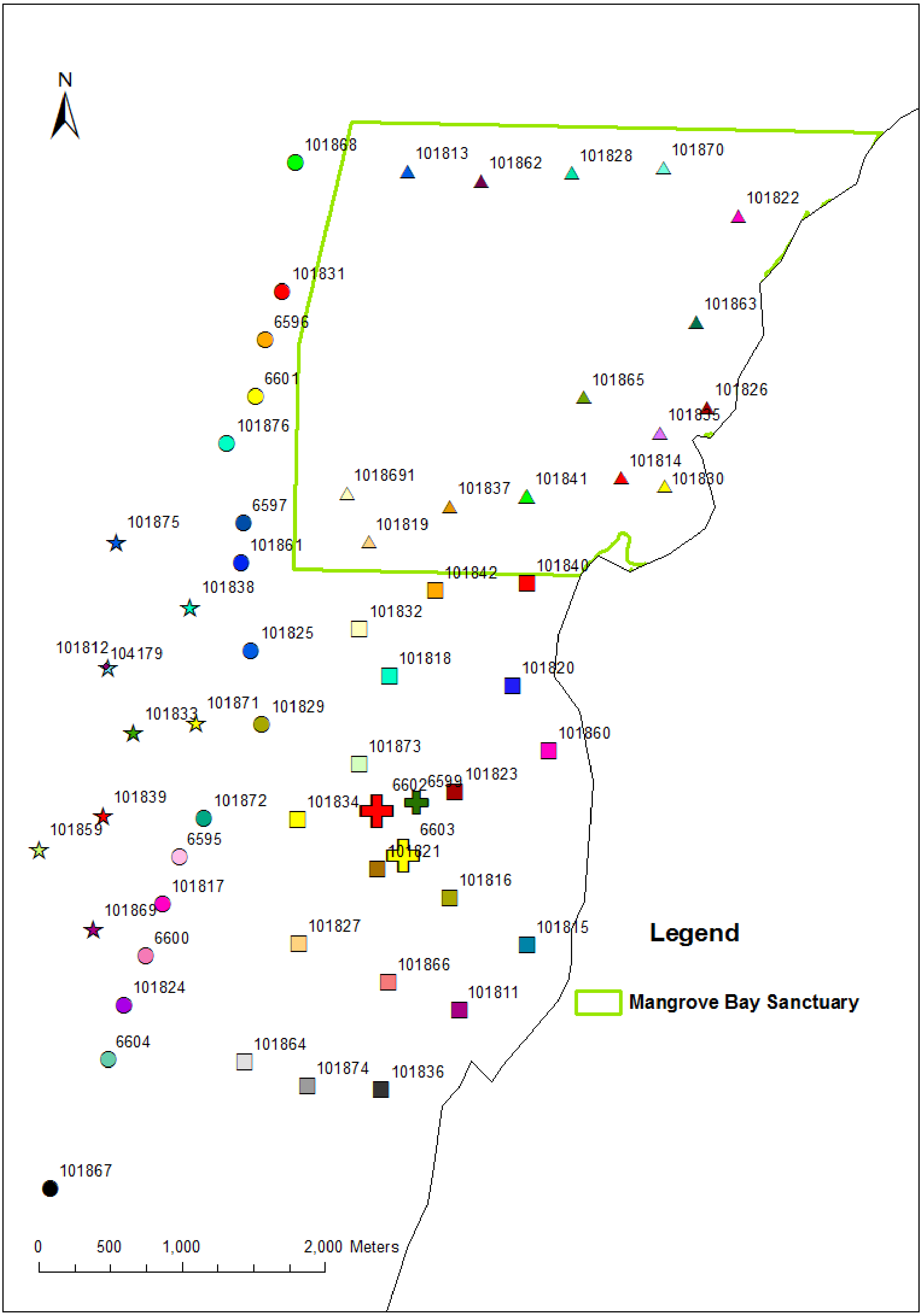
Lethrinus nebulosus





8022 Notes

Appears to have different preferences for day and night time activity. Record is very similar to 8173 Seems to be in the channel during the day and on shallow pavement areas north of coral bay at night.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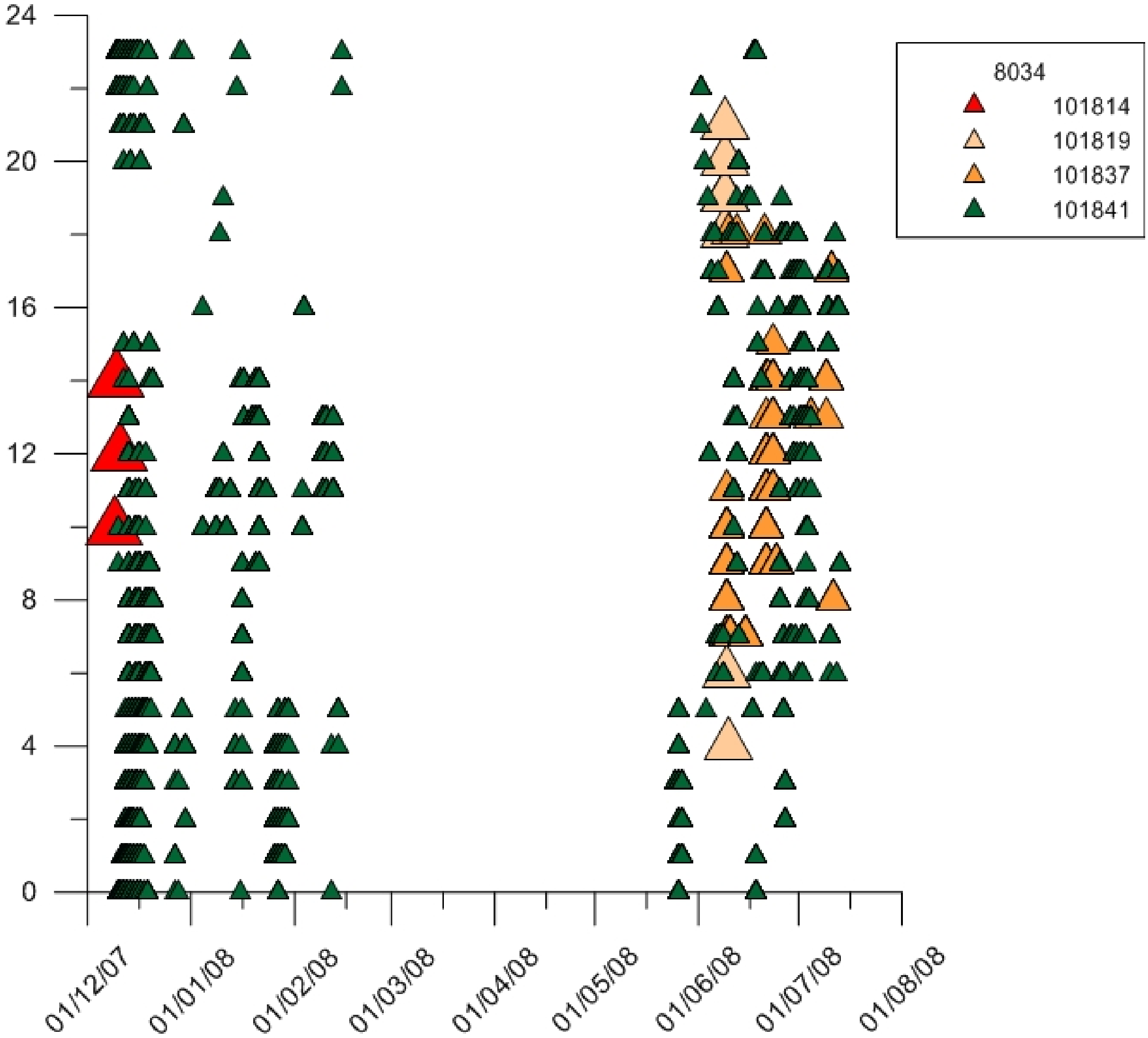
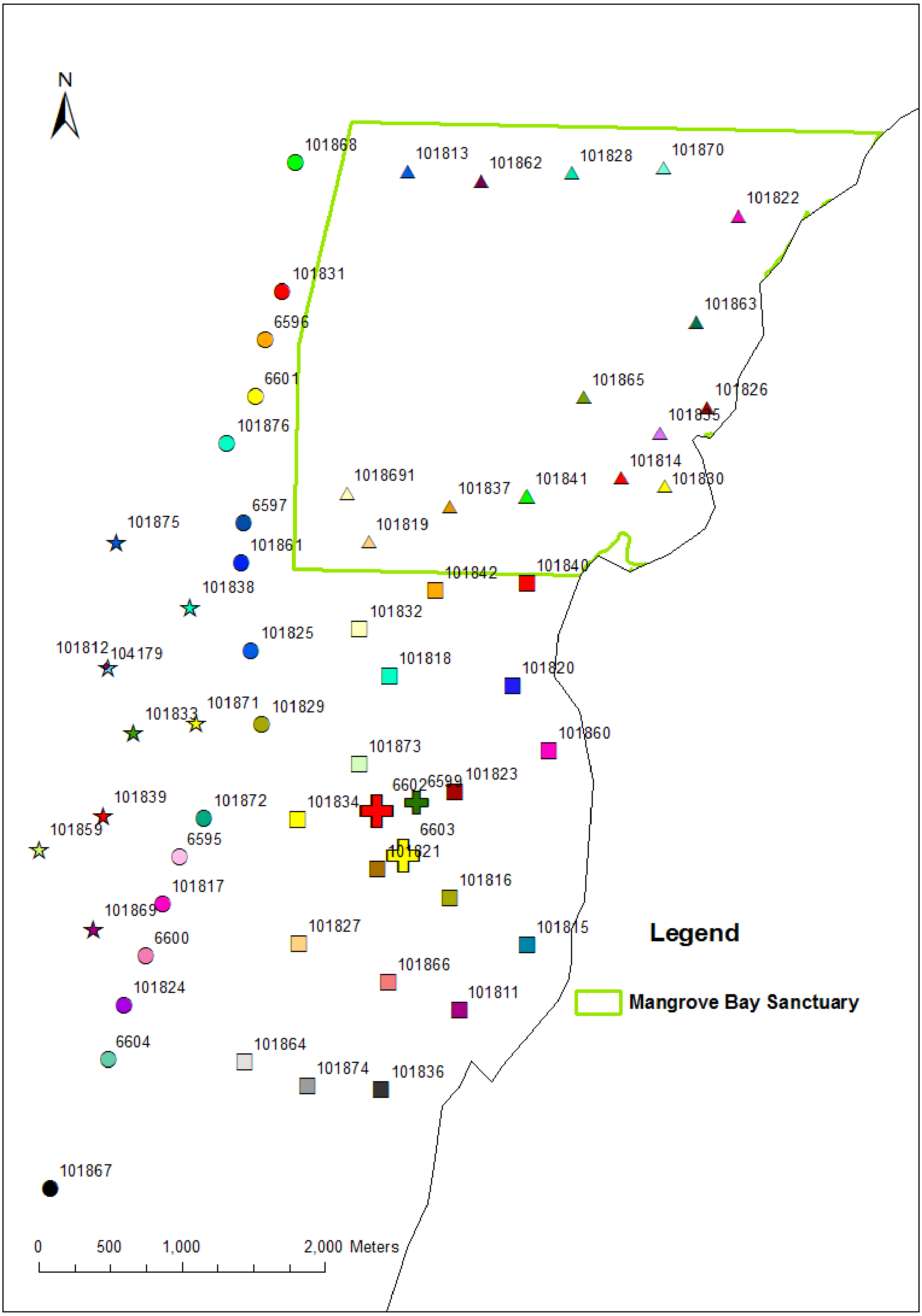


8034 Notes
Seems to move to shallower areas (either near shore or reef flat during night)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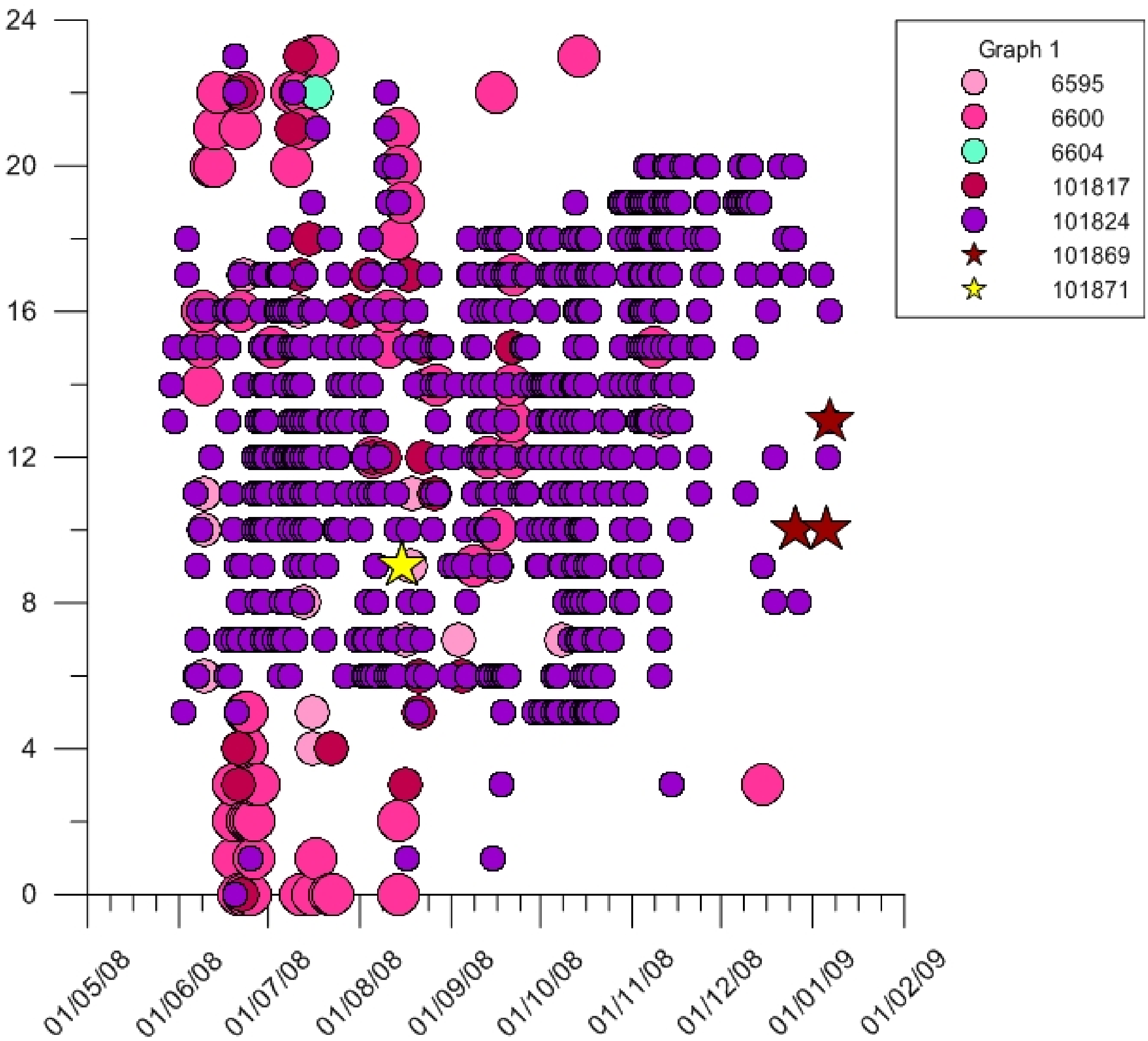
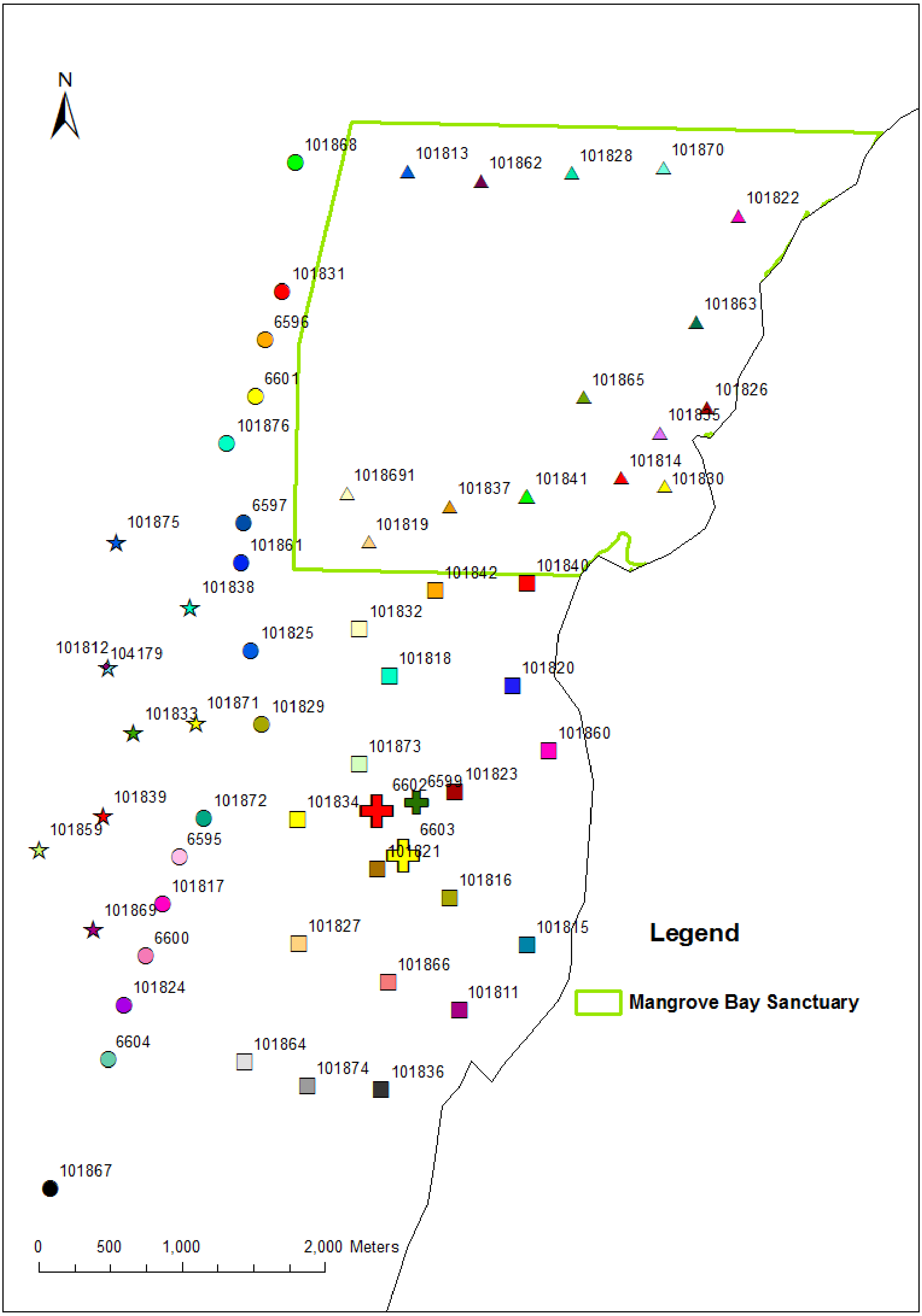


8039 Notes

Seems to stay in core area during day, move more widely along the reef slope at night.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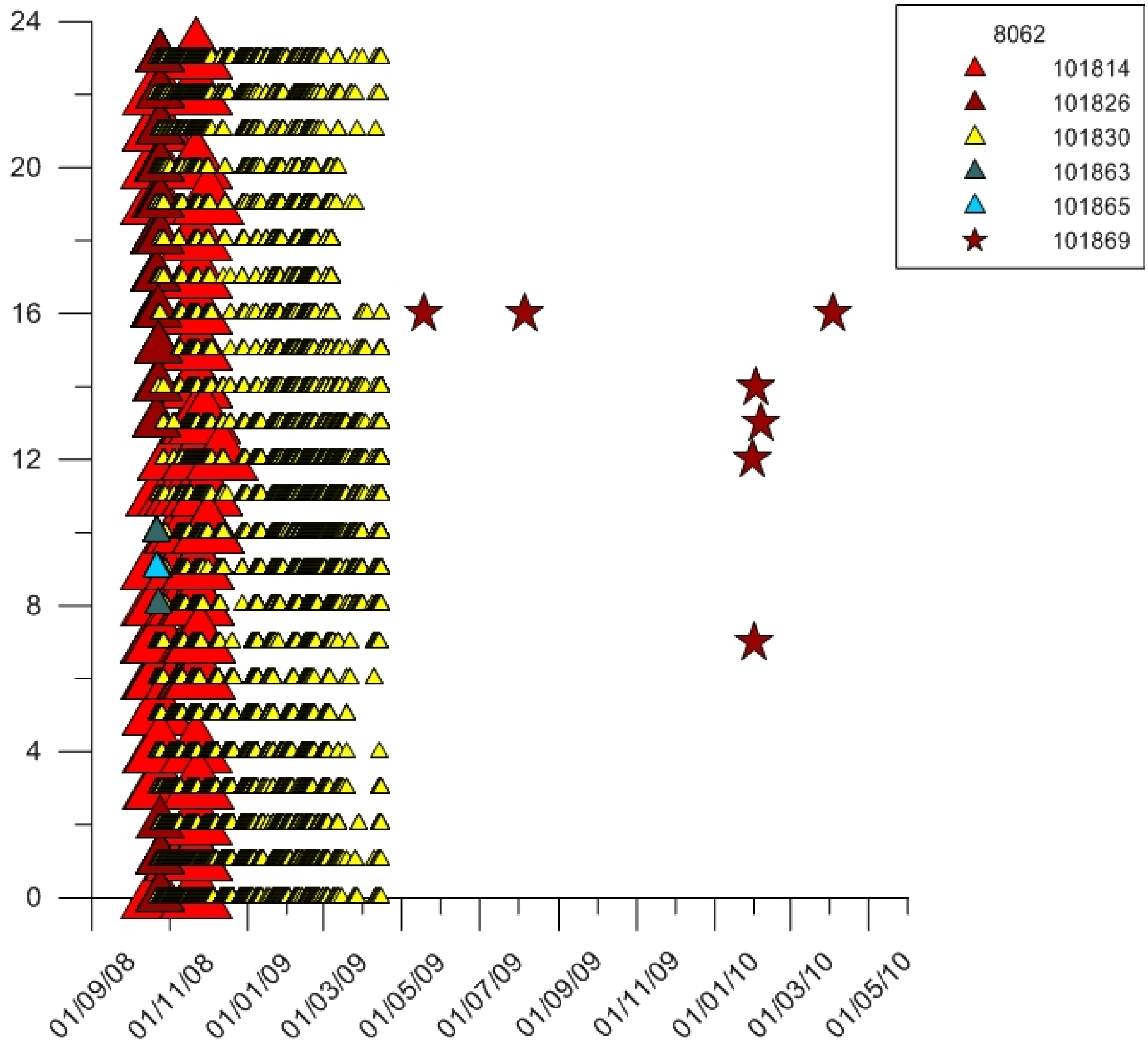
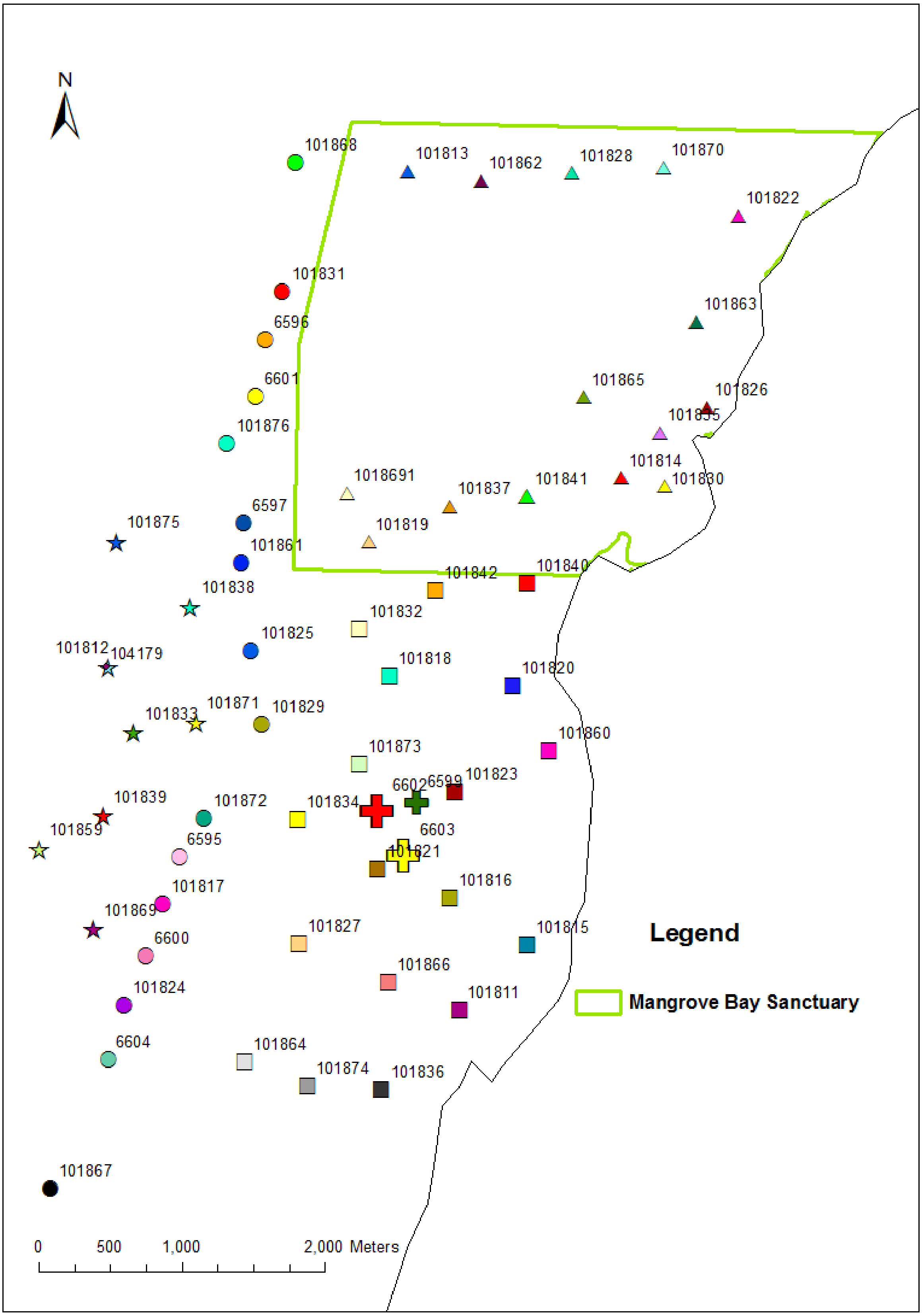


8062 Notes

Evidence of complete habitat shift, around April 2009. Possible shifts/gaps in record around Nov-Dec.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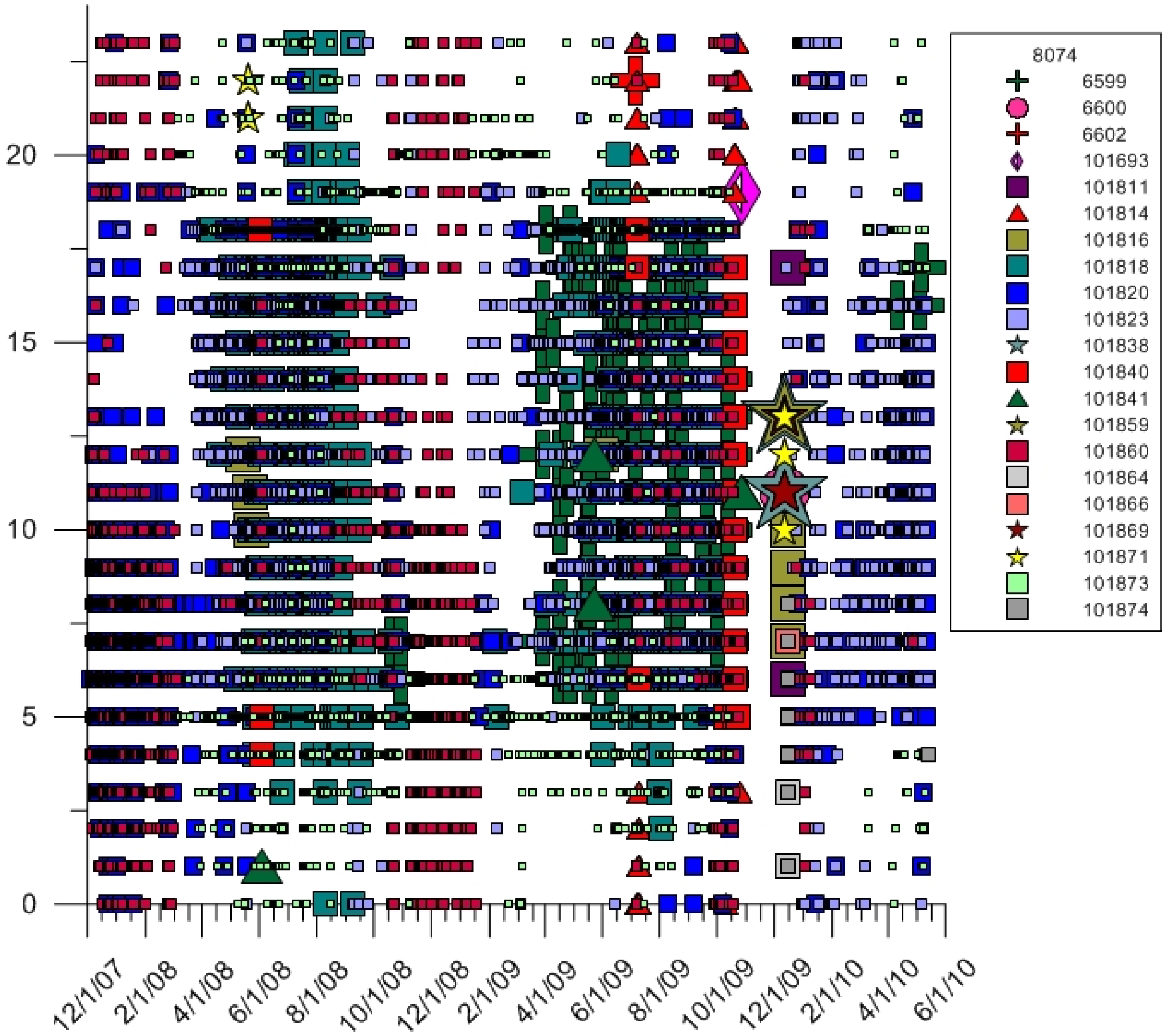
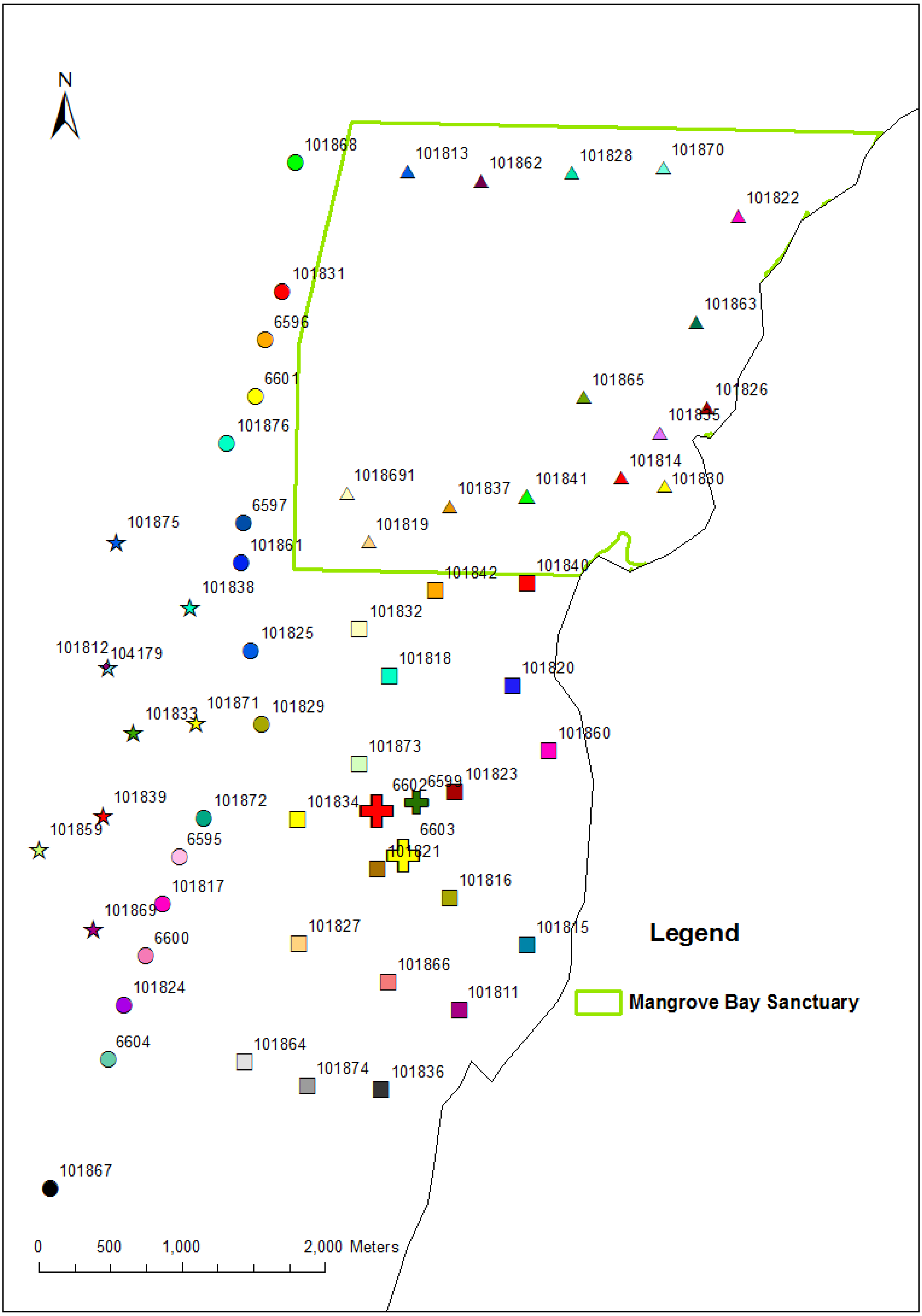


8074 Notes

Different day and night activity centres. Data gap in Nov ember 09 then picked up on numberous offshore stations. Then returned to lagoon.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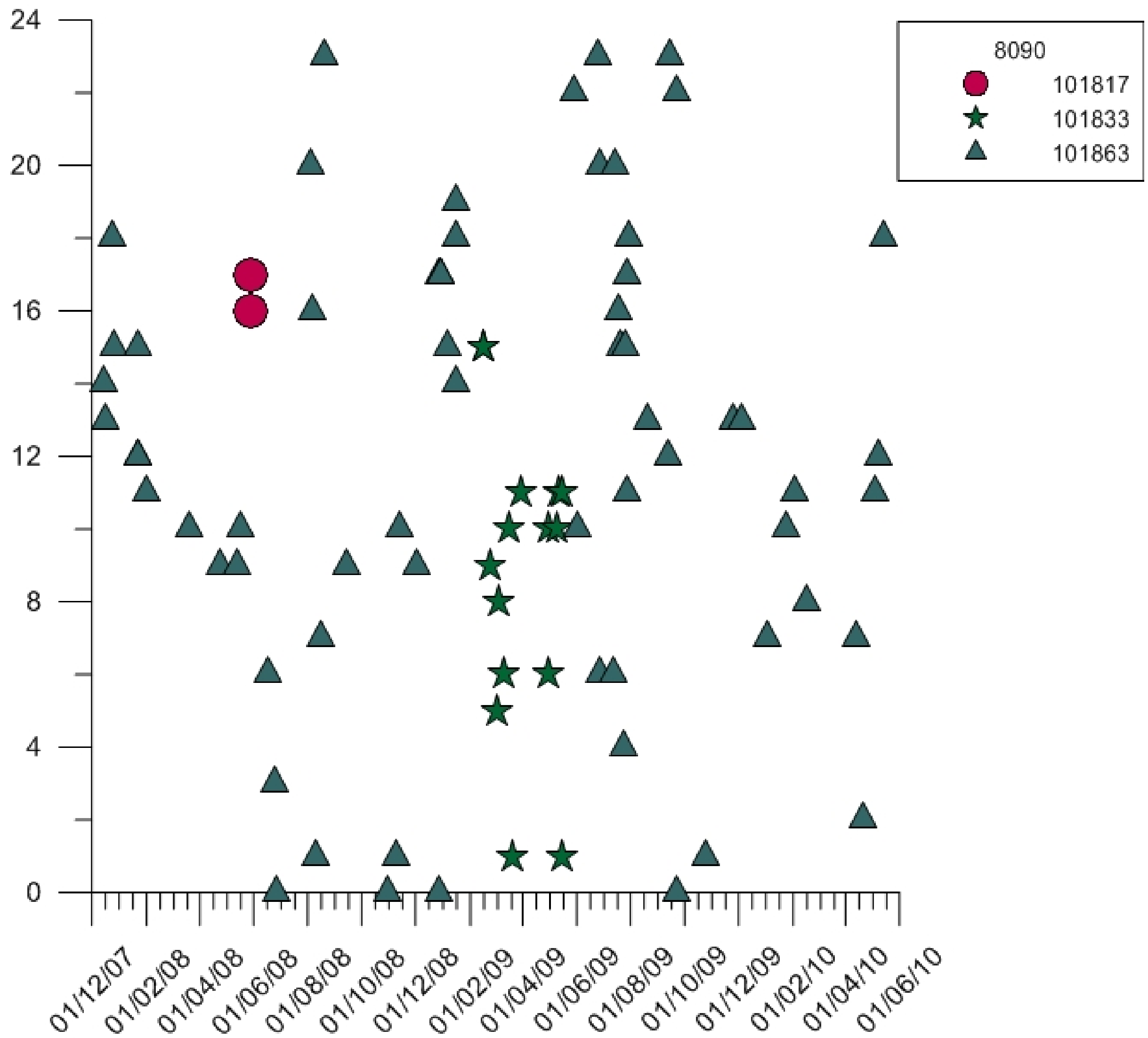
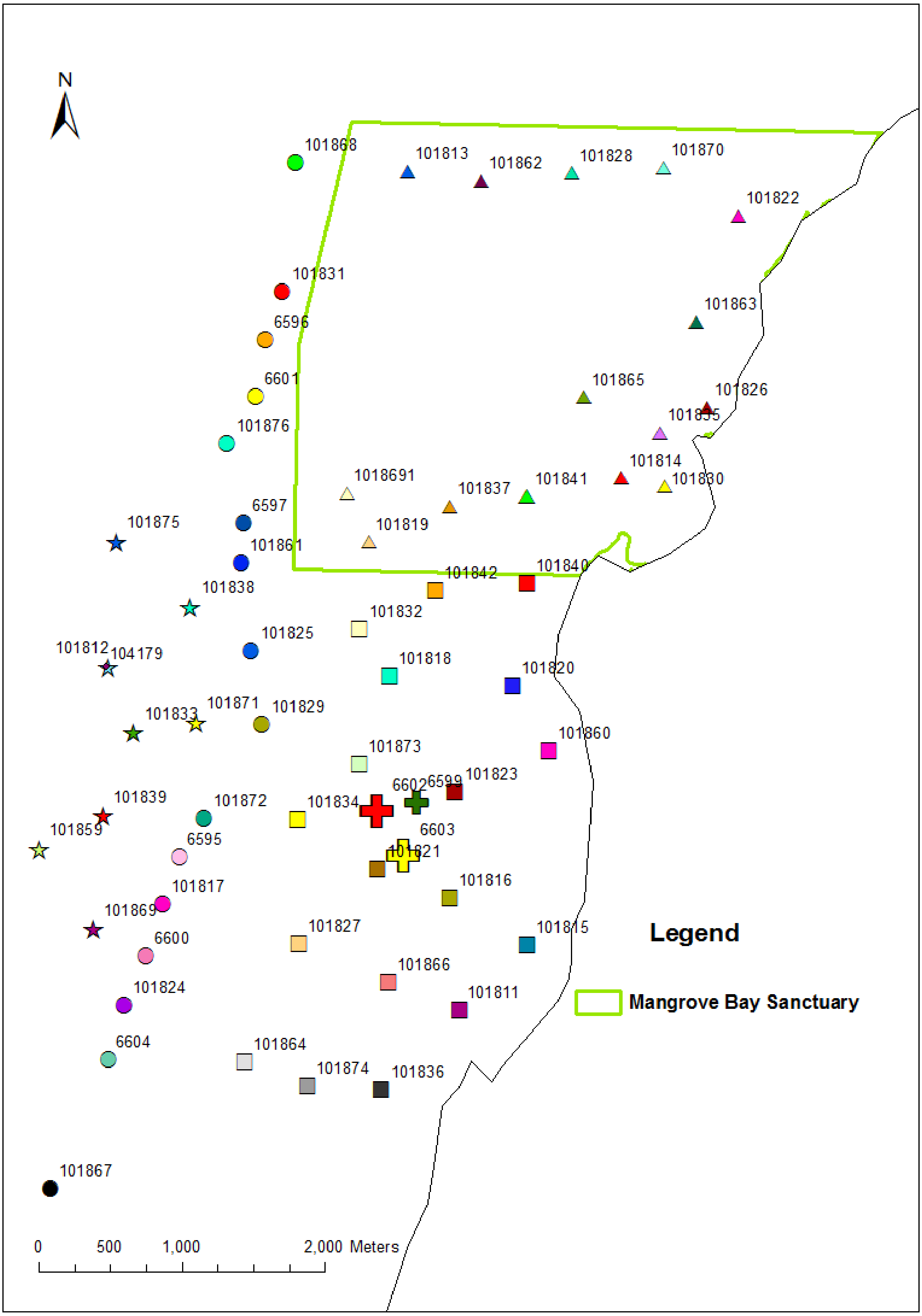


8090 Notes
Off shore movements in April-may 08 and 09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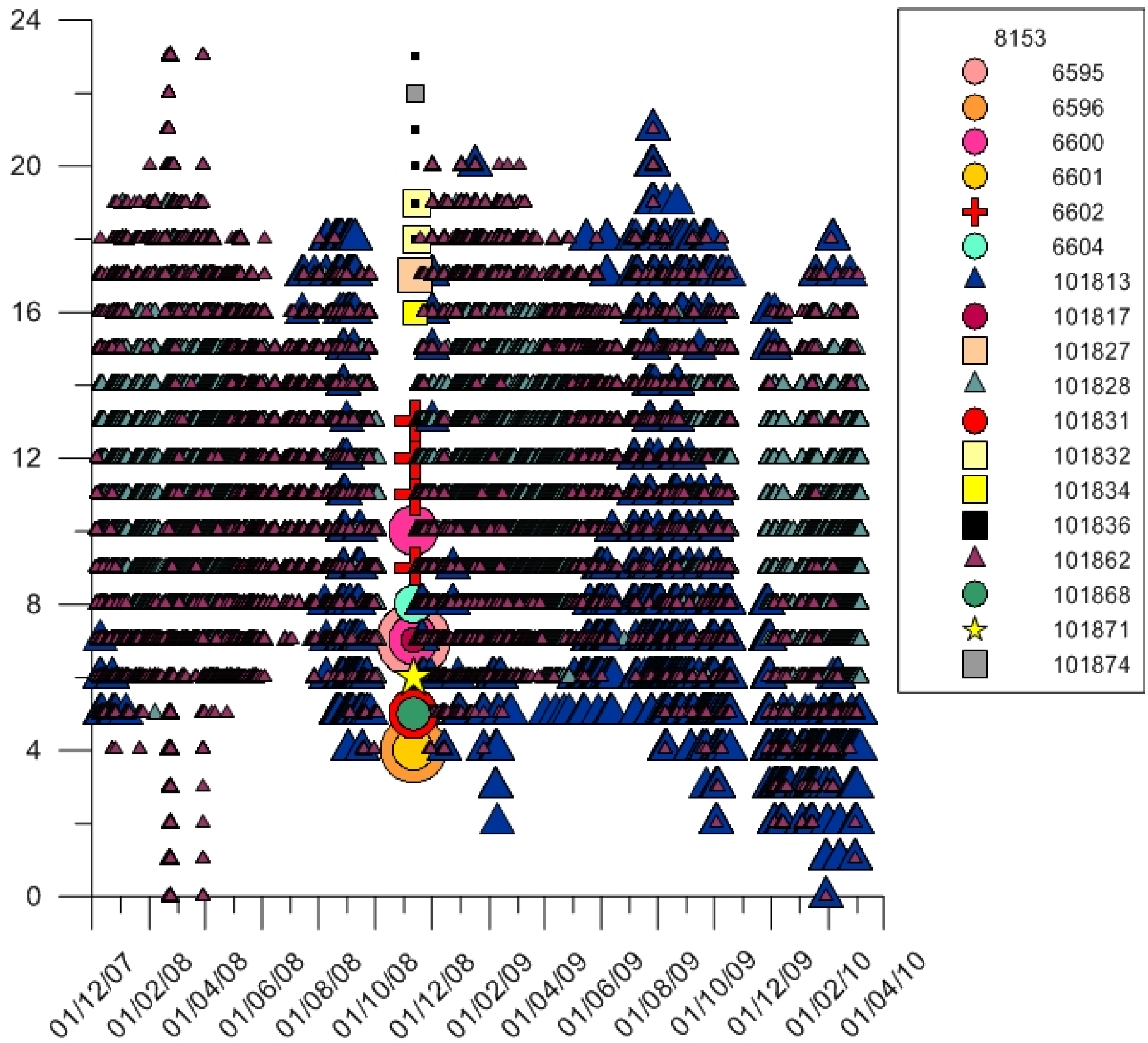
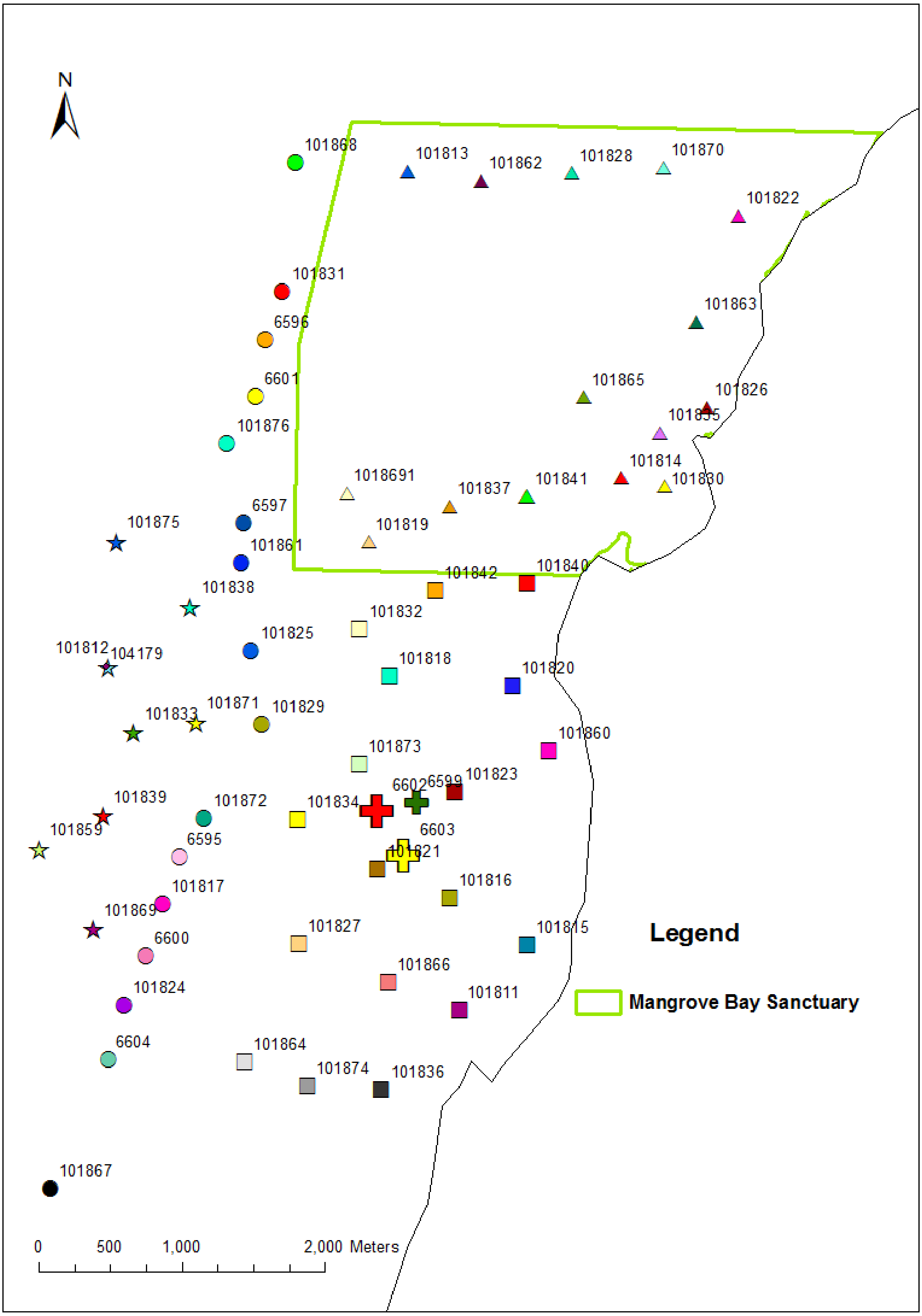


8153 Notes

Diurnal alternation of activity centres, with Lagoon during day, reef flat at night. Record breaks for a period around spawning during November, followed by detection on numerous reefslope and offshore receivers before returning to same lagoon area inhabited previously.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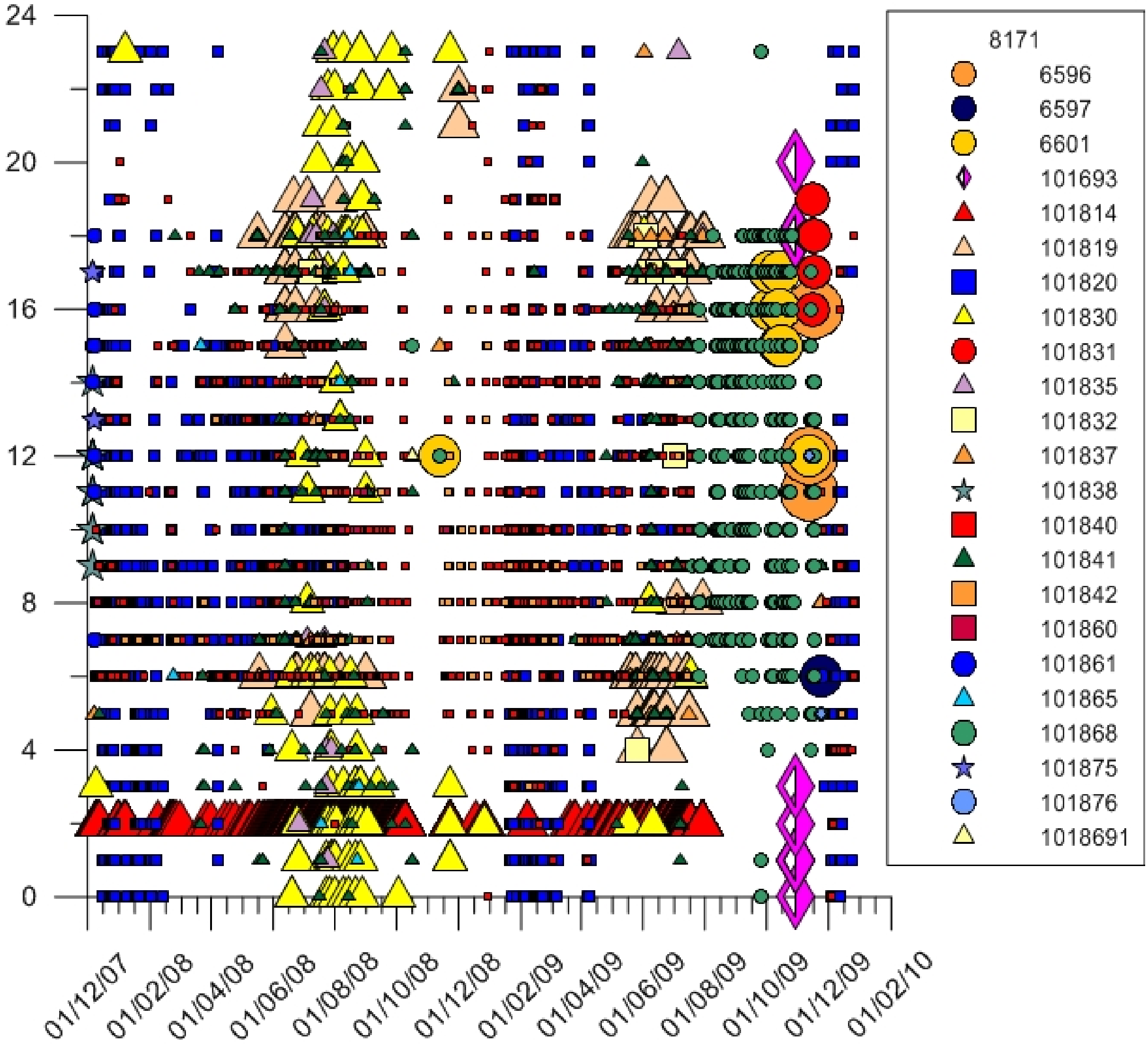
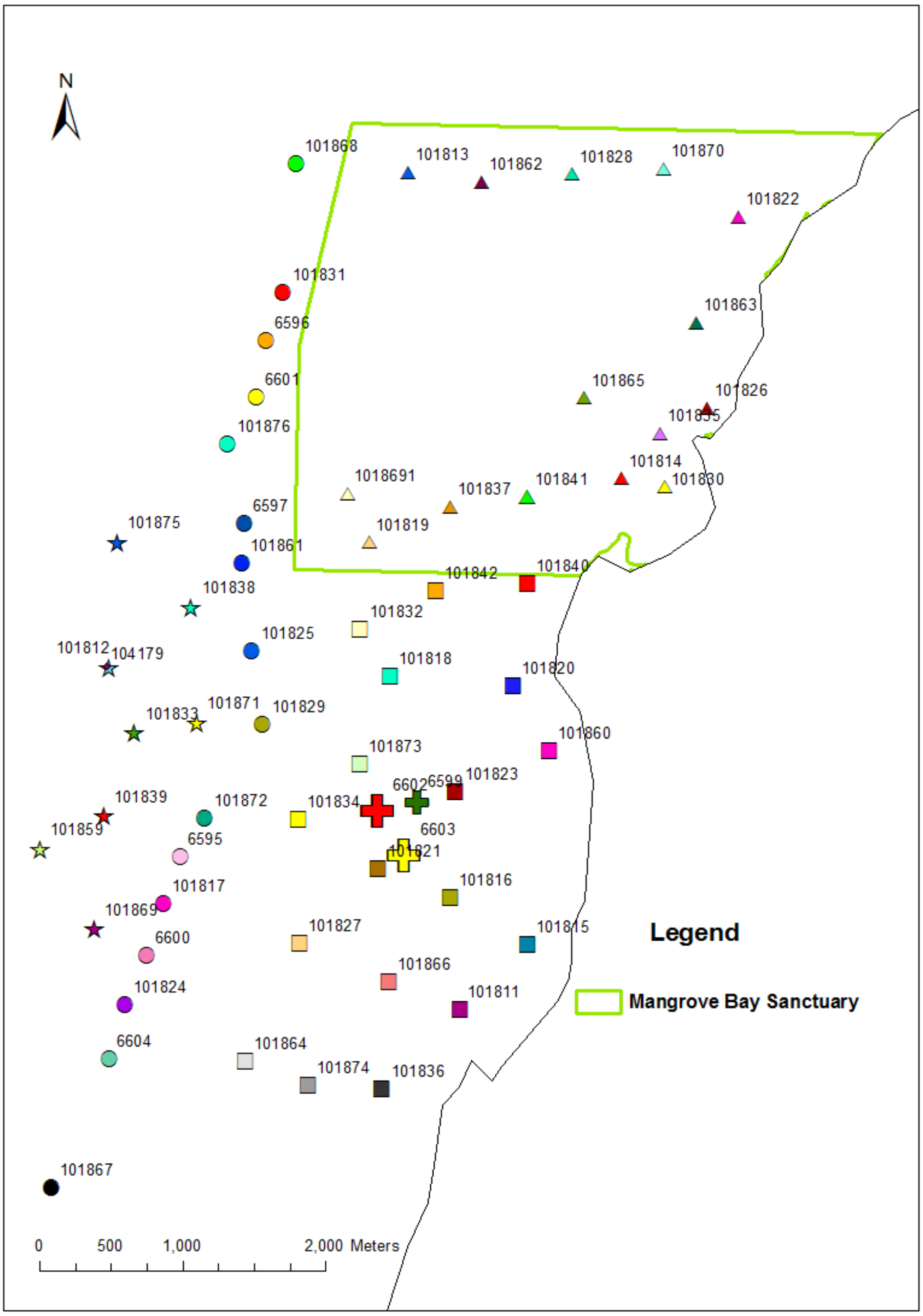
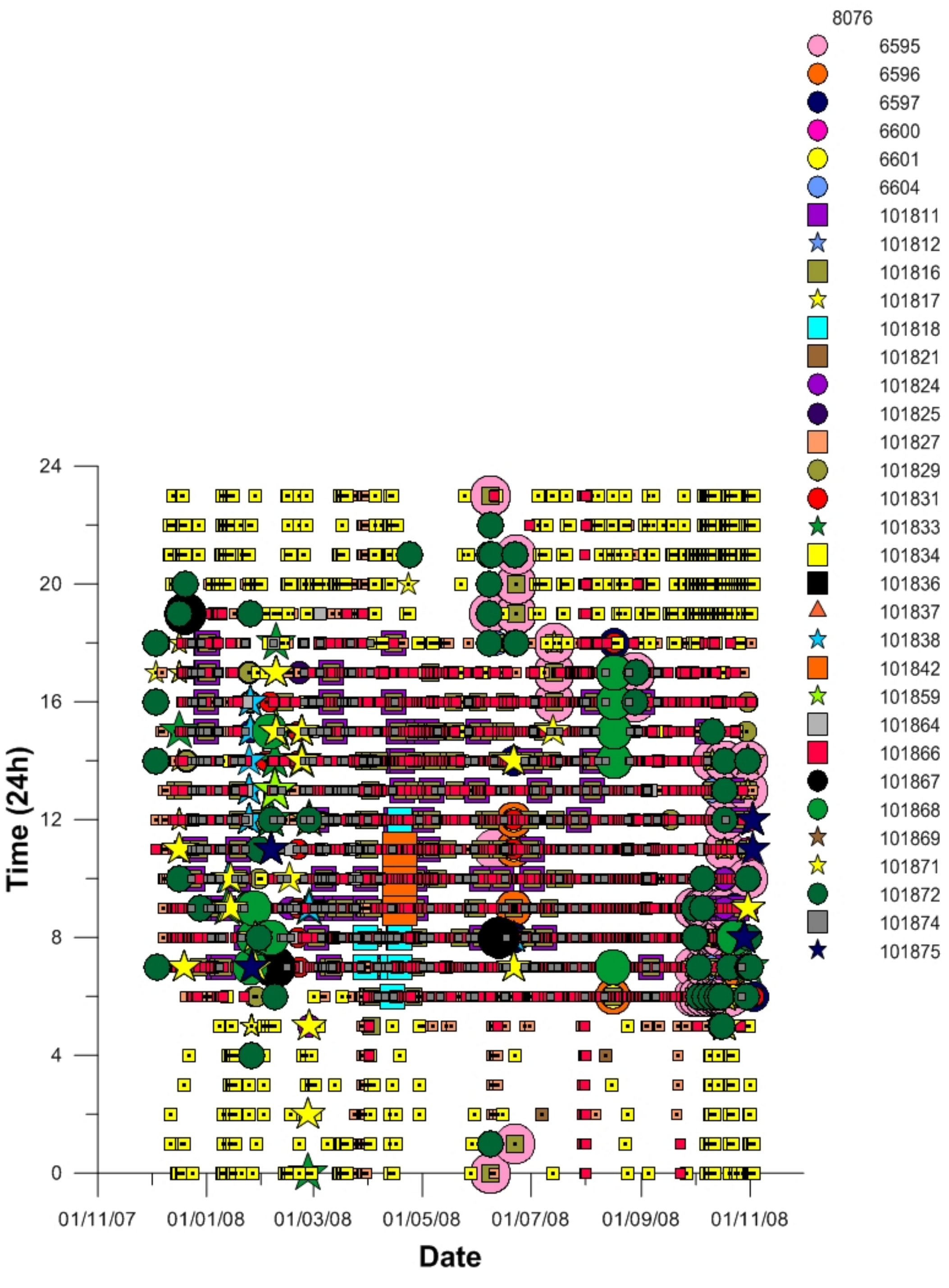


8171 Notes

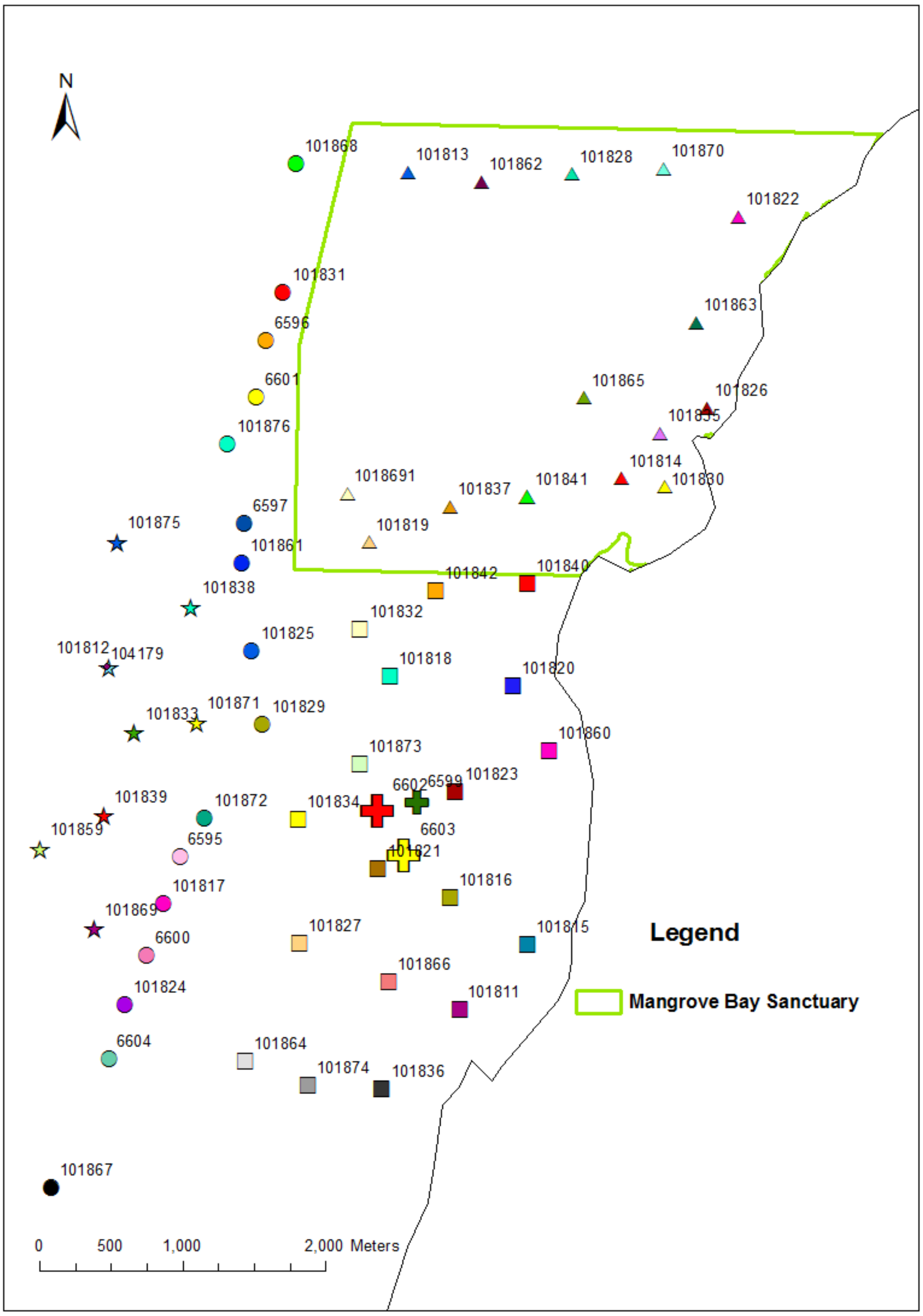
Tagged in spawning area off south passage November 2007, spent most of its time for the next year near shoreline. Left array for most of next November 2008,during spawning period, but was detected on reef slope at several sites. November 2009 spent extended periods off the front of the reef

Carangoides fulvoguttatus





8076 Notes
Distinct diurnal behaviour patterns with one location in particular at the mouth of South Passage channel the centre of activity at night. Daytime activity involved use of lagoon bommies and reef slope areas to the south of the passage. This individual did not utilise any of the areas to the north of the passage.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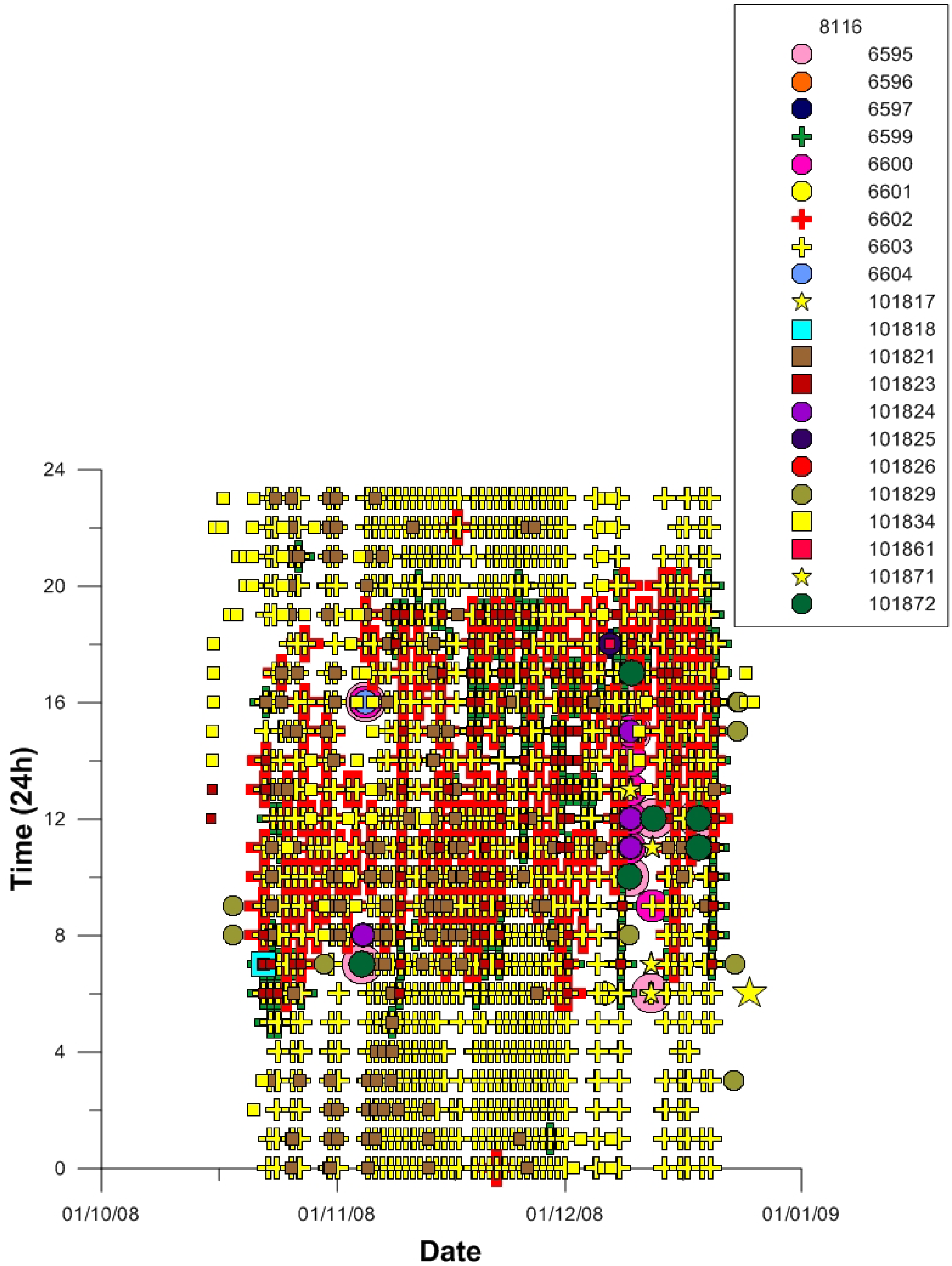

8116 Notes
Distinct diurnal behaviour patterns with one location in particular, a bommies in the lagoon inside South Passage, the centre of activity at night. Daytime activity involved use of other nearby lagoon bommies and reef slope areas to the south of the passage. This individual did not utilise any of the areas to the north of the passage.

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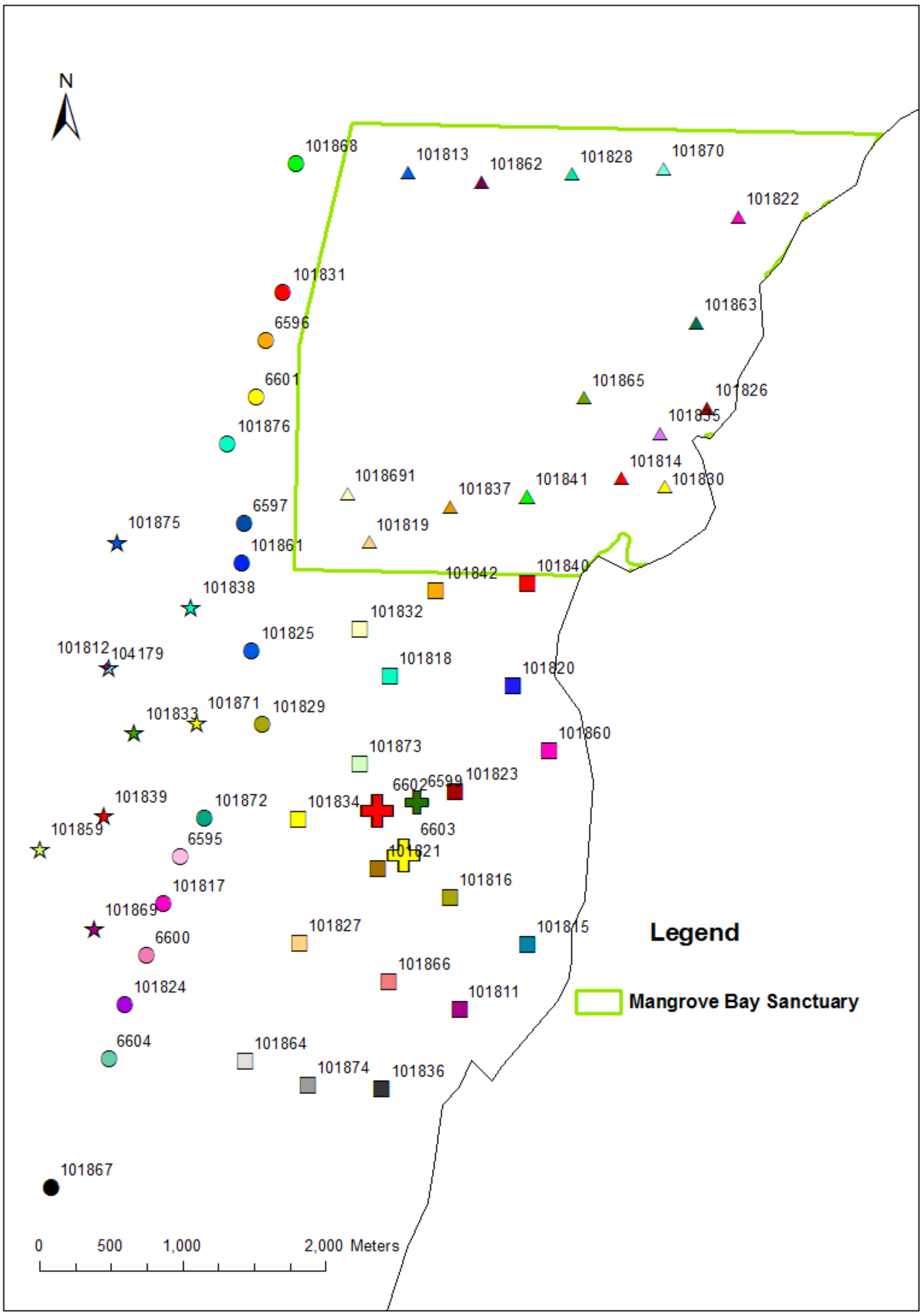
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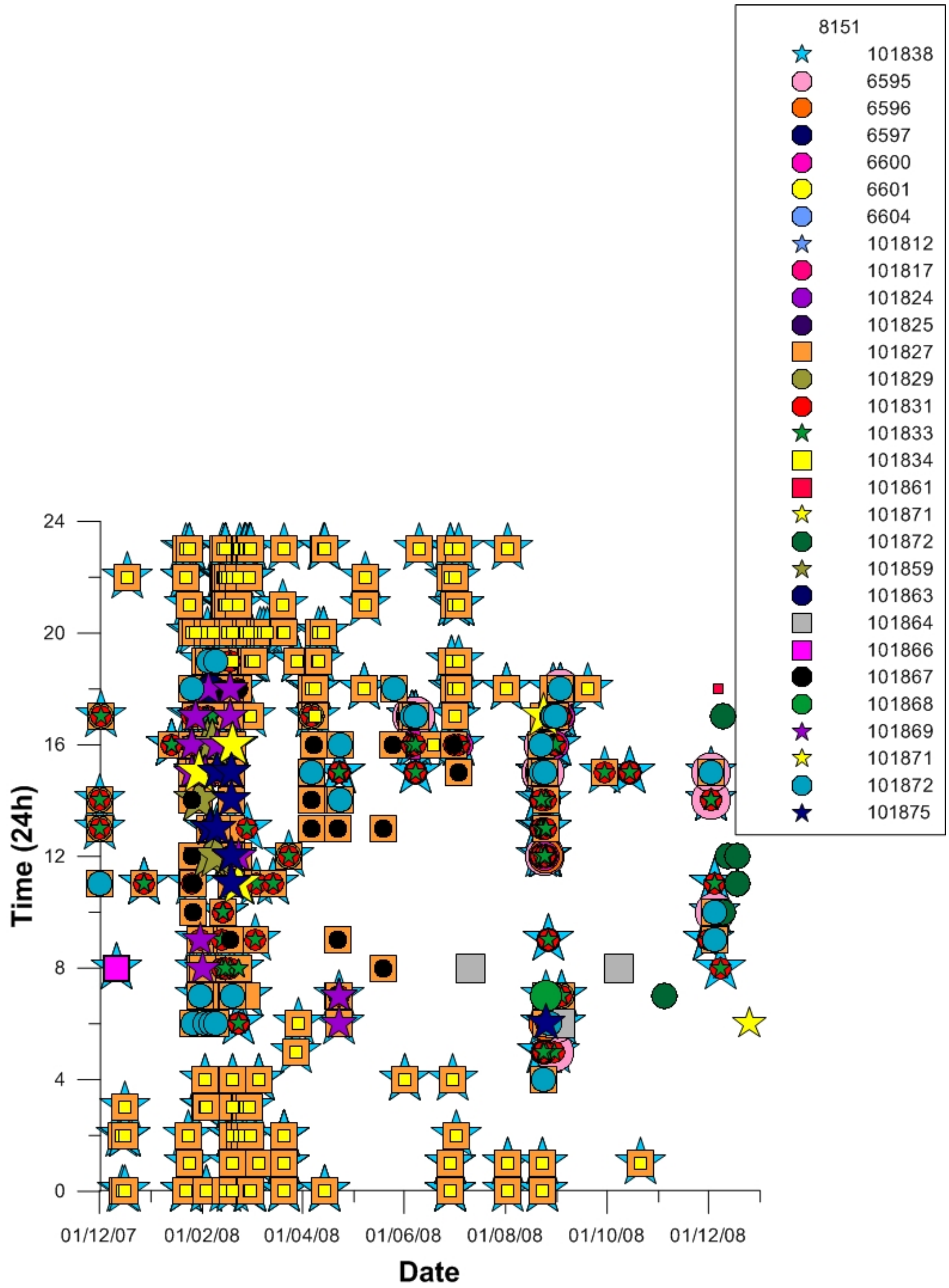
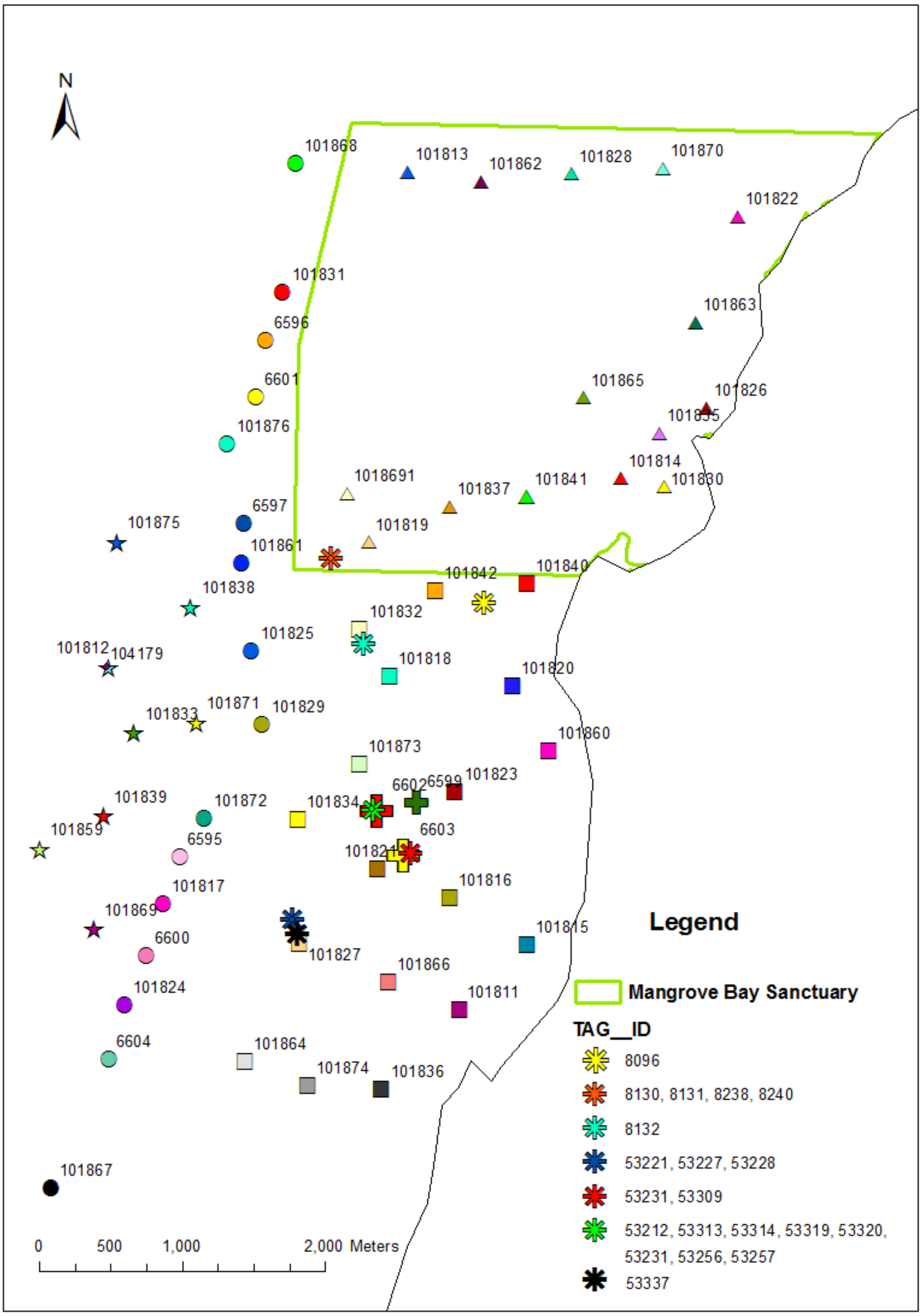
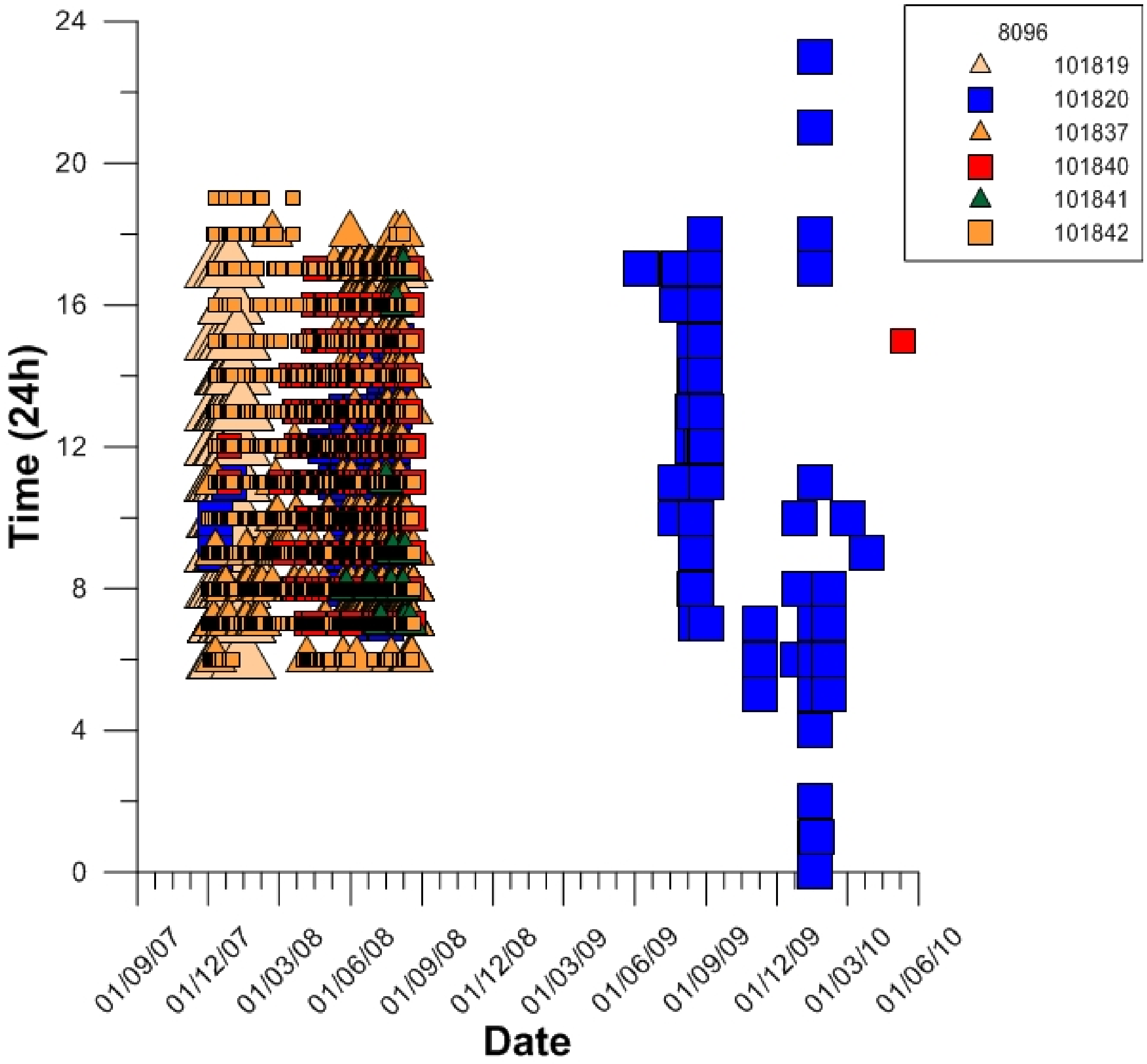


8151 Notes

Distinct diurnal behaviour patterns with nocturnal behaviour apparently shared between areas on the reef slope and the lagoon. Records of daytime activity are more sparse and indicate use of offshore areas in depths of >40m, as well as movements along the reef slope, with only occasional movements into the lagoon. This individual utilised areas both to the south and north of the passage.

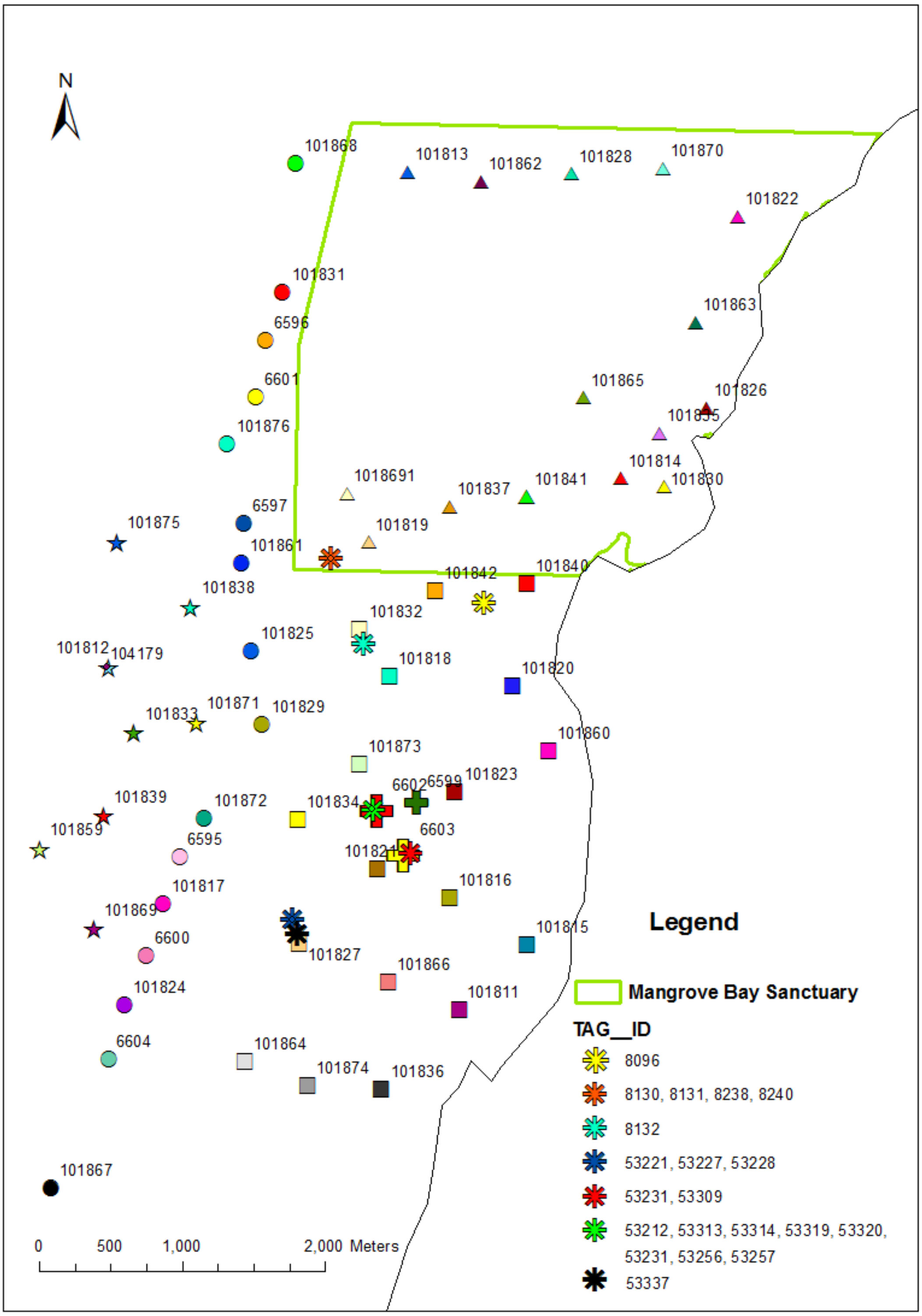
Coris aygula





8096 Notes

Initially activity centre was on reef flat areas in the south east of the sanctuary zone, though areas closer to the shore were also visited. The individual was absent for a period of approximately one year before re-establishing activity around a near shore receiver. Activity strongly diurnal though this was less pronounced in the latter period probably due to the reduced availability of cover that would attenuate tag signal during resting periods at night.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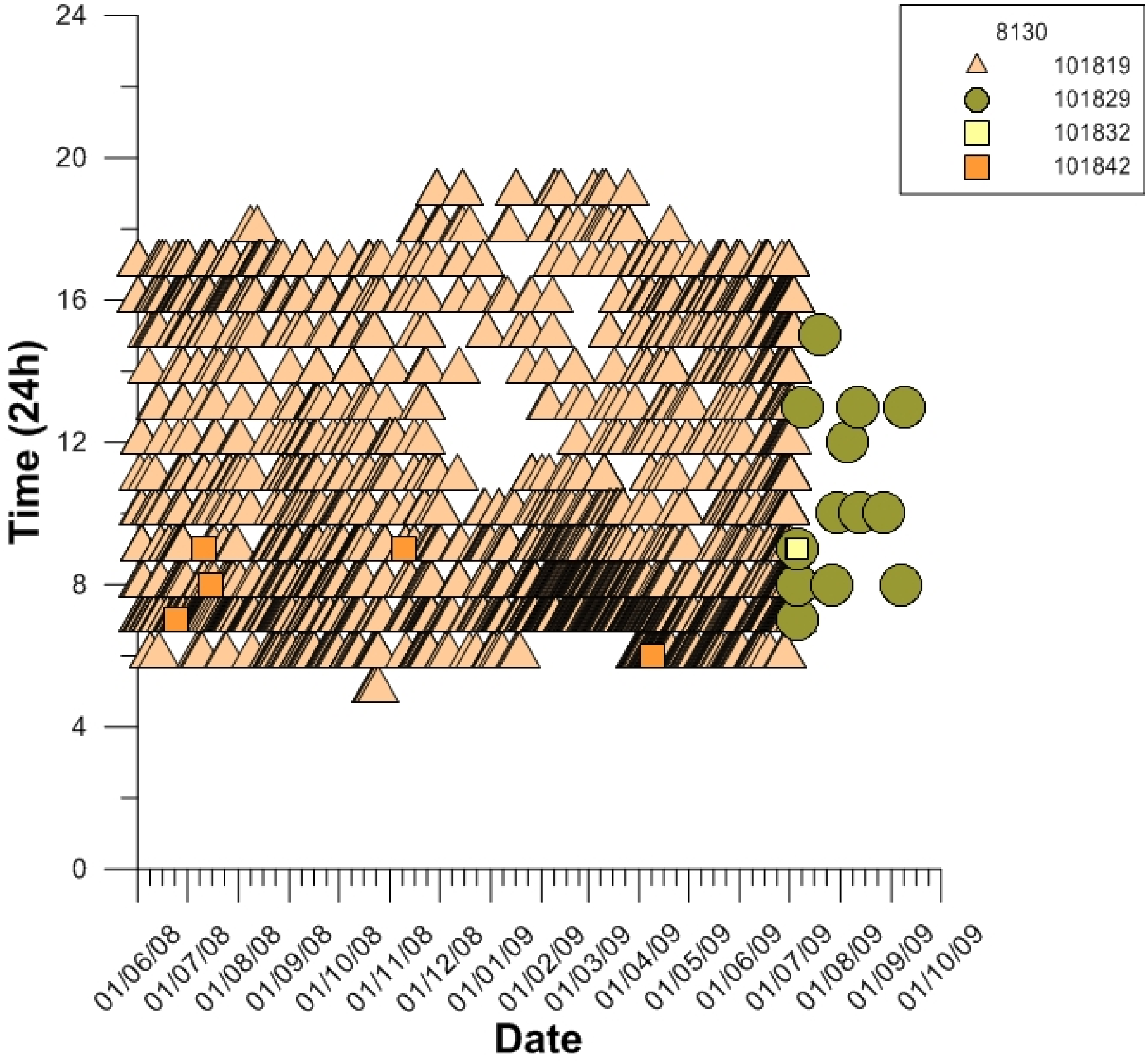
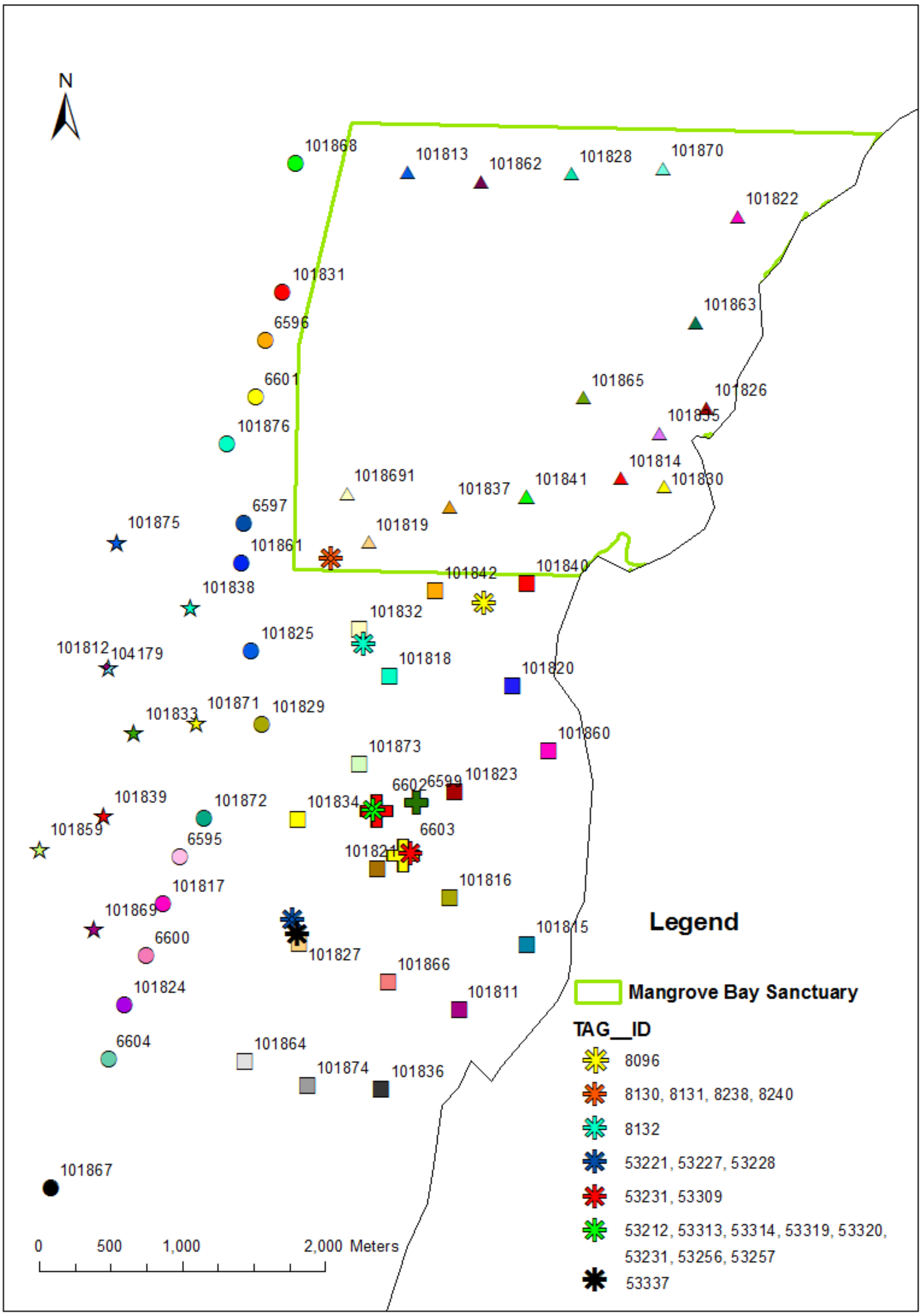


8130 Notes

Strongly diurnal activity with strong affinity to the reef flat. Abrupt shift to a new territory in the vicinity of the reef passage after one year.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Mangrove Bay Sanctuary
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8130, 8131, 8238, 8240
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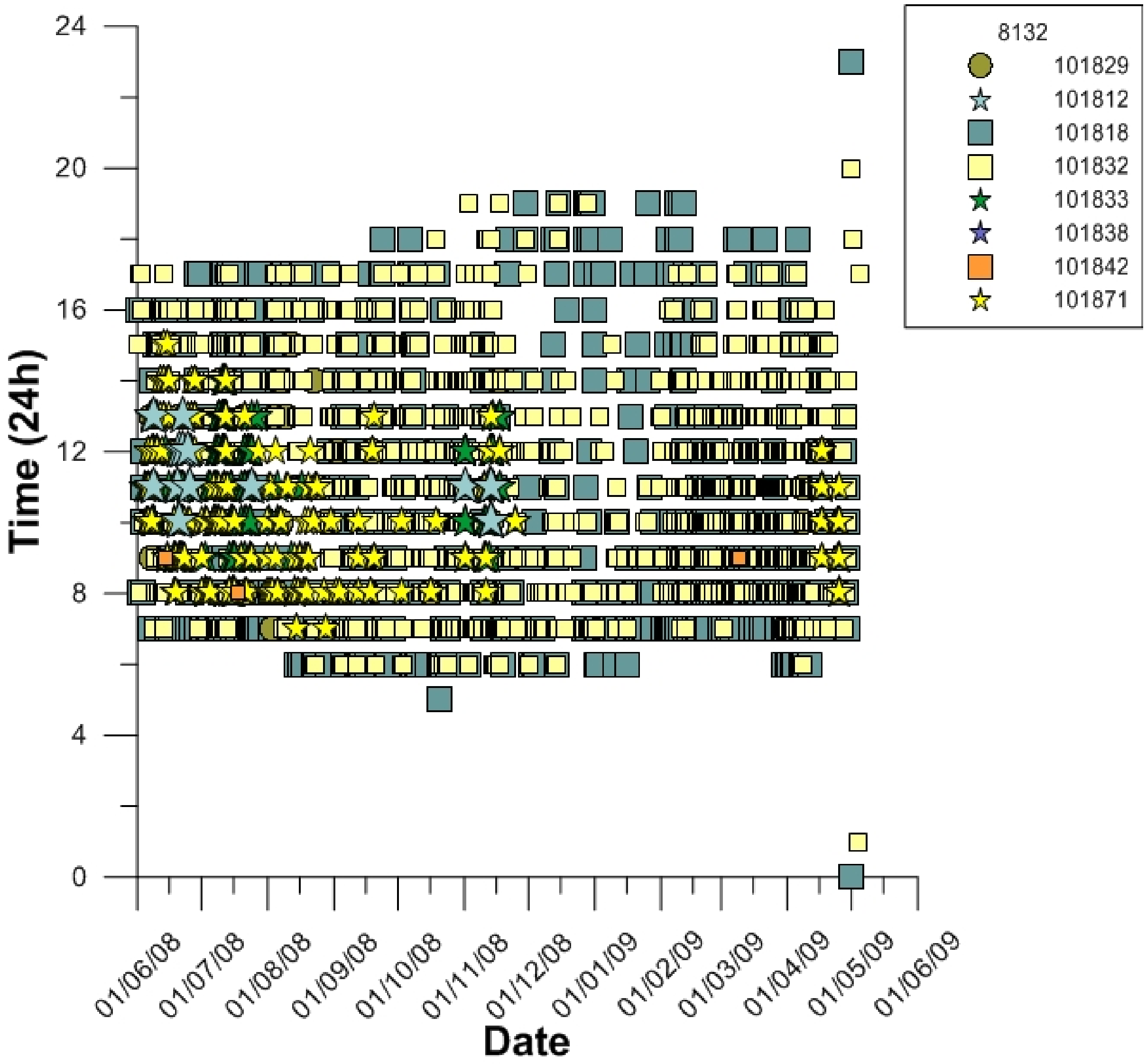
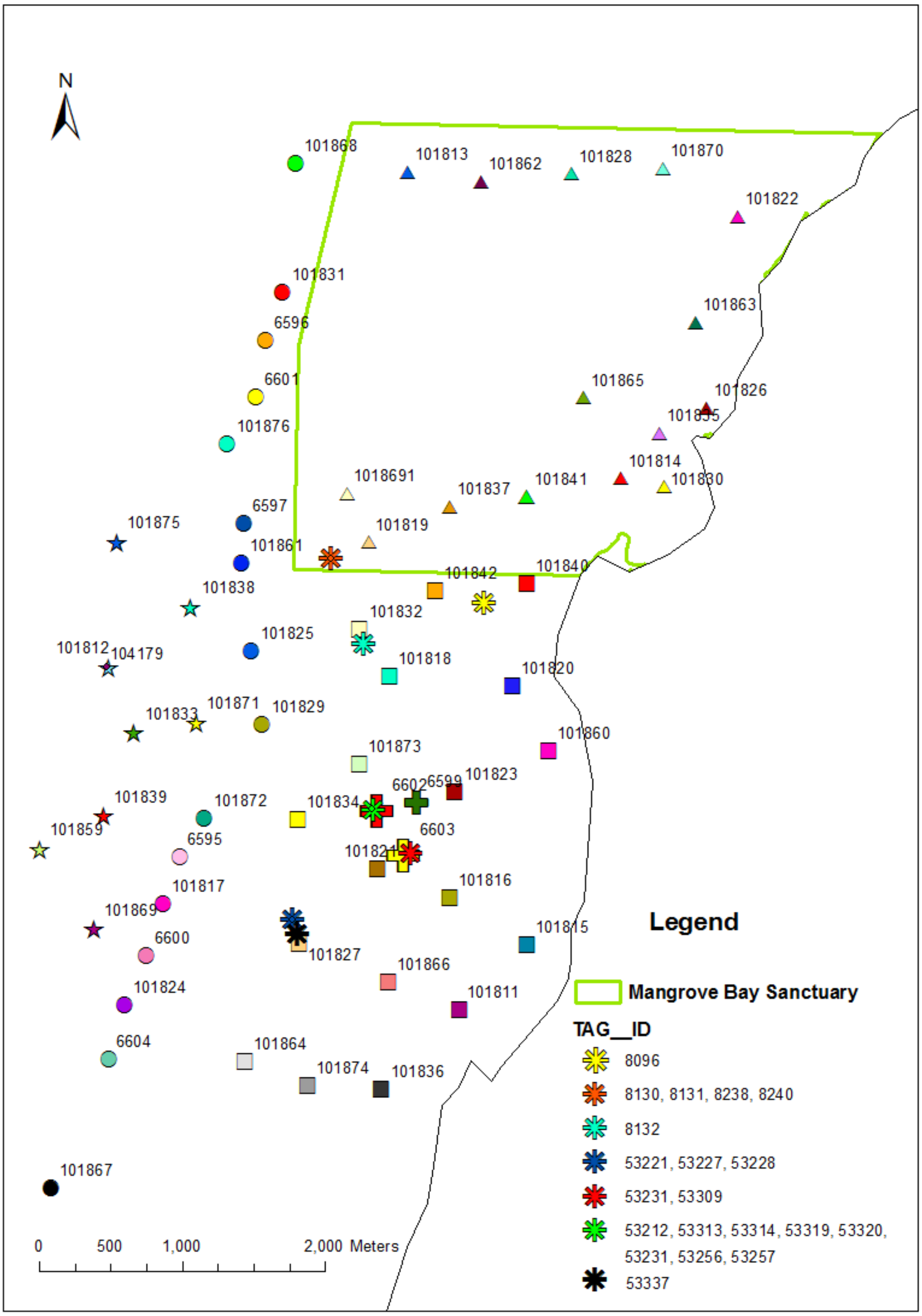
53337



Notes 8132

Strong diurnal activity pattern. Largely resident on the back reef area near to the point of capture, though excursions to distant off-reef areas in deeper water during the middle of the day were a prominent feature of behaviour over most of the record though these appeared to be infrequent during the summer from December to May.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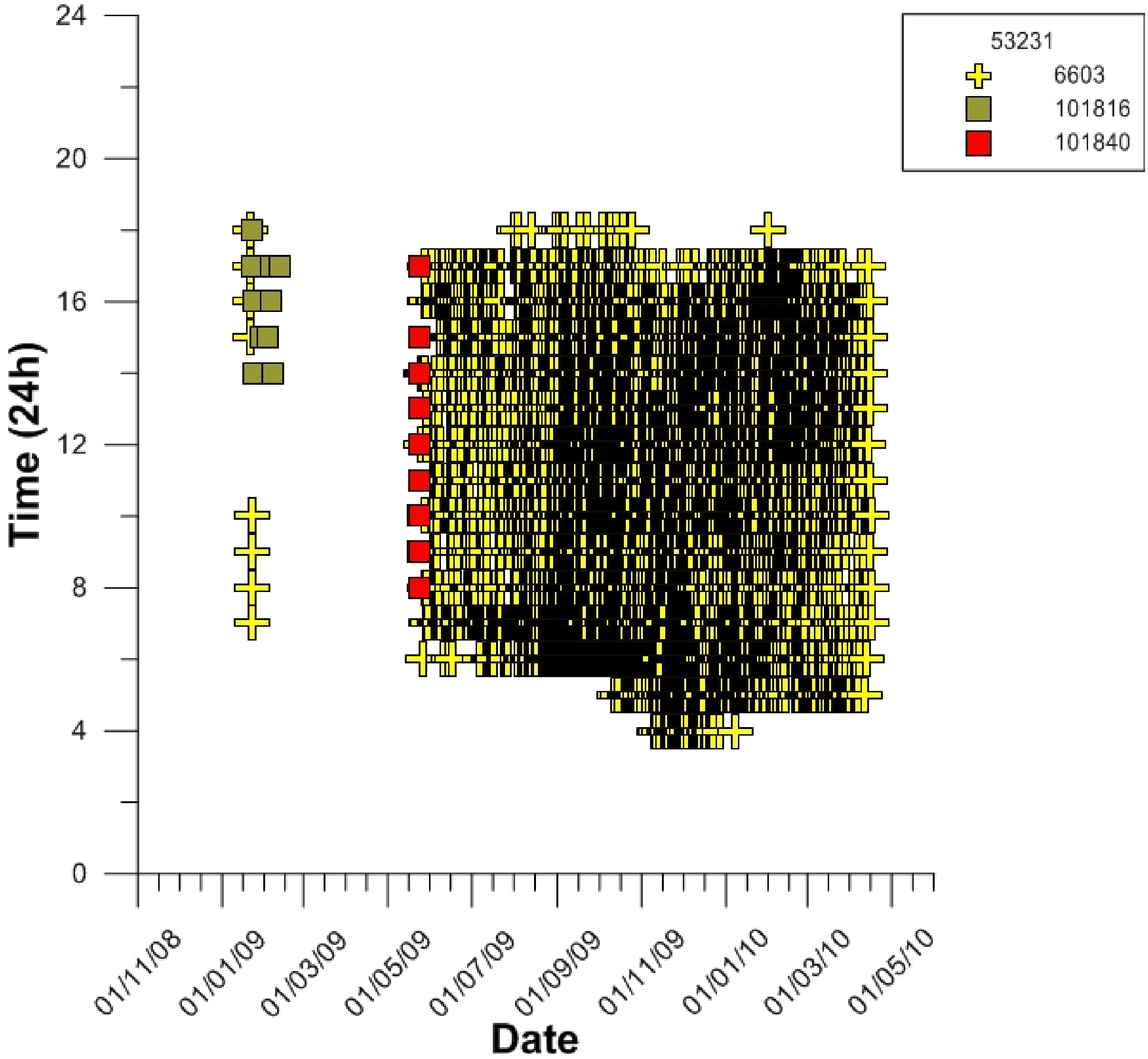
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101816
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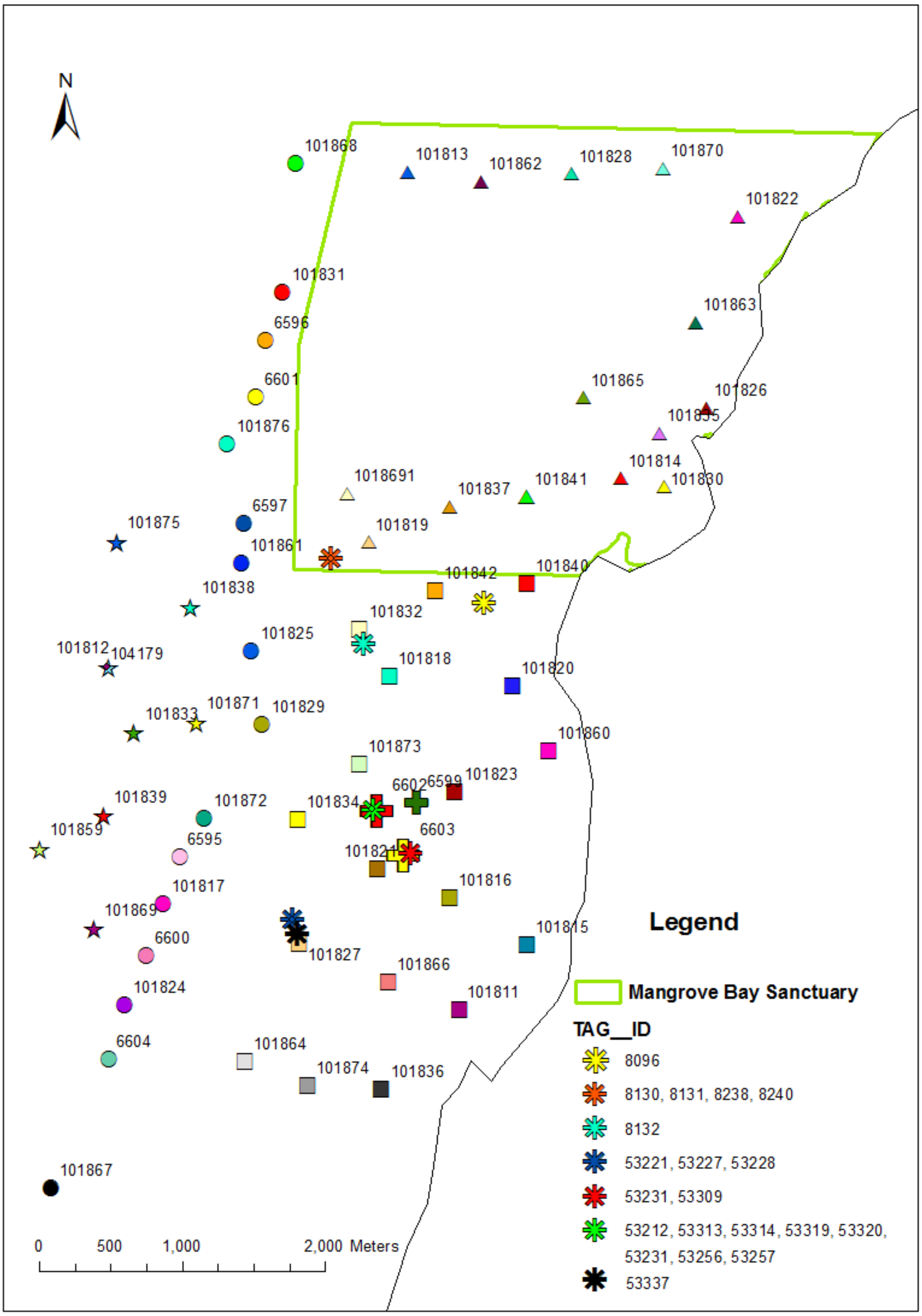
01/05/10
Date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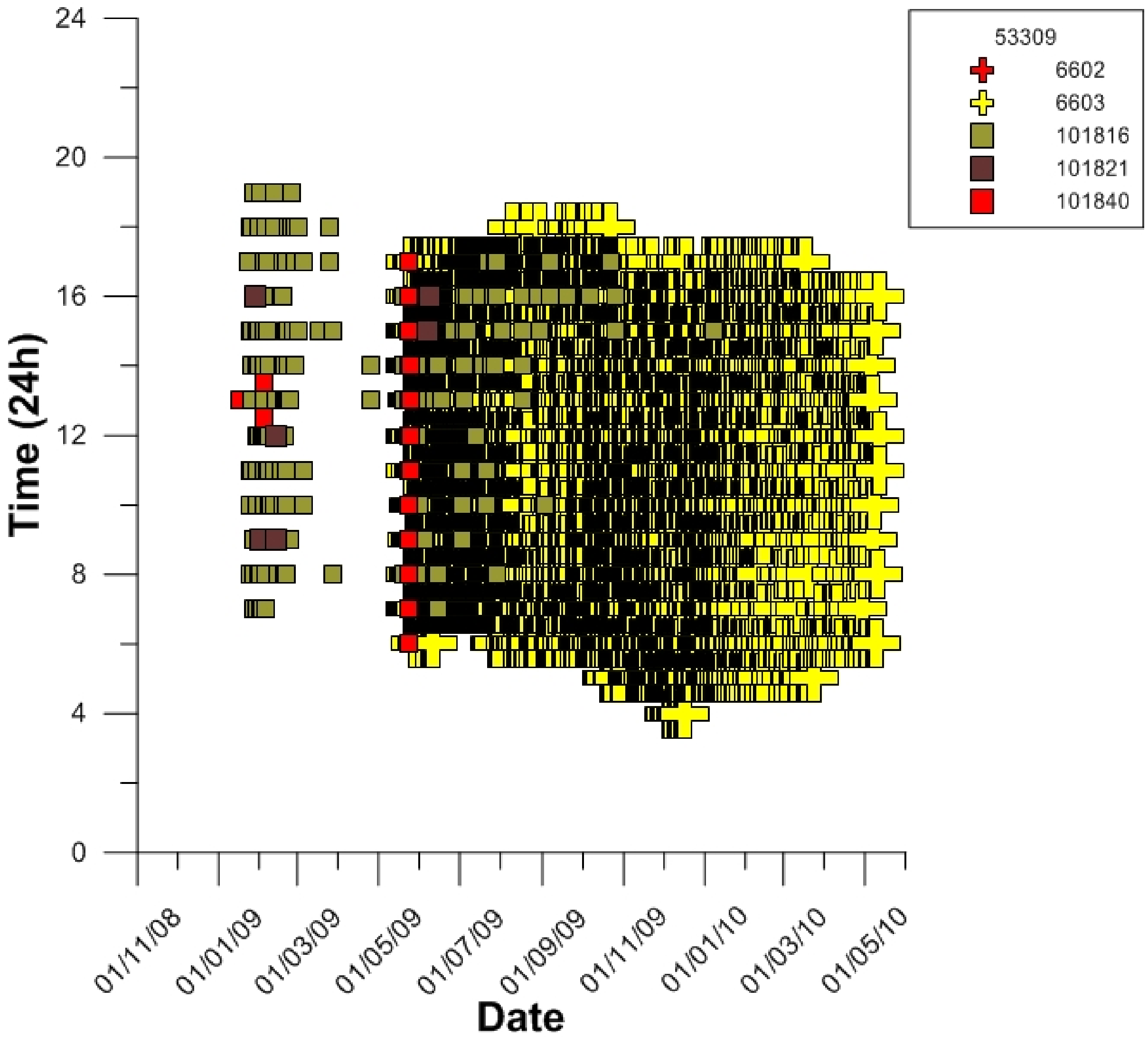

53309
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101840
Time (24h)
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01/05/09
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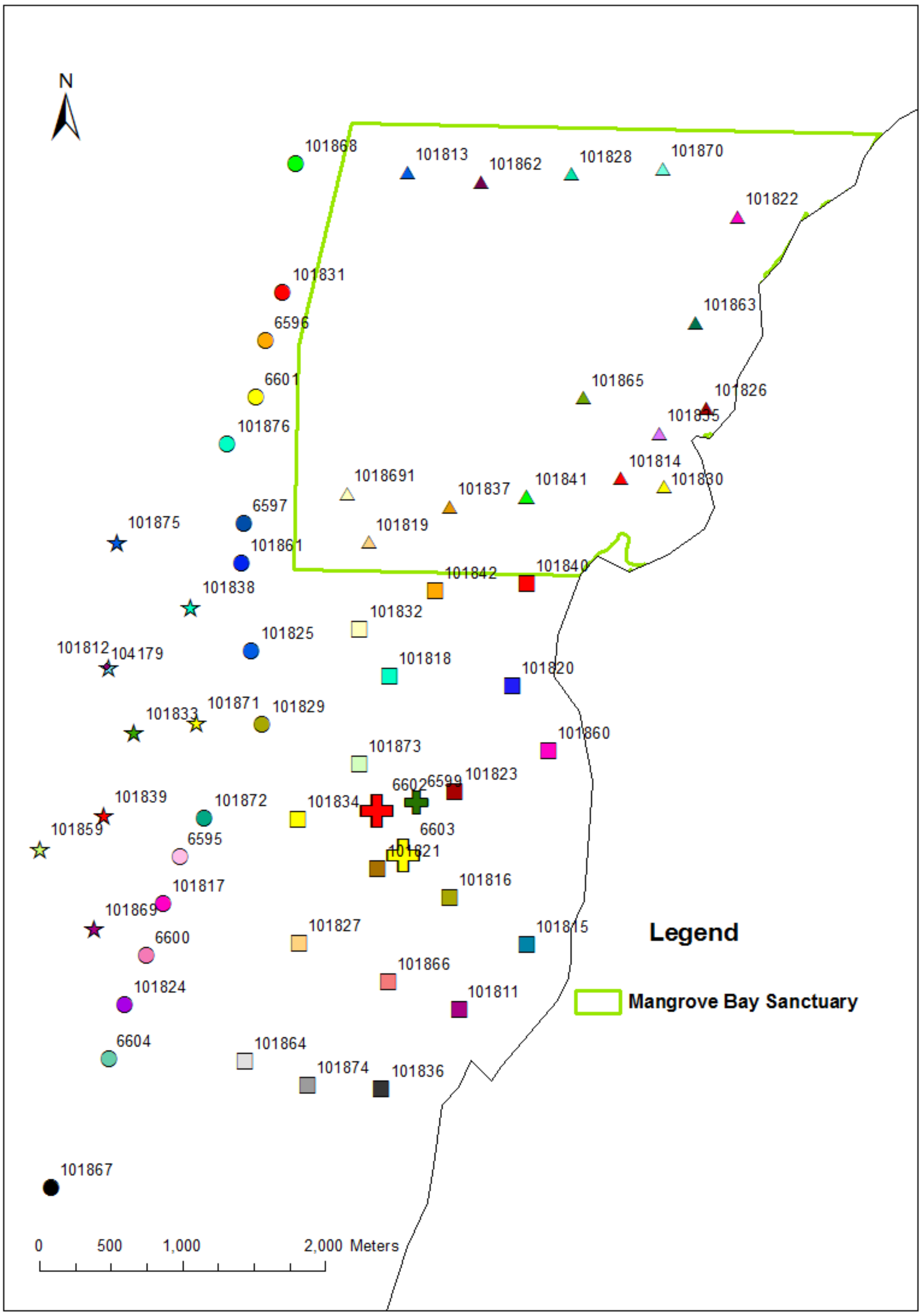
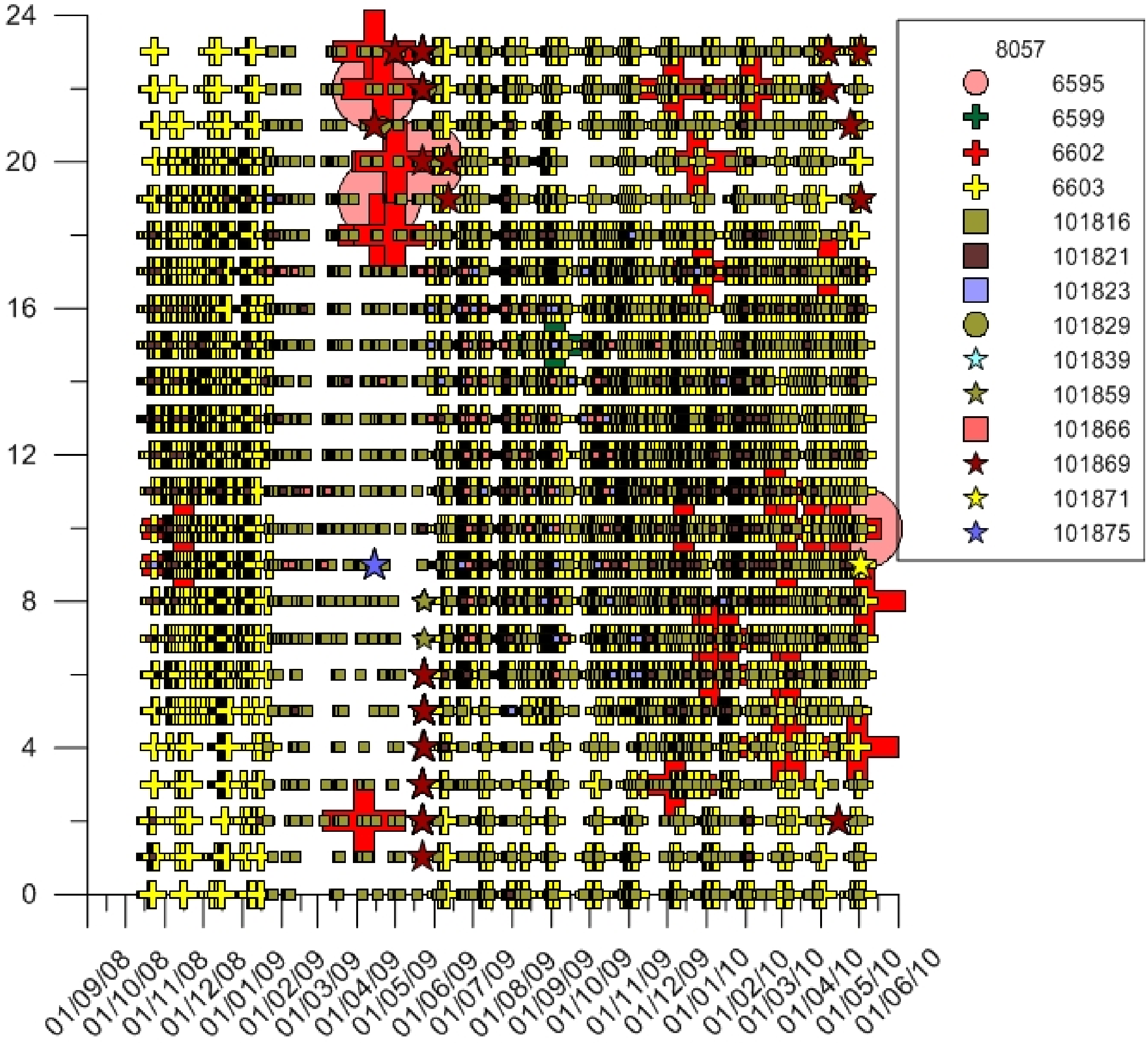
01/09/09
01/11/09
01/01/10
01/03/10
01/05/10
Date

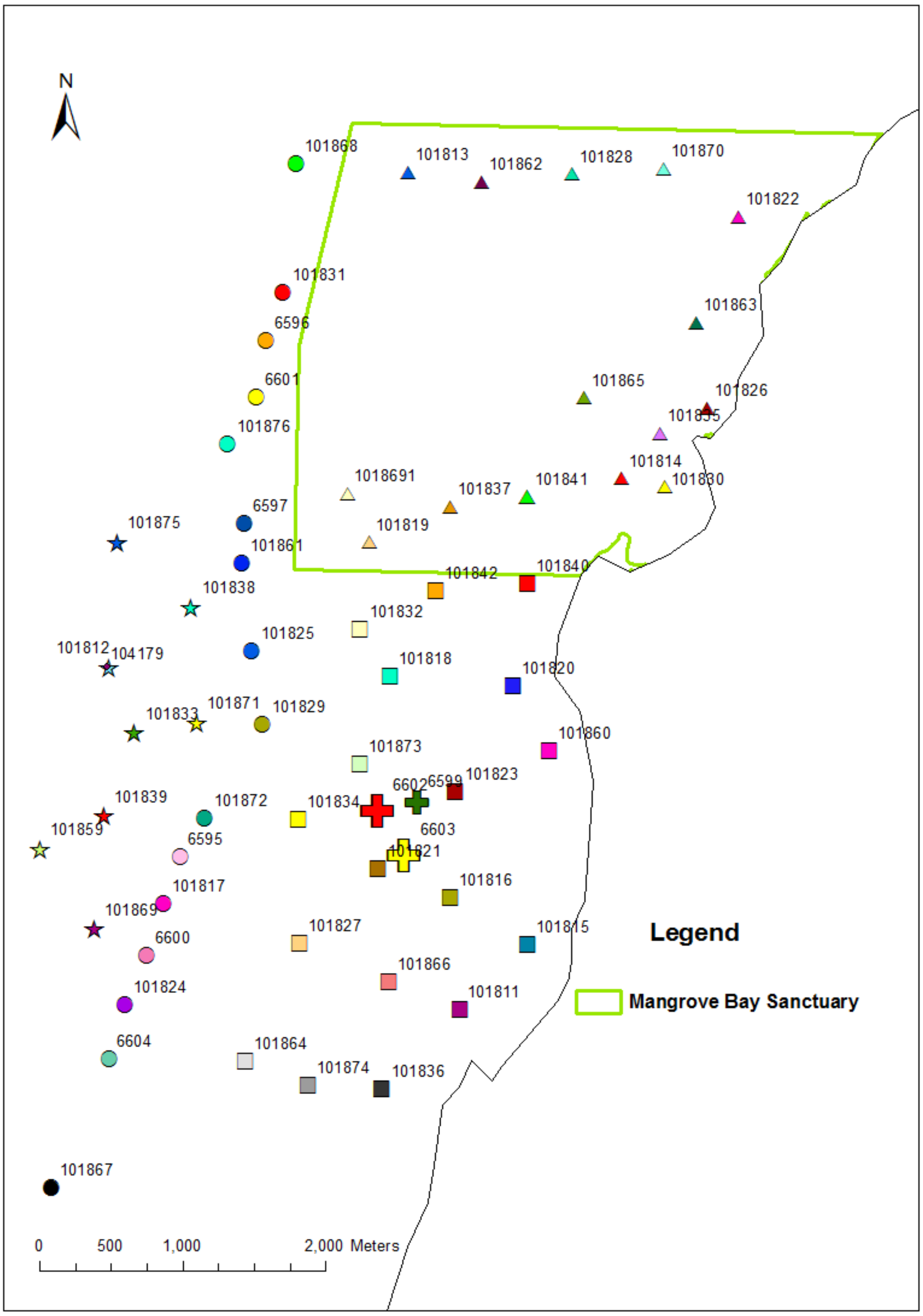
Kyphosus sydneyanus





8057 Notes

Consistently occupied areas near the tagging location around lagoon bommies inshore from south passage. Occasional movements to the reef slope.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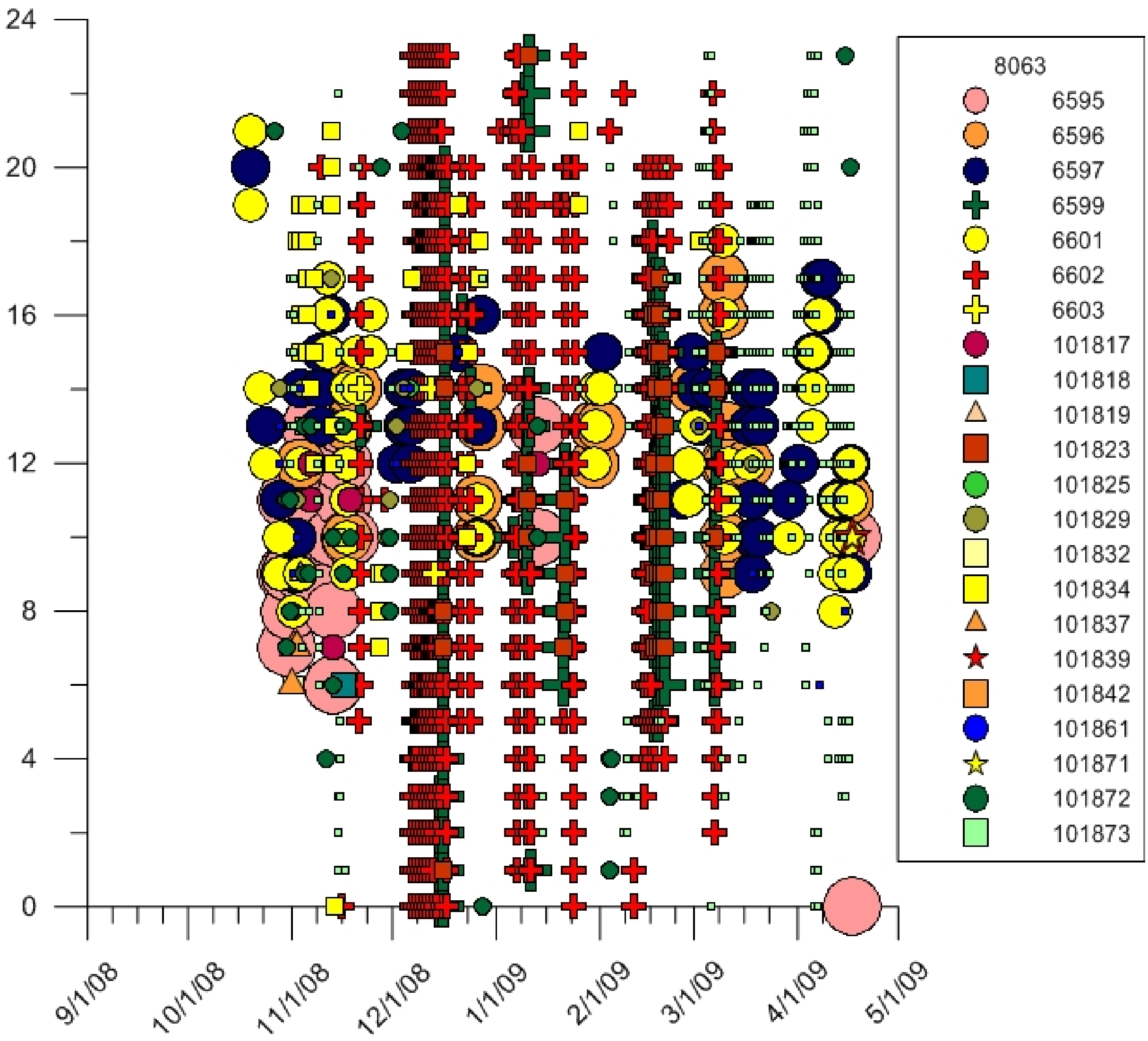
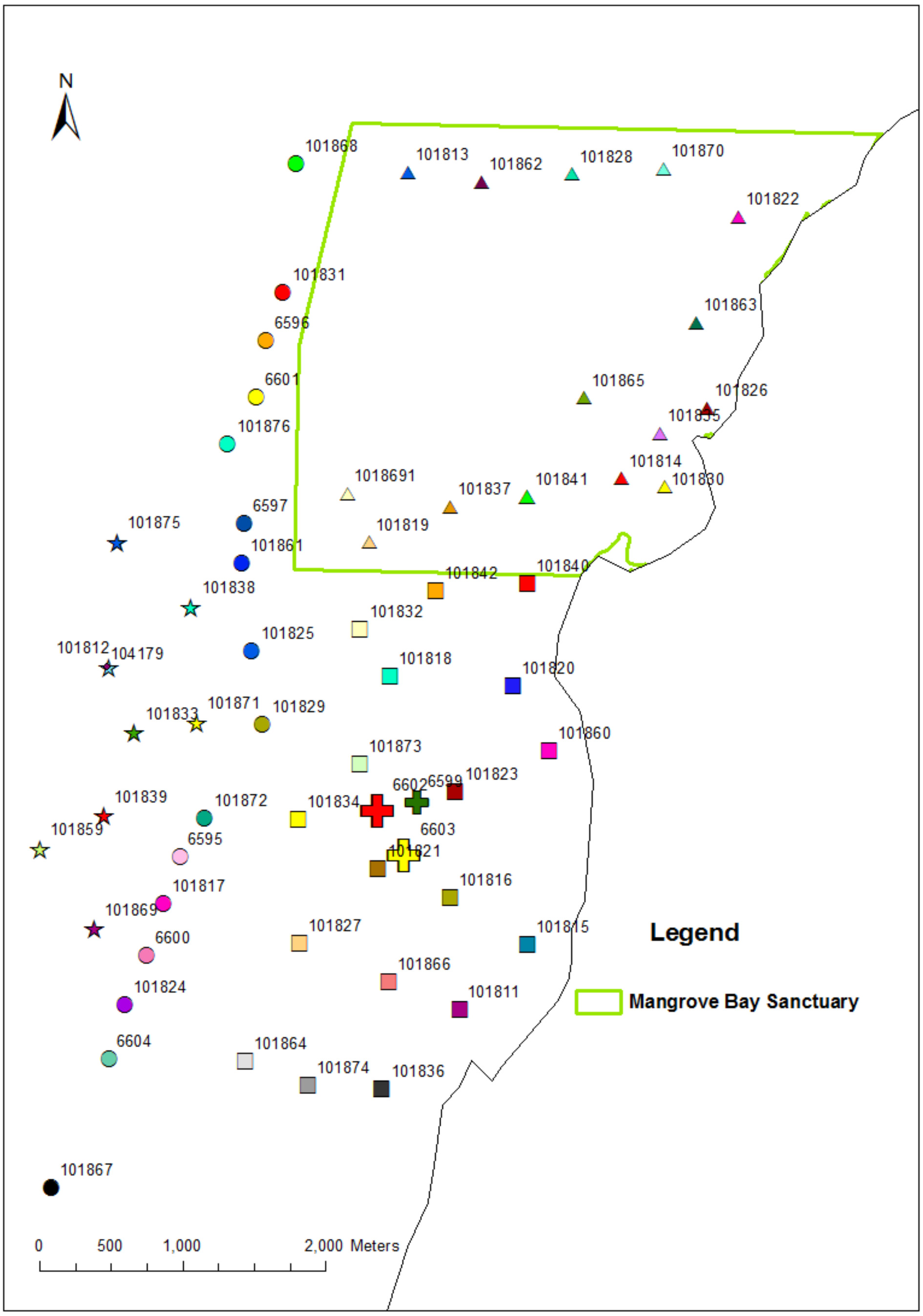
Legend
Mangrove Bay Sanctuary



8063 Notes

Diurnal variation in habitat use suggested with use of reef slope areas in the day but mainly detected around lagoon bommies during the night.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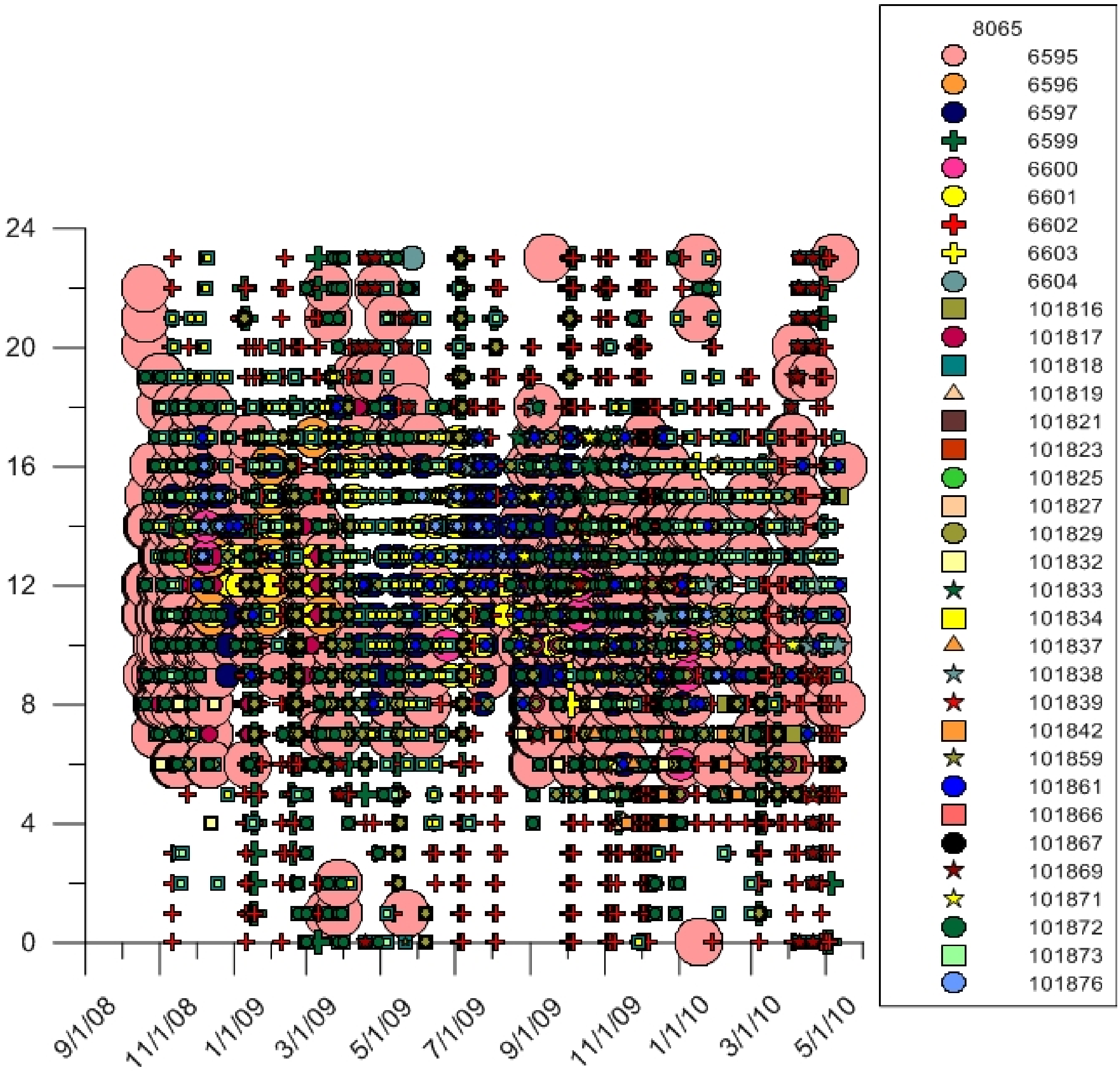

8065 Notes
Diurnal variation in habitat use suggested with use of reef slope areas in the day but mainly detected around lagoon bommies during the night.