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SPATIAL MANAGEMENT OF REEF FISHERIES AND ECOSYSTEMS: UNDERSTANDING THE IMPORTANCE OF MOVEMENT

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2004/002 Evaluation of spatial management of reef fisheries and ecosystems: understanding the importance of movement

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OBJECTIVES

1. To study the movement patterns of key reef associated fishes in Tasmania and the Northern Territory.

2. To link movement patterns with critical life history events and habitat utilisation.

3. To evaluate these results in the context of spatial management options for specific fisheries, including performance of closed areas.

NON-TECHNICAL SUMMARY

OUTCOMES ACHIEVED TO DATE

In the Northern Territory, the primary outcome was an improved understanding of the temporal and spatial dynamics of *Protonibea diacanthus* aggregations. Most importantly, the study demonstrated that the aggregations are likely to be separate adult populations. This has significant implications for stock assessment and management of the resource as such populations are likely to be highly vulnerable to localised depletion.

In Tasmania, the primary outcome was an improved understanding of the temporal and spatial movement patterns of *Cheilodactylus spectabilis* and *Latridopsis forsteri*. *C spectabilis* only moved to depth during the spawning season, suggesting that the deep water stocks that fishers believe act as a refuge population are in fact temporary residents during the spawning season, and the fishery may in fact target a major component of the stock. The result of *C. spectabilis* being highly site attached and occupying very small core areas of reef suggests that fishing has the potential to cause localised and serial depletion of this species. Despite being a mobile species, some *L. forsteri* individuals were site attached, suggesting that closed areas may be of some benefit for the sustainable management of this species.

Movement information is essential to understanding many aspects of exploited populations such as replenishment of fished reefs (from local, adjacent or deep reefs), aggregation behaviour, critical habitat requirements and cyclic variation in catch rates.

It is particularly important to the understanding and application of spatial fisheries management techniques, including MPAs.

This project focused on species of commercial interest in both Tasmania and the Northern Territory in order to evaluate the effectiveness of spatial management for fishes with a range of life histories.

The Northern Territory component focused on the black jewfish *Protonibea diacanthus,* a large tropical sciaenid that forms a substantial component of both commercial and recreational inshore fisheries in the region. Fishers target spatially and temporally predictable aggregations, and catches have increased substantially over the past decade. Repeated fishing of aggregations is not considered to be sustainable, particularly given the decline of *P. diacanthus* at other localities in Australia and the Asian-Pacific region.

Acoustically tagged fish were monitored at two of the three known major aggregation sites, Channel Point and Chambers Bay, to determine whether the aggregations were separate populations and whether management measures such as spatial and temporal closures might be effective.

No evidence of movements between aggregations within the time frame of the study (~ 1 year) was observed although there was evidence for different behavioural types in the aggregations, with ‘movers’, which were highly mobile and ‘stayers’, which were site attached to varying degrees. Fish monitored for ≥ 1 year showed a decreased presence during cooler months, and an increased presence during warmer months, when peak spawning occurs. The tidal cycle significantly influenced the detection of tagged fish, with detections peaking on running tides. This coincided with the peak period for catching *P. diacanthus,* evidence that suggests this is when they are most active.

The existence of separate adult populations at each aggregation site has significant implications for assessment and management of the *P. diacanthus* resource in the NT, with the potential for each population to be highly vulnerable to localised depletion. Area closures during the peak summer spawning period may be a practical way to manage the resource, and would protect fish moving in and out of the aggregation sites to spawn. However, given *P. diacanthus* appears to form resident spawning aggregations, with fish present and caught at the sites year round, the fish would remain highly vulnerable during other periods of the year, potentially negating, or at least reducing the benefits of seasonal closures. As such, other management measures may need to be looked at in combination with seasonal closures, such as reducing catches in the different sectors of the fishery.

The Tasmanian component focused on two key large temperate reef species found in inshore south-eastern Australian and New Zealand waters, banded morwong *Cheilodactylus spectabilis* and bastard trumpeter, *Latridopsis forsteri*. Banded morwong are commercially gill netted in Tasmania and Victoria, and sold live for the Asian restaurant market. In Tasmania the biomass has been significantly fished down and as a result the population is mostly younger fish that are growing faster and maturing earlier. The fish down of the biomass has been compensated to some extent by increasing productivity and recruitment, which means that the stocks have become increasingly reliant on recruitment events. As it is a live-fish fishery, there is very little fishing at depths greater than 30 m, to avoid barotrauma. Fishers believe that stocks in deep water habitats may buffer against overall stock decline, acting as a ‘refuge’ population. Bastard trumpeter is a coastal schooling fish that resides on inshore reefs as juveniles, moving offshore after maturing. The fishery exhibits strong recruitment variability, is targeted by both commercial and recreational fishers and is based almost entirely on juveniles. All make them vulnerable to overexploitation.

Large- and fine-scale acoustic monitoring was used to examine the temporal/spatial movement patterns of both species on rocky reefs on the Tasman Peninsula. Banded morwong were highly resident, occupying very small core areas of reef which were maintained over the study period. Bastard trumpeters were more mobile, but a third of the monitored individuals were site attached at the scale of the detection range of a single receiver (~200 m). Both species were not detected on receivers separated by large areas of sand (embayments and offshore reef), suggesting that these act as natural barriers to movement.

Both species demonstrated clear diurnal activity patterns. Banded morwong fitted with depth tags moved to depths > 20 m and up to 45 m each morning, returning to depths < 20 m in the afternoon. This movement was only observed during the spawning season which suggests that the so called deep water stock that fishers believe acts as a refuge is more likely to be temporary residents during the spawning season. If this is the case the fishery is probably targeting a major component or all of the stock. Combined with the observation that they are highly site attached and occupying core areas as small as 175 m^2, fishing has the potential to cause localised depletion with the additional threat of serial depletion. Given that morwong populations are partially structured by size it also supports the hypothesis that the removal of biomass has led to reduced competition for space, with smaller fish replacing larger fish removed by fishing.

Spatial protection, even at a small scale (< 1 km^2), is likely to provide protection to morwong because they are highly site attached and are shown to share small patches of reef. Trumpeter, although relatively more mobile, are also likely to benefit from spatial protection because some individuals were shown to be site attached and were not detected moving across sand boundaries between reefs.

KEYWORDS: Black jewfish *Protonibea diacanthus*, banded morwong *Cheilodactylus spectabilis*, bastard trumpeter *Latridopsis forsteri*, spawning aggregations, site fidelity, residency, acoustic monitoring, fisheries management, movement, home range, core areas, spatial management.

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BACKGROUND

Fisheries managers have used spatial management techniques such as nursery areas and spawning area closures for many years, however, there has been a resurgence of interest in spatial closures because of number of marine protected areas (MPAs) that are being proclaimed in coastal waters around the world (Smith *et al*. 2003). While in Australia the primary motivation for the establishment of a National System of Marine Protected Areas (NRSMPA) is the conservation of biodiversity, MPAs are used in fishery management in many parts of the world. Spatial closures remain an import part of the management toolbox especially as our knowledge of the biology of certain target species improves.

Rigorous assessment of the effectiveness of spatial closures (including MPAs), at both the species and ecosystem level, is of crucial importance. Understanding the movement patterns of a species is essential for determining whether they will derive benefits from spatial management, and how these benefits may be maximized.

Movement information is essential for understanding the source (if any) of replenishment of fished reefs (via movement from local, adjacent or deep reefs), aggregation behaviour relative to stock density, critical habitat requirements and interpreting cyclic variation in catch rates. Few Australian studies have examined the movement patterns of reef fishes in any detail Barrett (1995), Cappo (1995), Murphy and Lyle (1999), Connolly et al (2002) and Edgar et al. (2004), and in most cases they include few commercial species, and lack resolution on a spatial and temporal scale. Fisheries such as those targeting the "live" banded morwong in Tasmanian and black jewfish in Northern Territory urgently require movement information to make reliable stock assessments. In both cases it is not known to what extent fishing in a restricted location or depth range is influencing the overall stock. Movements may be small, with substantial reserve stocks at depths or locations outside the fished areas buffering against overall stock decline, or alternatively the fishing of aggregations or selected depths may be targeting the overall stock.

The paucity of detailed movement information for fish species is primarily consequence of the level of effort required to obtain reliable estimates of movement over a meaningful range of spatial and temporal scales using traditional tagging methods. The development of ultrasonic telemetry technology has overcome these difficulties, providing a means of remotely tracking fish movement over a broad range of spatial and temporal scales, without the need to recapture tagged animals. The Tasmanian Aquaculture and Fisheries Institute (TAFI) has developed a substantial ultrasonic telemetry capability based on the acquisition of capital equipment and an expanding expertise in utilising this technology to understand movement patterns. This capability can be used to substantially advance our knowledge of the movement patterns of reef associated species in Australian waters.

By focusing on species of commercial interest in each State we propose to evaluate the effectiveness of spatial management for fishes with a range of life histories (schooling, resident, migratory). The influence that this information has on the outcome of stock assessments of target species will be investigated. The study would include key species within each region so that we generate solid information on species of particular interest to local area managers, planners and interest groups.

NEED

Little is known of the movement patterns of most commercial reef species, an aspect that is crucial for evaluating the effectiveness of spatial management and interpretation of local stock dynamics. By undertaking a broadly applicable movement study drawing on examples over an Australia wide scale and using model species representing differing life histories, we will address a key issue identified in several national strategic priorities (SCFA Research Priorities for Australian Fisheries and Aquaculture - Program 4). These priorities include understanding the ecosystem effects of fishing and the need to assess the merits and performance of spatial management. They were identified at the Aquatic Protected Areas R&D workshop (Cairns) and in a recent spatial management discussion paper by Smith et al (2003).

In Tasmania, defining movements of commercial finfish species (e.g. banded morwong) between and within reefs has been identified as an important research issue by the Scalefish RAG, and essential for understanding local stock dynamics and interpreting CPUE data. Current fishing practices target juvenile trumpeter species, and spatial ‘nursery area’ closures may be one option of ensuring a significant proportion of fish reach maturity before becoming vulnerable to the fishery.

In the Northern Territory the black jewfish is an important species for both commercial and recreational fisheries, yet it appears to be particularly vulnerable to overfishing due to a mix of aggregating behaviour and an increasing knowledge by fishers of the location of these aggregations. Understanding the nature of these aggregations and the threat posed by fishing has been identified as the number one priority for fisheries research. Knowledge of fish movements with respect to these aggregations is an important requirement for development of effective management plans.

OBJECTIVES

1. To study the movement patterns of key reef associated fishes in Tasmania and the NT.

2. To link movement patterns with critical life history events and habitat utilisation.

3. To evaluate these results in the context of spatial management options for specific fisheries, including performance of closed areas.

CHAPTER 1: SPATIAL AND TEMPORAL USE OF AGGREGATION SITES BY THE TROPICAL SCIAENID *PROTONIBEA DIACANTHUS*

Fish spawning aggregations are generally spatially and temporally predictable which makes them particularly vulnerable to fishing. The removal of a significant proportion of the aggregated adults has been shown to be able to disrupt the aggregating behaviours and may have significant consequences for egg production. . In the Northern Territory of Australia repeated fishing of known aggregations of the tropical sciaenid *Protonibea diacanthus* is considered unlikely to be sustainable, particularly given the decline of this species elsewhere. Acoustic monitoring (VR2's) was used to examine the temporal/spatial movement patterns and aggregation fidelity of *P. diacanthus* in several key areas of the Northern Territory. Fish were only detected at their respective aggregations, providing no evidence of large-scale movements between aggregations. There was evidence of three separate behavioural types in the aggregations, and fish monitored for ≥1 year showed decreased presence during cooler months, and increased presence during warmer months, when peak spawning occurs. The tidal cycle significantly influenced the detection of tagged fish, with detections peaking on running tides, the peak period for catching *P. diacanthus*, suggesting that this is when they feed. This study has provided important information on the connectivity and dynamics of *P. diacanthus* aggregations in the Northern Territory, Australia, including providing crucial information for implementing appropriate management strategies for this vulnerable species. This large sciaenid appears to have high adult aggregation fidelity, suggesting each aggregation supports separate adult (and possibly juvenile) populations. This has significant implications for fisheries management of *P. diacanthus*, with the potential for each aggregation to be vulnerable to localised depletion.

1.1 INTRODUCTION

Fish spawning aggregations may be transient, lasting for a period of hours or days or weeks or they may be resident with extended spawning seasons of several months or even year round. Individuals may travel distances of 100's km or travel short distances of 10-100's m. (see reviews by Claydon 2004, Sadovy & Domeier 2005). Whether transient or resident, spawning aggregations are generally spatially and temporally predictable. As such they are particularly attractive targets to fishers who are able to locate the aggregations and obtain a predictably high catch per unit effort (Johannes *et al.* 1999, Claydon 2004, Sadovy & Domeier 2005, Phelan 2007). This makes spawning aggregations particularly vulnerable, with heavy fishing capable of rapidly removing a significant proportion of the aggregated adults and reducing egg production (Sadovy & Domeier 2005). Overfishing spawning aggregations may truncate the size and age structure through targeting of larger fish (Beets & Friedlander 1992, Sala *et al.* 2001), leaving the population less fecund (Eklund et al. 2000, Sala *et al.* 2001), and may alter genetic composition (Smith et al. 1991). These effects may cause the loss of the aggregation altogether (e.g. *Totoaba macdonaldi*, Cisneros-Mata et al. 1995, *Epinephelus striatus*, Sadovy & Eklund 1999, Sala et al. 2001, *Bahaba taipingensis*, Sadovy & Cheung 2003), from which they are believed not to ever recover (Sadovy & Eklund 1999).

The potentially catastrophic effects of overfishing on spawning aggregations may be managed by seasonal closures, spatial management or gear restrictions (see reviews by Sadovy & Cheung 2003, Claydon 2004, Sadovy & Domeier 2005). Management requires knowledge of the geographic extent from which a particular aggregation site draws from (catchment area), aggregation fidelity, participation rate in aggregations, residence time at the aggregation and potential differences between the sexes, and where the resultant larvae settle (Zeller 1997, Johannes et al. 1999, Sadovy & Domeier 2005).

The tropical sciaenid *P. diacanthus* grows to a large size (≤ 1.5 m TL and ≤ 45 kg) and aggregates in inshore Australian waters from central Queensland to northern Western Australia (Phelan 2007). In the Northern Territory *P. diacanthus* are caught at aggregating sites year-round, with spawning taking place between August and January, and peaking in December (Phelan & Errity 2008). This suggests that these may be resident spawning aggregations.

Sciaenids are widely distributed in tropical and subtropical waters (Trewavas, 1977, Sasaki, 2001) and aggregate to spawn (e.g. Saucier & Baltz 1993, Griffiths & Hecht 1996, Sadovy & Cheung 2003, Norbis & Verocai 2005); these aggregations often forming the basis of commercial, recreational and indigenous fisheries (e.g. Mohan 1991, Apparao et al. 1992, De Bruin et al. 1994, Williams 1997). Despite being fast growing and highly fecund (Sadovy & Cheung 2003), they are particularly vulnerable to overfishing because aggregations are largely confined to heavily exploited coastal waters.

As a result of their vulnerability, at least two sciaenids, *T. macdonaldi* and *B. taipingensis,* are close to extinction due to overfishing with at least 11 other species vulnerable to overfishing throughout all or parts of their geographic distribution (see Sadovy & Cheung 2003 for a review). *P. diacanthus* is one of those species under threat, and is no longer a significant fishery in the Hong Kong region (Sadovy & Cheung 2003), and with the fishery becoming non-existent on the Gujarat-Maharashtra coast of India (James 1992). In Australia anecdotal evidence suggests that intensive fishing has also severely affected several annual *P. diacanthus* aggregations along the Queensland east coast (Bowtell 1998, in Phelan 2007) and far-north coast (Phelan 2007). Phelan (*op. cit.*) documented a reduction in the number, size and age structure of fish caught, as well as a decrease in the number of mature fish, the age of first maturity and the duration fish were present at the aggregation sites following increasing fishing pressure over five decades.

P. diacanthus are a substantial component of both the commercial and recreational inshore fisheries catch in the Northern Territory, with fishers targeting spatially and temporally predictable aggregations. The combined harvest of *P. diacanthus* in this region has risen from 443 t in 1995 to at least 667 t in 2005 (Phelan & Elphick 2006); an increase of 150%. During this time, the harvest of *P. diacanthus* by commercial fishers in the coastal line fishery has increased by 480%, accounting for 87% of the total catch from this fishery in 2005 (Phelan & Elphick 2006). Recreational fishing surveys in 2000 estimated the *P. diacanthus* catch to be approximately one third of the total recreational catch, exceeding that of the commercial catch by almost 250 tonnes (Coleman 2004). The aggregation sites are located close to major population centres and' with the increasing availability of inexpensive GPS units' are easily located by all stakeholder groups due to the publication of the latitude and longitude of each site in local fishing publications.

Repeated fishing of these aggregations is unlikely to be sustainable, particularly given the decline of *P. diacanthus* at other localities (James 1992, Bowtell 1998, Sadovy & Cheung 2003, Phelan 2007). Although they may be the result of other factors, such as data collection methods and market pressure, decreases of almost 10% and 25% in the recreational harvest between 1996 (Coleman 1998) and 2000 (Coleman 2004) and in the commercial harvest between 2004 and 2006 respectively (Phelan et al. 2008b) suggests that *P. diacanthus* may already be declining as a result of overfishing. Importantly, Phelan (2007) noted that a two-year moratorium on fishing an over-fished *P. diacanthus* aggregation in far-north Queensland only resulted in a slight recovery of the population, suggesting that any management action to protect these aggregations needs to be taken long before changes in the population structure are noted.

This study used acoustic telemetry to examine the temporal and spatial movement patterns of *P. diacanthus* within and between two of the three known major aggregation sites in the Northern Territory. The objectives were:

- To study the movement patterns of key reef associated fishes in Tasmania and the NT.
- To link movement patterns with critical life history events and habitat utilisation**.**

The aggregation fidelity of *P. diacanthus* was studied to help determine whether the aggregations were separate populations and, with the level of site fidelity of individuals, to determine the effectiveness of management measures such as spatial and temporal closures.

1.2 MATERIALS AND METHODS

1.2.1 Study sites and acoustic receiver deployment

Compact subsurface VR2 'listening stations' (Vemco, Canada) that use a multidirectional hydrophone to detect uniquely coded individual acoustic transmitters were used to monitor movements. Forty-seven VR2's were deployed in November 2004 between 11° 16.86' S 130° 19.08' E and 13° 24.48' S 129° 54.48' E (Figure 1a) to cover the commercially fished aggregation sites at Channel Point (13° 09' S 130° 04.80' E, Fig. 1b) and Caution Point (11° 24' S 130° 09' E, Fig 1c), and smaller aggregation sites targeted by recreational fishers in between Channel Point and Caution Point. On 14 March 2005 a Category 5 tropical cyclone (Ingrid) crossed the coast directly over Caution Point, resulting in the loss of most of the northern part of the array around Caution Point. Some receivers in the Channel Point region of the array were also lost due to the flood surge following the cyclone and were re-established with some new sites in April 2005, leaving 29 receivers in the array in total. To replace Caution Point, a new array of five receivers was established in September 2005 in Chambers Bay (12° 11.4' S 131° 49.8' E) (Fig. 1a, c), an aggregation site targeted by commercial fishers. This took the total number of receivers for the entire array to 34.

The Channel Point aggregation site was defined by a 35-40 m deep channel running in an NW-SE plane, with shallow (5-10 m) flats on either side of the channel (Meekan et al. 2008) (Fig. 1b). On the eastern side, the channel had steep rock walls which rose almost vertically from 35-40 m, forming a ledge between the deep part of the channel and the shallow flats. On this ledge commercial fishers catch mature aggregating *P. diacanthus* in approximately 10m of water (see Fig. 1b). Currents at Channel Point flow in a NW direction following the channel, with velocities of 0.3-1.0 ms^{-1} on the ebb tides (Meekan et al. 2008). Receivers were deployed approximately 400 m apart along the western edge of the channel, between 170 m and 350 m from the eastern edge of the channel (Fig. 1b). Receivers were also deployed north and south of the aggregation (Fig. 1a, b).

Chambers Bay is a shallow (< 10 m) muddy embayment interspersed with small rocky outcrops (Fig. 1c), which can be exposed at spring low tides (Meekan et al. 2008). *P. diacanthus* aggregate on these scattered outcrops and where they are targeted by commercial fishers. Receivers were placed directly adjacent to the rocky outcrops (Fig. 1c), with three placed in the heavily fished region of the bay (receivers 30, 31, 32, Fig. 1c). Two other receivers (receivers 33 and 34, Fig. 1c) were placed in a less fished region of the bay (only fished by one commercial fisher) 15 km from receivers 30-32. For those sites between Chambers Bay and Channel Point and south of Channel Point (see Fig. 1a), receivers were placed directly adjacent to the rocky reefs around which fish aggregate.

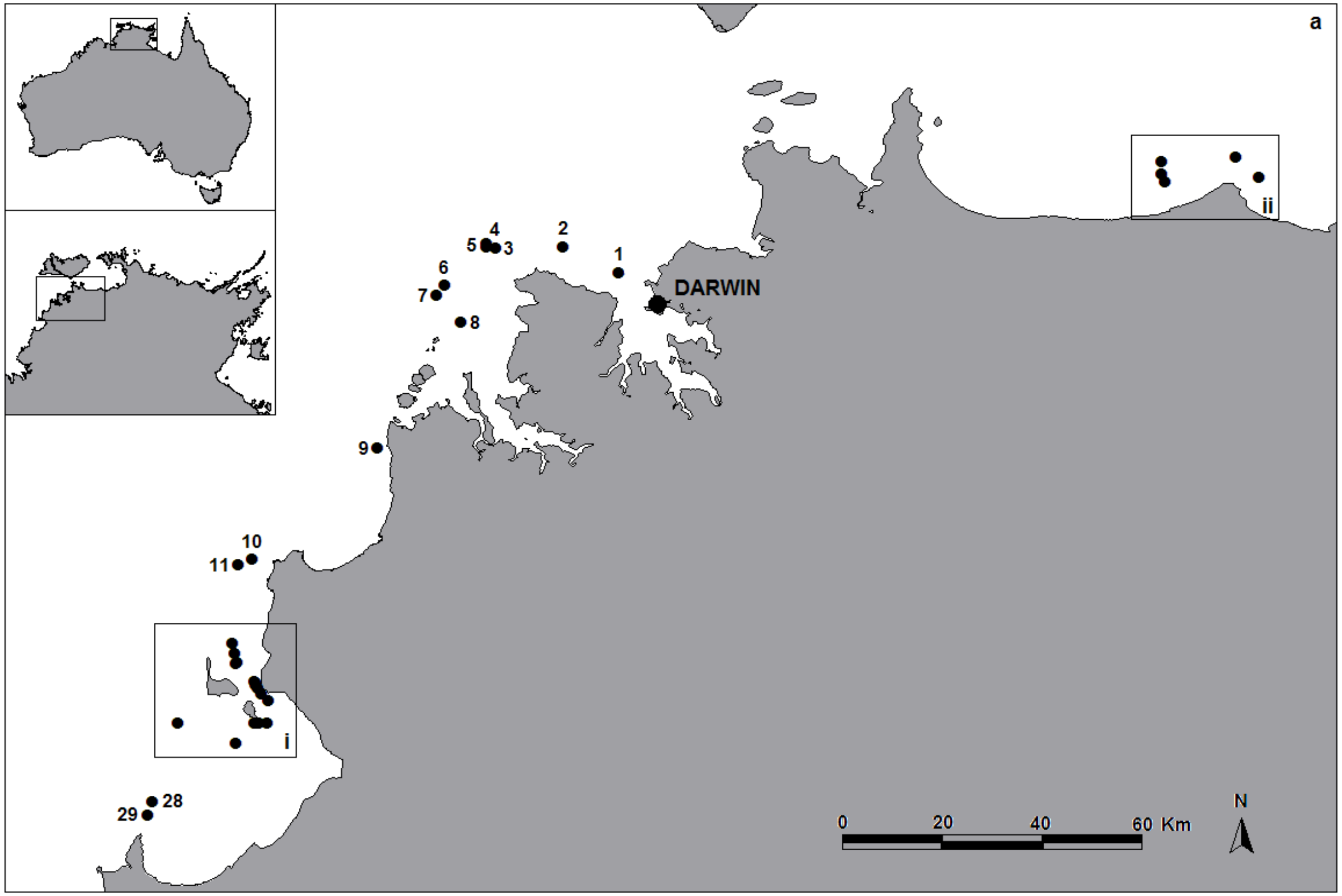


Fig. 1a. Map of Northern Territory, Australia indicating placement and identification numbers of individual receivers. Detail of Channel Point (inset i) and Chambers Bay (inset ii) are shown on Figs. 1b and 1c, respectively. Receivers 1 and 8 were not retrieved for the entire study. Receivers 28 and 29 were removed in April 2005. Receiver 10 was not retrieved between October 2005 and May 2006.

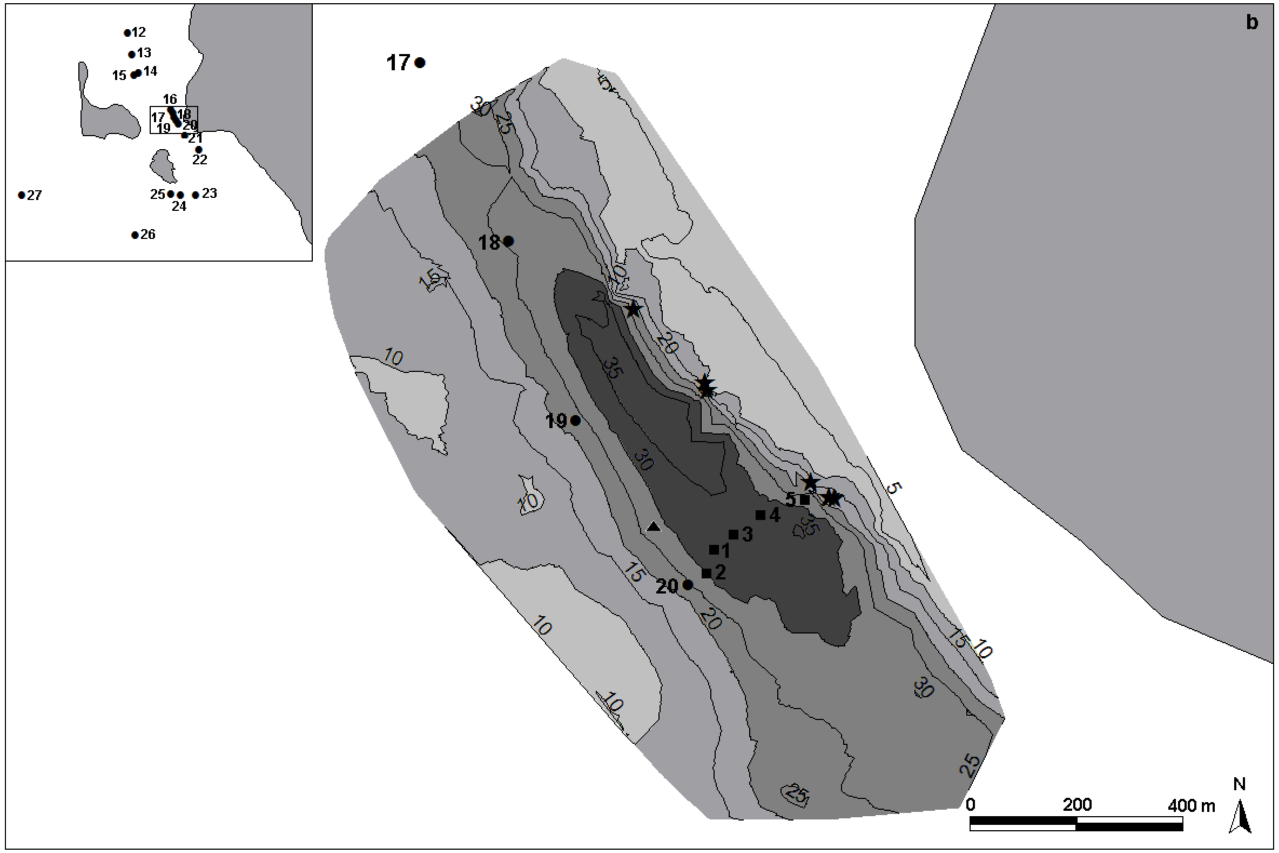


Fig. 1b. Channel Point aggregation bathymetric map indicating placement and identification of individual receivers. Receivers 12-15, 21, 24 and 25 were not retrieved for the entire study. Receivers 16 and 27 were removed in April 2005. Receiver 18 was not retrieved between April and October 2005, and was replaced. Numbered lines indicate depth contours. Stars indicate fish tagging sites. The triangle and numbered squares (numbers correspond to those in Table 3) represent the positions of the receiver and tags used in the post-deployment receiver range test respectively. The inset shows the general region and placement and identification of individual receivers

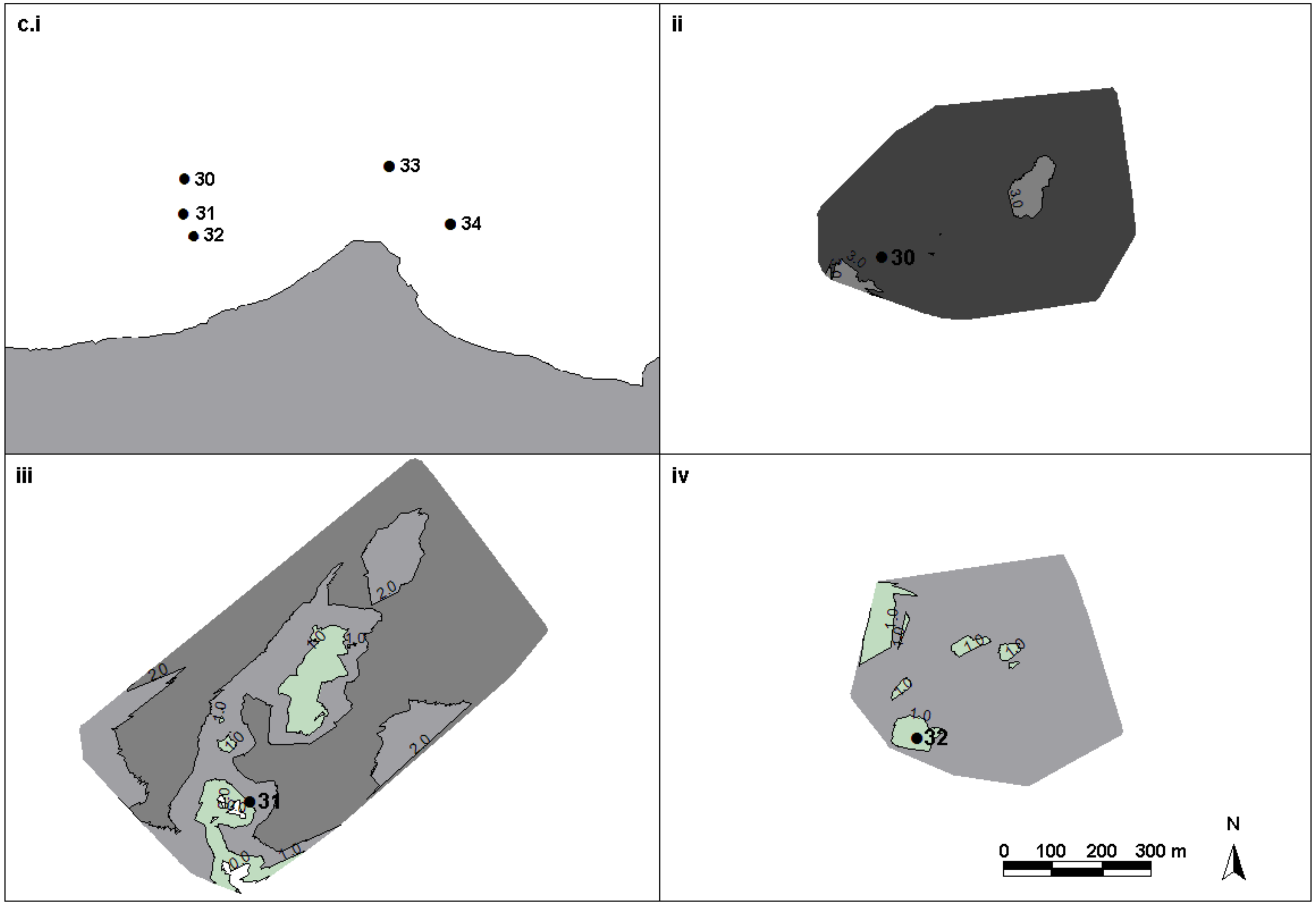


Fig. 1c. i. Chambers Bay aggregation indicating placement and identification of individual receivers. ii-iv bathymetric map of the reef surrounding receivers 30-32. Receiver 31 was not retrieved for the entire study. Numbered lines indicate depth contours.

Receivers were moored approximately 1.5-2.0 m above the substrate with the hydrophone pointing upwards, and were deployed in one of three ways. Method 1: Attached to a steel pole set in concrete, with a horizontal rope line attached to the mooring. These receivers were recovered by snagging the horizontal line with a grapple. Method 2: Attached to vertical rope line using an acoustic release (AR60E, Sub Sea Sonics, USA), such that the receivers (and the release) could be brought to the surface by sending a command (acoustic signal) to the release from a surface unit and transducer. Method 3: Attached to an acoustic release, but instead of initiating the release of the receivers, the units were sent a command to send out an acoustic signal, such that the release (and the receiver) could be found by a diver using a VUR96 underwater directional receiver (Vemco, Canada) and brought to the surface.

The receivers had a battery life of six months and most were downloaded, had their batteries changed and were re-deployed in April 2005 and either October or November 2005. The Chambers Bay receivers did not have a battery change during the study. In May 2006 the study was terminated but not all receivers were recovered.

1.2.2 Receiver range testing

Three pre-deployment trials of the receiving range of the VR2's were conducted in Darwin Harbour in August 2004. Range was determined by mooring a VR2 approximately 1.5-2.0m above the substrate and then suspending a test tag of the same power as the study tags (see below), but with a fixed period of five seconds between each code transmission, approximately 1 m above the substrate at set distances from the receiver for a known time period. The detections received at each distance were expressed as a percentage of the total number of detections expected in the time period.

A post-deployment trial of the receiving range of the array at Channel Point was conducted to determine the performance of the receivers over an entire tidal range. A VR2 was moored approximately 1.5-2.0 m above the substrate approximately 130 m NW of the site receiver 20 was previously located (Fig. 1b) and five tags the same specification as the study tags (see below) moored approximately 1 m above the substrate at set distances from the receiver (Table 1) running across the channel (Fig. 1b). The VR2 and tags were in place from 01 June 2007 to 02 July 2007, except for tag 1, which was removed on 03 June 2007. In order to determine the effect of tide on the performance of the VR2's, the total study time was divided into three tide states, spring tides (difference between high and low tides ≥ 5.0 m), neap tides (difference between high and low tides ≤ 2.9 m) and intermediate tides (difference between high and low tides 3.0-4.9 m) and four tide phases within each tide type; high (high tide ± 1 hr), ebb (between high and low tides), low (low tide ± 1 hr) and flood (between low and high tides). The percentage of detections received at each distance were then calculated, however, given the study tags do not have a set off time, an average off time (120 s) was used to determine the total number of detections expected during the range testing period.

1.2.3 Acoustic tags

All fish were tagged with V16-5H tags (Vemco, Canada), which were 16 mm in diameter, 95 mm in length and weighed 16 g. The transmitting frequency was 69 kHz, with each acoustic tag sending a uniquely identifiable coded signal, which was transmitted at a random interval between 60 and 180 s. The tags had a theoretical longevity of 900 days and signal strength of 159 dB re 1 μPascal at a distance of 1 m from the source.

1.2.4 Tagging trial

Five *P. diacanthus* individuals were captured on hook and line in water ≤ 10 m (so as to avoid barotrauma, see Phelan et al. 2008a) at Channel Point on 06 December 2004. The capture position was recorded using a hand-held GPS unit and the total length (TL) of fish measured after turning the fish upside down, upon which they went into a deep torpor and could be easily measured. After measurement fish were placed in an anaesthetic induction bath containing 27 mgL^{-1} AQUI-S (iso-eugenol) (AQUI-S New Zealand Ltd). Once a fish was at a surgical plane of anaesthesia it was transferred to a purpose-built surgical table with aerated water containing AQUI-S at 10.8 mgL^{-1} pumped over the gills. If necessary the swim bladder was bled of air by inserting a surgical needle through the body wall. Surgery involved making a 20 to 25 mm incision in the ventral abdominal wall, implanting the acoustic tag and suturing the incision with resorbable sutures. Close attention was paid to maintaining the best aseptic technique possible under field conditions.

Post-surgery, fish were tagged with an external dart-tag (Hallprint, Australia) just below the dorsal fin, injected in the tail musculature with 50 $mg.kg^{-1}$ of oxytetracycline and transferred to a large aerated recovery tank to ensure full recovery from the anaesthetic. However, three of the five fish did not recover consciousness following anaesthesia. The two fish that did recover took approximately 45-60 min to be in a state suitable for release, but swam off strongly.

Given the risk of death following anaesthesia, the long holding times and the difficulty of holding such large fish (940-1250 mm TL) for these times, and the fact that the fish went into a torpor when placed onto their back, it was decided to trial surgery without anaesthesia and approval was given from the University of Tasmania (UTas) Animal Ethics Committee (AEC) to do so on a one-fish at a time basis. Two further fish were tagged at Channel Point on 20 December 2004 without anaesthesia. The fish remained in a deep torpor throughout the surgery and showed no signs of discomfort, remaining completely still. Once the surgery was over and the fish were taken out of the tagging cradle, they immediately showed ‘fight’ and were released straight away, swimming off strongly. All four fish tagged in the tagging trial were captured in water ≤ 10 m and released where they were captured (see Figs 1b).

1.2.5 Tagging

Given that surgery without anaesthetic appeared to be much better for the health and welfare of the fish, the UTas AEC approved surgery without anaesthesia for implanting acoustic tags in the remaining fish. A further 36 fish (40 in total) were tagged at Channel Point (see Fig. 1b for tagging locations), with 18 tagged between 15-17 April 2005, 11 between 10-11 October 2005 and seven between 26-27 October 2005. Channel Point fish ranged from 940–1220 mm TL (average 1080 ± 12 mm se). Forty-four fish ranging from 980-1250 mm TL (average 1119 ± 9 mm se) were also tagged at receiver

#31 (33 fish) and 32 (11 fish) in Chambers Bay (see Fig. 1c), with 15 tagged between 29 September 2005 and the remaining 29 tagged between 9-10 November 2005. Tagged fish were not sexed, as it can not be done from external characters, but given their size they were all expected to be mature individuals (Phelan & Errity 2008). All fish were captured in water ≤ 10 m and were released where they were captured (see Figs 1b, c).

1.2.6 Analysis

Fish that were identified by only a single detection at a particular time or site were not included in the analyses, as there was a high probability that single detections were false positives created by acoustic code collision (see www.vemco.com). Daily fish presence at each site (Chambers Bay and Channel Point) was determined by grouping all detections for each individual fish for all receivers over the duration that the tag was monitored into daily bins, and if the fish was detected at least once in that day it was considered present for that particular day. The time at liberty and detection period was determined for all fish as the number of days between tagging and removal of the receivers and the period in days between the first and last detection respectively.

All other analyses were only performed on the Channel Point data, due to a lack of data for Chambers Bay, as a result of the loss of receiver (31), where 75% of the fish from this site were tagged (see Fig 1c). Hourly fish presence was determined using the same method as for daily presence, but using hour bins. Pearson correlation coefficients were used to determine the association between average percent days and hours present per month and average monthly sea surface temperature (SST) in °C derived from NOAA, USA satellite data, for the December 2004/April 2005 tagging periods combined and the October 2005 tagging period at Channel Point. Fish 2 (tagged in December 2004) and 11 (tagged in April 2005) were not included in the analysis, as they were predominately detected (≥99.8% of detections) on receiver 18, which was not recovered for the period between 10 April and 27 October 2005 (see results) and was replaced. The number of fish present per month (not including tagging month) was also correlated with % fish presence (days and hours) and SST for the October fish only, as sample sizes were too low for the December/April tagged fish.

The percentage of time at liberty (PTL) and the percentage of the detection period (PDP) that individual fish were detected were calculated as a measure of residency and site fidelity respectively. A linear-model one-way ANOVA was used to determine whether the PTL and/or the PDP were influenced by the tagging period (either April 2005 - 13 fish or October 2005 - 13 fish). Fish #11 tagged in April 2005 was not included in the analysis, as it was only detected on receiver #18, which was lost for part of the study (see results). The December 2004 fish were also not included in the analysis, as only three of four fish tagged were detected. Data were Log_{10} transformed to ensure a normal distribution and homogeneity of variances.

The temporal periodicity in fish presence at Channel Point was assessed using Fast Fourier Transformation analysis (FFT) (Cooley & Tukey 1965, in Hartill et al. 2003), a type of spectral analysis which decomposes a regular time series into a finite sum of sine and cosine waves of different frequencies. FFT can only be performed on a time series whose length is a power of two (Hartill et al. 2003), resulting in the need to truncate the time series to be examined. The hourly fish presence data from Channel Point for those fish that had at least 512 hrs (21.3 days) of data in one block of time (11 fish, see Table 3) was analysed using Microsoft Excel. Given fish #2 had two separate blocks of data (December 2004 to April 2005 and October 2005 to April 2006), with no data in between (see Fig. 3), a separate FFT was performed for each period (Table 3). Similarly, given fish #4 had a time series with two distinct components of at least 512 hrs with limited data in between (see Fig 3) and the fact that the FFT can only be performed on a data series of maximum 4096 hrs (170.7 days), two separate FFTs were also performed for this fish (Table 3).

1.3 RESULTS

1.3.1 Receiver range tests

The maximum effective detection range of the VR2's was 200 m, with between 73-91% detection over the three trials and 74% detection for all tide states and phases combined for the pre and post-deployment range tests respectively. At distances greater than 200 m detection dropped off significantly. For the post-deployment range test, tide phase (high, ebb, low and flood) and state (neap, intermediate, spring) had some effect on the detection ability of the VR2's, but the effect was not consistent for the various tide combinations (Table 1). In terms of tide state, spring tides had the largest effect on detections, although at the effective detection range of 200 m, there was little difference between the three states, except that detections were at their lowest (62%) during the ebb tide for the intermediate tide state, compared to the flood tide for both the neap (62%) and spring tides (54%). Despite there being no consistent trend, detection was generally lowest during the running tides, with the lowest detections on the ebb tide for four of the five tag distances during the intermediate tides and on the flood tide for three of the five tag distances and two of the four tag distances during the spring and neap tides respectively.

Table 1. Receiver range (distance from tag to VR2) testing results from Channel Point using moored tags

Tag #	Depth (m)	Hours deployed	Range (m)	Tide state	% Detections High tide	Ebb tide	Low tide	Flood tide
1	≈ 30 m	43 (removed)	135	Neap				
2	≈ 33 m	744	180	Neap	41	44	53	16
3	≈ 33 m	604 (lost)	200	Neap	84	96	74	61
4	≈ 33 m	744	250	Neap	51	48	48	48
5	≈ 25 m	744	340	Neap	41	28	35	31
1	≈ 30 m	43 (removed)	135	Intermediate	89	74	80	99
2	≈ 33 m	744	180	Intermediate	41	40	46	26
3	≈ 33 m	604 (lost)	200	Intermediate	74	62	75	81
4	≈ 33 m	744	250	Intermediate	44	30	47	55
5	≈ 25 m	744	340	Intermediate	32	14	37	36
1	≈ 30 m	43 (removed)	135	Spring	29	40	64	68
2	≈ 33 m	744	180	Spring	40	46	32	13
3	≈ 33 m	604 (lost)	200	Spring	80	82	72	55
4	≈ 33 m	744	250	Spring	35	35	31	26
5	≈ 25 m	744	340	Spring	19	13	21	18

Table 2. *Protonibea diacanthus* detected at Channel Point (receivers 17-22) and Chambers Bay (receivers 30 and 32). Fish not detected are not shown

Fish	Tagging Date	Tagging Site (receiver)	TL (cm)	Recaptured	First Detection	Last Detection	Detections Rec. 17	Detections Rec. 18	Detections Rec. 19	Detections Rec. 20	Detections Rec. 22	Detections Rec. 30	Detections Rec. 32	Total Detections	Total Days Detected
2	6/12/2004	opposite 18-20	119		30/12/2004	25/01/2006		2788	5					2,793	144
3	20/12/2004	opposite 18-20	102		23/12/2004	3/07/2005			955					955	59
4	20/12/2004	opposite 18-20	94		31/12/2004	4/05/2006		1	32,079	59				3,2139	327
5	15/04/2005	opposite 18 & 19	119		16/04/2005	22/04/2005	43		25	16				84	7
8	16/04/2005	opposite 18 & 19	109		16/04/2005	23/04/2005	14		16	35				65	7
10	16/04/2005	opposite 18 & 19	116		16/04/2005	19/04/2005	5		9	8				22	4
11	16/04/2005	opposite 18 & 19	106		28/10/2005	4/05/2006		12,244						12,244	131
12	16/04/2005	opposite 18 & 19	115		17/04/2005	19/04/2005	5			9	10			24	3
13	16/04/2005	opposite 18 & 19	107		19/04/2005	19/04/2005				25				25	1
14	16/04/2005	opposite 18 & 19	105		16/04/2005	5/05/2006			11,271	1				11,272	109
15	16/04/2005	opposite 18 & 19	99		4/05/2005	30/04/2006			1,463	84				1,547	83
16	17/04/2005	opposite 18 & 19	108		18/04/2005	21/04/2005	5		2	13				20	4
17	17/04/2005	opposite 18 & 19	117		22/04/2005	22/07/2005			692					692	31
18	17/04/2005	opposite 18 & 19	108		23/04/2005	25/04/2005			39					39	3
19	17/04/2005	opposite 18 & 19	108		17/04/2005	21/04/2005	3		6	37				46	5
20	17/04/2005	opposite 18 & 19	104		23/04/2005	2/06/2005			22					22	9

22	17/04/2005	opposite 18 & 19	102		18/04/2005	30/04/2006		67	401	14				482	29
23	10/10/2005	opposite 20	102		13/10/2005	6/05/2006				1,002				1,002	140
24	10/10/2005	opposite 20	112		26/12/2005	5/05/2006				617				617	84
25	10/10/2005	opposite 20	101		16/02/2006	2/05/2006				3,934				3,934	66
26	10/10/2005	opposite 20	102		11/10/2005	20/04/2006	6			59				65	34
27	10/10/2005	opposite 20	104		11/10/2005	27/01/2006				93				94	10
28	10/10/2005	opposite 20	103		10/10/2005	14/10/2005	32		4	19				55	5
29	10/10/2005	opposite 20	104		11/10/2005	6/05/2006				182				182	36
31	11/10/2005	opposite 20	112		12/10/2005	18/10/2005				292				292	7
33	11/10/2005	opposite 20	120		4/11/2005	30/03/2006				83				84	28
35	26/10/2005	opposite 19	100		27/10/2005	28/10/2005			13	20				33	2
37	26/10/2005	opposite 19	110		27/10/2005	28/10/2005			3					3	2
38	27/10/2005	opposite 19	103		28/10/2005	3/12/2005			76	1,691				1,767	25
40	27/10/2005	opposite 19	107		30/10/2005	30/03/2006			57					57	18
41	29/09/2005	31	119.5	28/04/2007	30/09/2005	7/04/2006						343	269	612	11
46	29/09/2005	31	112		6/10/2005	10/10/2005						8	23	31	4
49	29/09/2005	30	113		29/09/2005	29/09/2005						4		4	1
50	30/09/2005	31	114		1/10/2005	1/10/2005						18		18	1
51	30/09/2005	30	115		30/09/2005	7/10/2005						11		11	3
52	30/09/2005	30	111		30/09/2005	30/09/2005						3		3	1
53	30/09/2005	30	114		30/09/2005	13/10/2005						6		6	2
54	30/09/2005	30	113		30/09/2005	30/09/2005						7		7	1
55	30/09/2005	30	108		30/09/2005	1/10/2005						183		183	2
57	9/11/2005	30	120		9/11/2005	9/11/2005						9		9	1

58	9/11/2005	31	107	1/04/2007	19/12/2005	15/04/2006	209		209	24
59	9/11/2005	30	108		9/11/2005	13/12/2005	7		7	4
62	9/11/2005	31	106		10/11/2005	29/11/2005	65		65	9
66	9/11/2005	31	104		10/11/2005	23/01/2006	5	5	10	4
67	9/11/2005	31	98		17/11/2005	29/11/2005	8		8	3
70	10/11/2005	31	105	1/04/2008	16/01/2006	17/04/2006	1	4	5	4
74	10/11/2005	31	114		11/11/2005	22/11/2005	34		34	5
77	10/11/2005	31	116		24/11/2005	12/12/2005	1	14	15	3
84	10/11/2005	31	111	23/12/2005	10/11/2005	8/12/2005	3	57	60	8

1.3.2 Acoustic monitoring

General Results

Fish were only detected at their respective tagging sites, with 98.2% of the 71951 individual fish detections at Channel Point (Table 2). Thirty of the 40 fish tagged at Channel Point were subsequently detected, compared to only 19 of 44 tagged at Chambers Bay (Table 2). Despite the low number of fish detections (1297) and individual fish detected at Chambers Bay, it is assumed that tagging did not alter the behaviour, survivorship or predation risk of *P. diacanthus* at either site, as four fish tagged in Cambers Bay were recaptured close to their release sites in good condition, between 41 and 873 days after tagging (see Table 2). Of these four fish, fish #41, #58 and #70 (Fig. 2), had detection periods of 190, 118 and 91 days respectively and were recaptured more than a year after tagging (Table 2), suggesting that they were resident fish at the aggregation.

Fish were detected at two of four receivers recovered at Chambers Bay, receivers #30 and #32. Receiver #30 had 71.3% of all fish detections, with records for all 19 fish detected, while receiver #32 only detected six fish. Conversely, fish were detected on all of the permanent receivers at the Channel Point aggregation, with receivers #17-20 detecting 8, 4, 19 and 22 of the 30 fish detected respectively (Table 2). It should be noted that there were no fish detected on receiver #18 between April and October 2005, as it was not recovered in October. One fish (#12) was detected at receiver #22 (Table 2), 3.4 km south of the aggregation (Fig. 1b).

Chambers Bay fish were only detected for up to 24 days (Fig. 2, Table 2) or ≤ 19.5% of their time at liberty. Fish at the Channel Point aggregation, however, were detected for up to 327 days (Fig. 3, Table 2), or ≤ 67.3% of their time at liberty (Fig. 4). Tagging period significantly influenced the PTL (measure of residency) of Channel Point fish ($F = 5.984$, df 1, 24, $p = 0.022$), with three of the 13 October 2005 tagged fish being detected for > 30% of their time at liberty, compared to no April 2005 tagged fish being detected for this proportion of their time at liberty (Fig. 4). Conversely, tagging period did not influence the PDP (measure of site attachment) of Channel Point fish ($F = 0.020$, df 1, 24, $p = 0.888$), with fish detected for between 7.7 and 100% of the detection period (Fig. 4).

Site attachment and residency patterns at Channel Point

Three distinct fish behavioural types were recognised at the Channel Point aggregation. The first was 13 fish that were present for all or the majority of a short detection period of between one and eight days (see Fig. 3), but were only detected for less than 4.8% of the total days at liberty (Fig. 4). These fish were all last detected between 2-9 days after tagging (average 4.9 ± 0.7 days se). Seven of the fish were detected at three receivers including the northern most (#17) and southern most (#20) receivers at the aggregation proper and the southernmost receiver that had detections (#22) (see Fig. 1b), with ten of the 13 fish last detected on one of these receivers. As such these fish appear to have remained mobile, traversing the length of the aggregation site after tagging, and only stayed in the detection area of the receivers for a short period.

The second behaviour type was displayed by the five fish that had a detection period of between 37 and 490 days (see Fig. 3) and were present for a large portion of that period (between 64.1 and 86.8%), but also greater than 10% of the days at liberty (between 13.1 and 67.3%) (Fig. 4). All but one of these five fish was tagged in October 2005, with the other tagged in December 2004. In this group there was a mix between long-term detected fish (December tagged fish #4 and fish #23 detected for 65.1% and 67.3% of their days at liberty respectively, see Fig. 3) and shorter-term detected fish (#24, #25 and #38, detected for ≤ 40% of the days at liberty, see Fig. 3), which all had long periods (months) of non-detection during their time at liberty. These 'type 2' fish were highly site attached when detected, with > 95% of the detections occurring at a single receiver (Table 2).

The third behaviour type was those 10 fish that had detection periods of between 41 and 385 days (see Fig. 3), but were present for less than 34% of the detection period and were detected for less than 29% of the days at liberty (Fig. 4). These fish had multiple periods of non-detection (days to months) between periods of detection, but were highly site attached when detected (see Fig. 3), with > 83% of the detections occurring at a single receiver (Table 2). Despite not being able to be categorised due to receiver #18 being lost for a portion of the study, fish #2 and #11 were highly site attached when detected, with 99.8 and 100% of detections at receiver #18 respectively.

Monthly presence/absence at Channel Point

There was a strong positive correlation between the average % days and % hours per month fish were present at the Channel Point aggregation for both the fish tagged in December 2004/April 2005 combined (r = 0.942, n = 17, p = 0.000) and those tagged in October (r = 0.937, n = 7, p = 0.002) (see Fig. 5a & b). Although the general trend between the two measures of fish presence was the same, the average % days present per month was generally much higher (up to approximately five-fold) than that for average % hours present (Fig. 5a & b), for both tagging periods, suggesting that fish were only detected for a relatively small portion of each day.

Although there was a high degree of variability in individual fish presence in some months, for the December 2004/April 2005 tagged fish combined there was a general pattern of a high average % presence in the Austral summer of 2004/5, with fish presence declining over autumn to reach the lowest levels in winter/spring months, after which it again peaked over the summer months (2005/6) and remained at these levels during autumn 2006 (Fig. 5a & b). Percentage fish presence for the December 2004/April 2005 tagged fish combined showed a strong positive correlation with SST°C (days: r = 0.681, n = 17, p = 0.003; hours: r = 0.663, n = 17, p = 0.004) (Fig. 5a & b).

A different trend was displayed for those fish tagged in October 2005, with generally lower average % presence compared to the December/April tagged fish, and average % presence declining in December 2005, and then steadily increasing to peak in April 2006 (Fig. 5a & b). As a result of this trend, average % fish presence for the October 2005 tagged fish showed a negative correlation with SST (days: r = -0.829, n = 7, p = 0.021; hours: r = -0.715, n = 7, p = 0.071) (Fig. 5a & b). Correlations between the number of fish present for the October 2005 tagged fish (with October 2005 removed from the analysis) were all weak (% days present: r = -0.250, n = 6, p = 0.632; % hours present: r = -0.309, n = 6, p = 0.551; SST: r = -0.217, n = 6, p = 0.680), with fish numbers remaining relatively steady throughout the study period (Fig. 5a).

1.3.3 Spectral analysis

The dominant biorhythm detected by the spectral analyses (FFT) at Channel Point was tidal, with all 11 fish examined demonstrating either a primary peak at approximately 12.3 hrs for a full tidal cycle (10 fish, including both time periods examined for fish 4), or a primary peak at 6.2 hrs for a half tidal cycle (fish #2 for both time periods examined) (Table 3). Six of the 11 fish also demonstrated a secondary tidal peak of either 12.3 hrs (fish #2, first period), 8.2 hrs (fish #17), 6 hrs (fish #14 & #38) or 4.1 hrs (fish #15 & #25). There were no other common biorhythms, however, the remaining five fish all showed different secondary periodicity (Table 3).

For all 11 fish the number of detections showed either one of two general opposite patterns with tidal phase; detections either peaked at the ebb tide and declined to be lowest at the flood and high tides, as was the case for fish #2, #11 (Fig. 6) and #38 or more commonly, detections peaked at the flood and high tides, declining at the ebb and low tides, as was the case for fish #3, #4, #14 (Fig. 6), #15, #17 and #23-25. For the first pattern, two of the fish (2 & 11) were predominately (≥ 99.8%) detected at receiver 18, while fish 38 was detected at receiver 20 for 95.7% of detections (Table 2). For the second pattern, five of the fish (3, 4, 14, 15 and 17) were predominately (≥ 94.6%) detected at receiver 19, while the three other fish (23-25) were detected at receiver 20 for 100% of the time (Table 2).

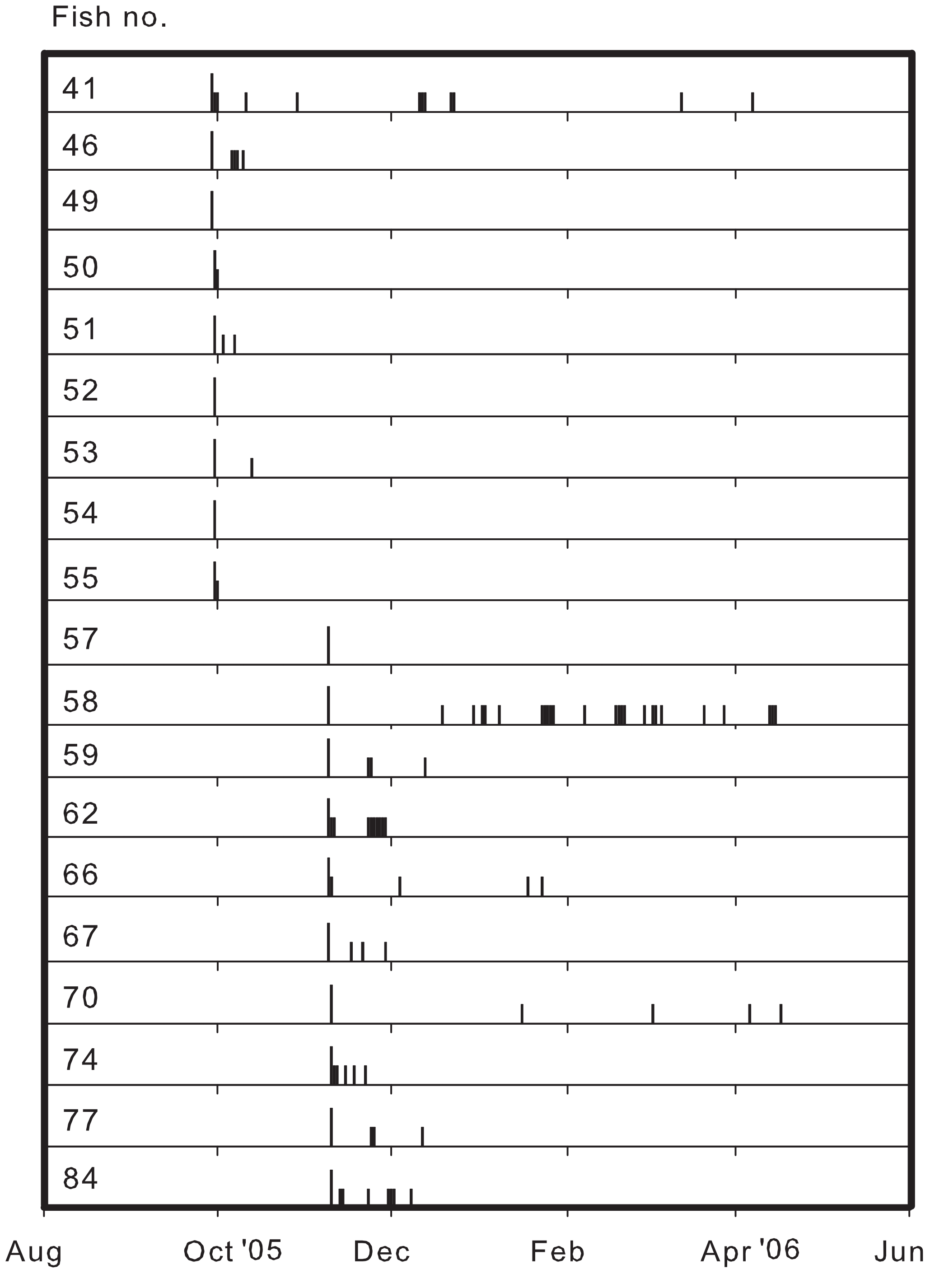


Fig. 2. *Protonibea diacanthus*. Presence/absence of individual fish detected at Chambers Bay. The initial line for each fish represents the tagging day and each subsequent line represents a day that the fish was detected

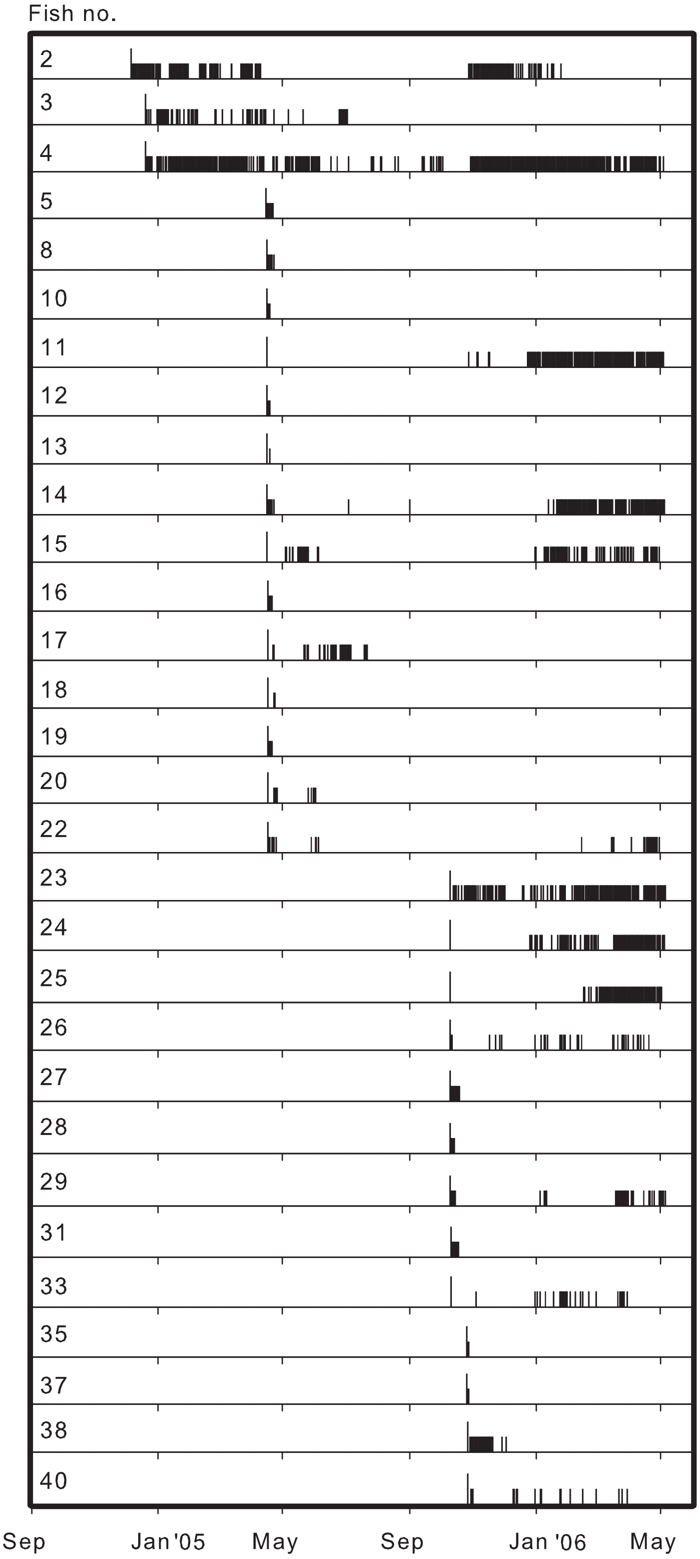


Fig. 3. *Protonibea diacanthus*. Presence/absence of individual fish detected at Channel Point. The initial line for each fish represents the tagging day and each subsequent line represents a day that the fish was detected

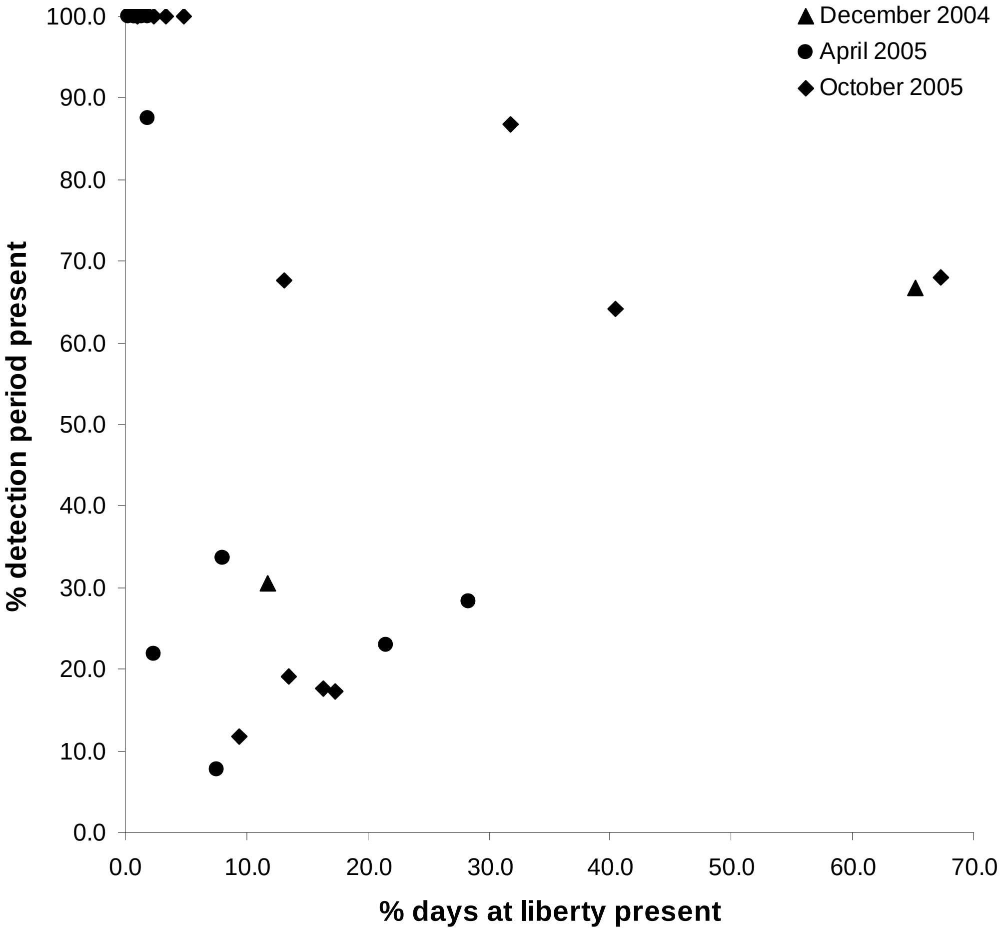
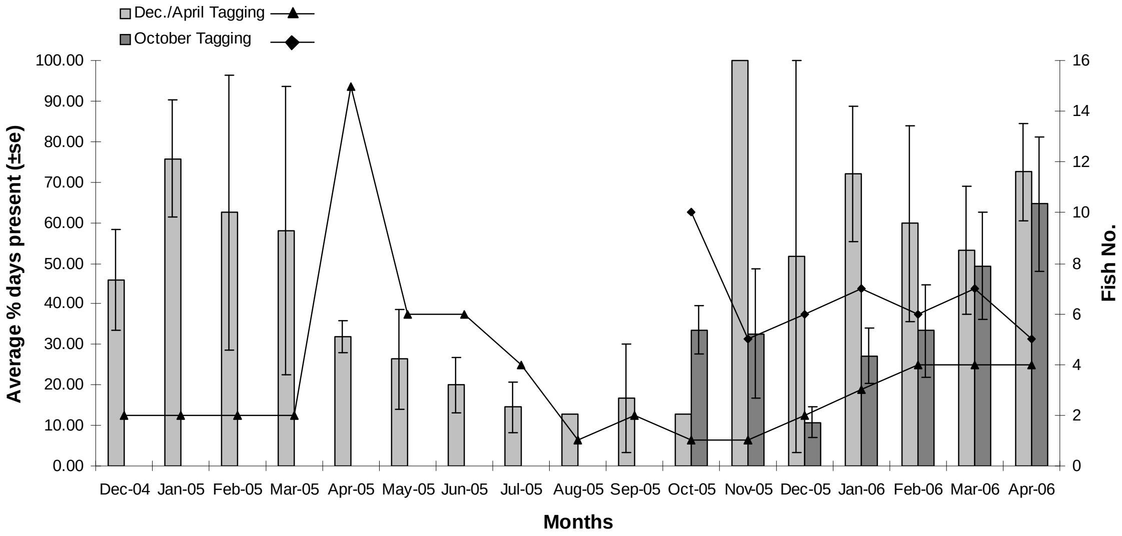


Fig. 4. *Protonibea diacanthus*. % days at liberty present vs. % detection period present for each tagging period for Channel Point fish. Note fish #2 (December 2004) and #11 (April 2005) are not represented, as they were predominately detected (≥ 99.8% of detections) on receiver #18, which was not recovered for the period between April and October 2005

a)



b)

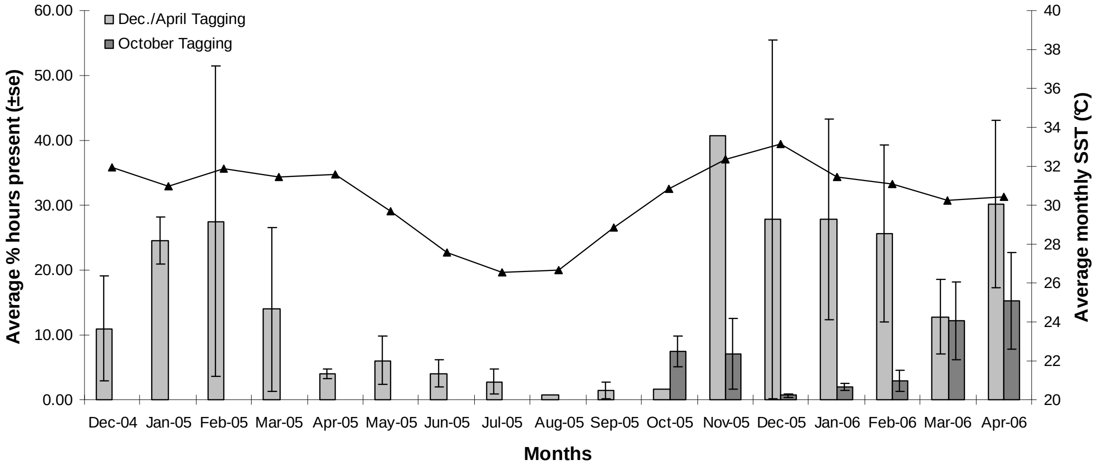


Fig. 5. *Protonibea diacanthus*. a) Total days (bars) and number of fish (lines) present per month at the Channel Point aggregation for fish tagged in December 2004, April 2005 and October 2005. b) Total hours (bars) present per month at the Channel Point aggregation for fish tagged in December 2004 and April 2005 and October 2005 and average monthly SST ºC (lines). Number of fish and SST values apply to both a) and b).

Table 3. *Protonibea diacanthus*. Periodicity of presence/absence assessed using Fast Fourier analysis on a continuous series of 1 hr periods

Fish	Time Period	Total (hrs)	Detections	1° peak (hrs)	2° peak (hrs)
2	7/12/04-2/03/05	2,048	1,962	6.2	12.3
2	28/10/05-21/01/06	2,048	645	6.2	409.0
3	31/12/04-11/2/05	1,024	799	12.5	35.3
4	21/12/04-3/06/05	4,096	8,784	12.4	341.0
4	4/11/05-23/04/06	4,096	22,592	12.4	1,024.0
11	25/12/05-5/02/06	1,024	9,680	12.2	23.3
14	27/01/06-22/04/06	2,048	9,554	12.3	6.2
15	10/01/06-5/04/06	2,048	863	12.3	4.1
17	27/04/05-22/07/05	2,048	683	12.3	8.2
23	10/02/06-6/05/06	2,048	643	12.3	292.0
24	9/02/06-5/05/06	2,048	531	12.3	512.0
25	6/02/06-2/05/06	2,048	3,934	12.3	4.1
38	28/10/05-18/11/05	512	1,659	12.1	6.0

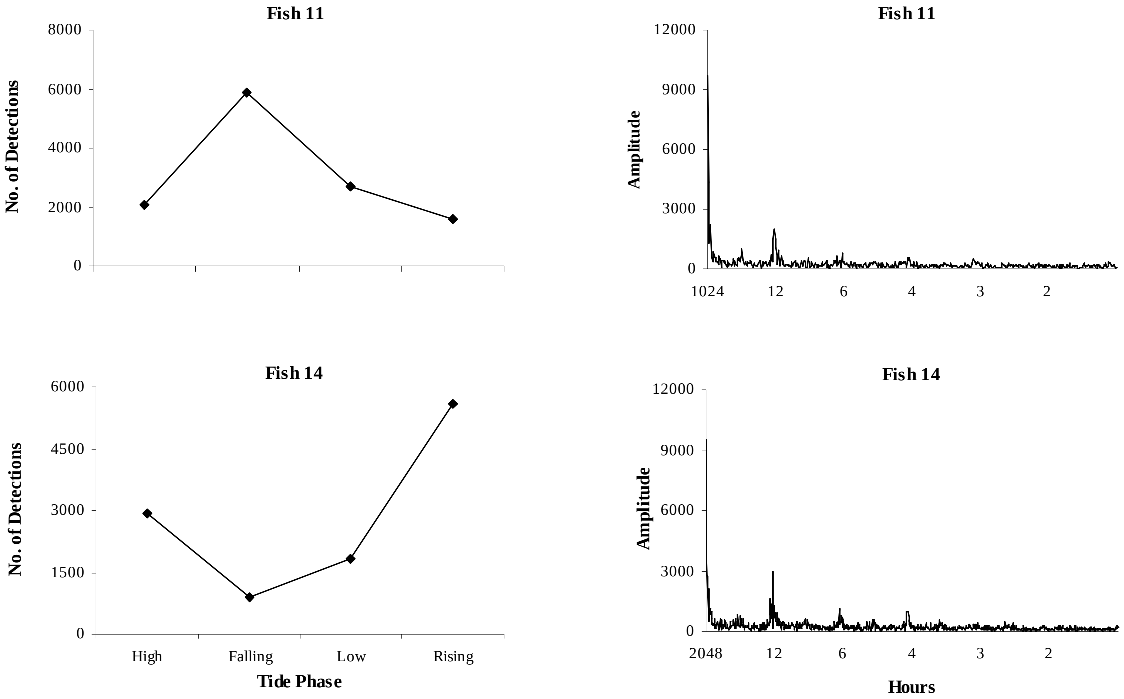


Fig. 6. *Protonibea diacanthus*. Biorhythmic patterns of detection for fish #11 and #14, with number of detections against tide phase on the left hand side and the matching Fast Fourier analysis of hourly fish presence on the right hand side

1.4 DISCUSSION

This study has provided detail about the movements of individual adult *P. diacanthus* for up to 17 months, including a spawning season between August and January. No evidence of large-scale movements of *P. diacanthus* between the aggregations studied, indicated that these sites support essentially separate adult populations. By comparison a *P. diacanthus* tag recapture program in Cape York Peninsula, Queensland, Australia (Phelan 2002) showed that *P. diacanthus* adults could move between aggregations. Of 114 tagged fish, one of the 3 recaptures had moved between the two aggregation sites separated by approximately 30 km, covering the distance in 13 days. Given the fish in the Northern territory study were monitored for between 7-17 months, providing sufficient time to move between aggregations, the difference between the results of the two studies may be related to the greater distance between aggregations, with the smallest distance between either Channel Point or Chambers Bay, which are separated by approximately 250 km, and any another acoustically monitored aggregation site being approximately 60 km (receiver 9, Fig 1a).

DNA fingerprinting using the Amplified Fragment Length Polymorphisms (AFLP) technique demonstrated that there was no significant genetic variation between *P. diacanthus* individuals sampled from the two aggregation sites on Cape York Peninsula at which the tag recapture program was undertaken (Phelan 2002), suggesting that they were utilised by the same genetic population. Additionally, AFLP analysis of *P. diacanthus* from Cape York Peninsula and the Northern Territory, suggested that these individuals were also from the same homogeneous genetic population (Phelan 2002).

However, genetic variation can be inadequate for examining population structure where even low levels of adult or larval mixing can occur (Begg & Waldman 1999), which may be as little as a few individuals per generation (Kimura & Ohta 1971, Allendorf & Phelps 1981). For example, estimates of natal homing in the sciaenid *Cynoscion regalis* using otolith elemental signatures indicated a high level of spawning-site fidelity ranging from 61% to 81% (Thorrold et al. 2001), however, there was no genetic divergence between locations, suggesting that low exchange rates of individuals between spawning sites was sufficient to prohibit genetic divergence between sites (Cordes & Graves 2003).

Although the results from this study suggest that there is limited adult movement between *P. diacanthus* aggregations, such movement could occur in immature individuals. Given high current velocities at aggregation sites (Meekan et al. 2008) and sciaenids having larval durations of several weeks (Duffy & Epifanio 1993), it is possible that larvae could be widely dispersed and mixed throughout the region, with adults (or potentially sub-adults) of mixed origin forming aggregations at the various sites. Alternately, *P. diacanthus* could exhibit high levels of spawning-site (aggregation) fidelity, as found for *C.regalis* (Thorrold et al. 2001). As such, further studies are needed to determine the natal origins of the separate aggregations of adult *P. diacanthus* in the Northern Territory, such as targeted otolith elemental chemistry of both young of the year and adults (e.g. Thorrold et al. 2001), or the use of novel larval mass-marking methods based on maternal transmission of isotopic markers to the otoliths of offspring (Thorrold et al. 2006, Almany et al. 2007).

There was evidence for three separate behavioural types in the Channel Point aggregation: mobile, long-term site-attached and short-term site-attached. Despite the limited data, given that three fish were recaptured at the Chambers Bay aggregation over a year after they were tagged; at least the long-term behavioural type also exists at this aggregation site. Multiple behaviour modes appear common in reef fish that are monitored over relatively long periods of time (e.g. Egli & Babcock 2004; Star et al. 2002; Attwood & Bennett 1994; Jadot et al. 2002). Similarly, Fraser et al. (2001) divided a population of freshwater killifish into ‘movers’ and ‘stayers’, suggesting such behavioural polymorphism is the result of the temporal and spatial variability of such things as mortality risk and foraging success. This is likely to also be the case for *P. diacanthus*, but may also be related to maximising the chances of spawning success.

‘Type 1’ fish appear to be mobile, with no site attachment to the portion of the channel where they were captured. These fish were only detected for short periods after tagging, but were generally detected each day of that period, with many moving the length of the aggregation. Given that these fish were all last detected on average approximately five days after tagging, it is possible that their behaviour was altered by the tagging procedure, however, it is unlikely that any ill effects would last for longer than a day, particularly as none of these fish were anesthetised and all swam away strongly when released. Hartill et al. (2003) and Dresser & Kind (2007) allowed just 24 hours following the release of acoustically tagged sparids (*Pagrus auratus*) and the sciaenid *Sciaenops ocellatus* respectively to account for potentially atypical behaviour following surgery using an anaesthetic. Instead, these fish most likely moved away from the aggregation, which is supported by the fact that the majority were last detected on a receiver at the extremities of the aggregation.

The remaining two types of fish at the Channel Point aggregation both had detection periods of greater than a month and exhibited high site fidelity when detected, with the majority of all detections at one receiver, as has also been demonstrated for other sciaenid species, e.g. *Argyrosomus japonicus* (Taylor et al. 2006) and *S. ocellatus* (Dresser & Kind 2007). ‘Type two’ fish were detected for the majority of the detection period, however, three of the five fish had long periods (months) of non-detection during their time at liberty. All but one of the ‘type 2’ fish were tagged in October 2005, suggesting these fish were generally more site attached than those tagged earlier in the year, perhaps as a result of being tagged during the spawning season (August-January). ‘Type three’ fish all had multiple periods of absence (days - months) between short periods of presence (days - months). Despite their high site fidelity, both ‘type 2’ and ‘type 3’ fish may have left the aggregation site during periods of long absence (months).

For the fish tagged in December 2004/April 2005 at Channel Point there was a clear trend of increased fish presence during the warmer summer and early autumn months, and decreased presence during the cooler winter and spring months. This suggests that some fish may be leaving the aggregation in the cooler months, after which they start to return, with the majority of the fish that had long periods of absence all present by January 2006. Given the spawning period for *P. diacanthus* in the Northern Territory is between August to January, peaking in December during the summer monsoon season (Phelan & Errity 2008), as is also the case for this species in north-west India (Rao

1963), fish may be leaving the aggregation in the cooler months and then returning to spawn, with activity and numbers building up by November-January. Alternatively, the fish may be leaving the site to spawn in the cooler months of the proposed spawning season, e.g. August-October, although given the peak of spawning is in December, this is less likely. Other sciaenids e.g. *A. japonicus* (Smale 1985), *Atractoscion aequidens* (Griffiths & Hecht 1995), *Micropogonias furnieri* (da Costa & Araújo 2003), and *S. ocellatus* (Nicholson & Jordan 1994, in Dresser & Kneib 2007) are most abundant in inshore areas during the warmer months, moving into deeper offshore waters during the cooler months, with some species spawning offshore in the cooler months (e.g., *M. furnieri*, da Costa & Araújo 2003) and others inshore in the warmer months (e.g., *S. ocellatus*, Nicholson & Jordan 1994, in Dresser and Kneib 2007).

As was the case for the behaviour types, those fish tagged at Channel Point in October 2005, showed a different trend to those tagged in December 2004/April 2005. There was in general lower monthly fish presence for the October tagged fish. This may be due to the majority of the December 2004/April 2005 fish being tagged towards the northern end of the channel, while the October 2005 fish were predominately tagged at the southern end, with the bathymetry and morphology of the channel where the fish were present likely to influence the ability of the receiver to detect the fish, and also the fish's behaviour (see discussion of tidal influence). There was a strong negative correlation between monthly fish presence and SST°C for the October 2005 tagged fish, with presence lowest in the summer months, particularly December, where the peak of spawning occurs. However, there was no matching trend for fish numbers, which remained steady after the initial decline following tagging. This suggests that fish did not move away, but were ranging outside of the detection range of the receivers more often during this period, perhaps as the result of courtship/spawning behaviour.

Tidal cycle significantly influenced the detection of tagged fish at Channel Point, explaining the fact that average percentage hours present per month was generally much lower than that for average percentage days present. This result is not surprising given velocities of up to $1 ms^{-1}$ being recorded on the ebb tide. This relationship does not appear to be related to the performance of the receivers declining with tide phase (high, ebb, low and flood) or state (neap, intermediate, spring), as despite tide having some effect on the detection ability of the VR2's, the receivers never had zero detection periods during the post-deployment range testing, and had an effective detection range of 200 m (55-96% detection). Additionally, the two general opposite patterns that fish demonstrated with tidal phase showed detections to peak at the ebb and flood tides i.e. the running tides, which would not be expected if tide was significantly affecting receiver performance. In fact this result conforms to the fishers rule of thumb for catching *P. diacanthus*, which states "no run, no fun", i.e. you will not catch fish unless the tide is running, suggesting that this is when they feed. During the tide phases where fish detections were low, the fish may have been close to the channel rock wall at their 'home sites', and as such could not be easily detected (e.g., Matthews 1992, Bradbury et al. 1997). Similarly, the sciaenid *S. ocellatus* monitored using VR1 receivers (the predecessor to the VR2) showed high site fidelity at low tide, with movement occurring on the running tides (Dresser & Kneid 2007), and the periods of the greatest movement of *A. japonicus* coincided with that of their prey (Taylor 2006).

The tidal movements detected in this study were most likely relatively small, as the fish were generally still in the detection range of their home receiver (i.e. approximately 200 m), which further supports the observation that these fish are highly site attached. Hartill et al. (2003) demonstrated a similar result of small tidal movements for *P. auratus*, with fish occupying relatively small (100's m) discrete home sites. Numerous studies employing acoustic telemetry have noted distinct tidal movements and or activity, with the same general movement exhibited each tidal cycle for both fishes (e.g. *Tautoga onitis*, Arendt et al. 2001a, *Liza ramada* (Mugilidae), Almeida 1996) and sharks (e.g. *Carcharhinus plumbeus* (Carcharhinidae), Wetherbee et al. 2001, *Triakis semifasciata* (Triakidae), Ackerman et al. 2000, *Carcharhinus obscurus* (Carcharhinidae), Huish & Benedict 1978 in Ackerman et al. 2000). Almeida (1996) suggested that these tidal movements occur in the direction of the tide in order for the animal to cover greater area at a smaller energetic cost.

This may be the case for *P. diacanthus* at the Channel Point site, and may explain why some fish were mostly detected on the ebb tide, while others were mostly detected on the flood, as depending on where their 'home site' was in relation to the receivers, fish alternately moved away or towards receivers on each of the running tides, resulting in either a decrease or an increase in detections respectively. Alternately, given fish detected on the ebb tide were found predominately at the shallow northerly end of the channel, while those fish with detections peaking on flood tides were predominately found adjacent to the deepest part of the channel, the hydrodynamic conditions created by the particular region of the channel the fish was found may have dictated when it could leave the shelter of the channel wall. Fine scale (1-2 m's) tracking (e.g. VRAP, Vemco, Canada), rather than acoustic monitoring as used in this study, combined with activity tags e.g. electromyogram (EMG) telemetered tags (see Cooke et al. 2004) or caudal differential pressure tags (see Webber et al. 2001) would be needed to determine exactly how *P. diacanthus* at Channel Point move in relation to the tides.

CHAPTER 2: SPATIAL AND TEMPORAL MOVEMENT PATTERNS, SITE FIDELITY AND RESIDENCY OF TWO VULNERABLE TEMPERATE ROCKY-REEF FISH, *CHEILODACTYLUS SPECTABILIS* AND *LATRIDOPSIS FORSTERI*

Objective 1: To study the movement patterns of key reef associated fishes in Tasmania and the NT.

Objective 2: To link movement patterns with critical life history events and habitat utilisation.

Understanding temporal and spatial utilisation of habitats through movement by fishes is critical to evaluating and protecting fishery resources. In Tasmania, Australia, detailed movement information is urgently required for banded morwong *Cheilodactylus spectabilis* (Hutton 1872) and bastard trumpeter *Latridopsis forsteri* (Castelnau 1872), given their apparent vulnerability to fishing. Large- (VR2's) and small-scale (VRAP) acoustic monitoring was used to examine the temporal/spatial movement patterns of both *C. spectabilis* and *L. forsteri* and home range size for *C. spectabilis* on rocky reefs on the Tasman Peninsula, Tasmania. Both species were not detected on receivers separated by large areas of sand (embayments and offshore reef), suggesting that these act as natural barriers to movement. *C. spectabilis* were highly site attached residents, with ≥ 83% of VR2 detections on one or two adjacent receivers at the tagging site for ≥ 40 days, and those individuals tracked with VRAP occupying very small core areas of reef between 175-868 m^2 over multiple array deployments The level of site attachment and residency exhibited by *C. spectabilis* was influenced by tagging period, with fish tagged in September 2006 showing greater site fidelity and residency than those tagged in January 2007. *C. spectabilis* fitted with depth tags showed a clear repeatable pattern of fish moving to depths >20m and up to 45 m in the morning and returning to depths < 20 m in the afternoon during the spawning period. Both *C. spectabilis* and *L. forsteri* demonstrated a clear diurnal activity pattern. Despite limited data, VR2 monitoring showed *L. forsteri* to be more mobile than *C. spectabilis*, but also capable of being site attached at the scale of a single receiver. This study has provided important information on the temporal and spatial movement patterns of both species studied, but *C. spectabilis* in particular, in Tasmania, Australia, including providing crucial information for implementing appropriate management strategies for these vulnerable species.

2.1 INTRODUCTION

Understanding temporal and spatial utilisation of habitats through movement by fishes is critical to evaluating and protecting fishery resources (Arendt et al. 2001b, Hartill et al. 2003, Sale et al. 2005, Jorgensen et al. 2006, Hindell 2007). Information on the space a species utilises (home range), the level of residency within that space, preference for particular habitats or sites (core areas) within that space, and timing of any movement in and out of the space is essential for making reliable stock assessments and implementing effective spatial and closed area management, including MPA's (Edgar et al. 2004, Buxton et al. 2006, Heupel et al. 2006, Pecl et al. 2006). The effectiveness of any area closed to fishing is dependent on the spatial and temporal scale of movement of the target species relative to the size (Corless et al. 1997, Zeller 1997, Ingram & Patterson 2001, Egli & Babcock 2004), and in the case of temporary closures the timing (Pecl et al. 2006), of the closure. Despite this, the home range and spatial and temporal utilisation patterns of most fished species remains unknown, especially in temperate regions (Lowe et al. 2003).

The paucity of detailed movement information for fish species is primarily the consequence of the level of effort required to obtain reliable estimates of movement over a meaningful range of spatial and temporal scales using traditional tagging methods. The rapid development of acoustic telemetry technology over the last two decades (see Heupel et al. 2006 for a recent review) has provided a means of remotely tracking fish movement over a broad range of spatial and temporal scales, without the need to recapture tagged animals (Arendt et al. 2001a).

In Tasmania, defining movements of fish species targeted by commercial and/or recreational fisheries has been identified as an important research issue by resource managers and fisheries representative groups. Two key species identified for such study, given their apparent vulnerability to fishing, are banded morwong *Cheilodactylus spectabilis* (Hutton 1872) and bastard trumpeter *Latridopsis forsteri* (Castelnau 1872).

C. spectabilis is a large temperate reef fish which is common in shallow coastal waters in southern Australia and northern New Zealand to at least 50 m. This species is very long lived, reaching over 90 years of age, and is sexually dimorphic with males growing faster and larger than females (McCormick 1989a, Ewing et al. 2007). *C. spectabilis* appears to be a serial spawner, spawning in late summer to early autumn, with a peak in March/April (McCormick 1989b, Murphy & Lyle 1999, Ewing et al. 2007). In New Zealand *C. spectabilis* populations have been shown to be structured by sex, size and depth (Leum & Choat 1980, McCormick 1989a & b), with juveniles and females dominating shallow reef (4-16 m), and the larger males dominating the deeper reef (17-25 m). Populations of another related morwong species, *C. fuscus*, also appear to be structured by size and depth (Lowry & Suthers 1998).

C. spectabilis is commercially fished in Tasmania and Victoria, Australia using gill nets, and sold live for the Asian restaurant market. In Tasmania there is an annual catch of around 40-50 t per annum (Ziegler et al. 2007). However, the biomass has been significantly fished down, with catches rising from less than 10 t pre 1993 to a peak of over 100 t in 1994, although this figure appears to have been inflated (Ziegler et al.

2006), after which catches declined to less than 40 t by 1999 (Ziegler et al. 2007). As a result of this reduction in the biomass, the population on the east coast of Tasmania has become younger, with these younger fish growing faster and maturing earlier (Ziegler et al. 2007). These age structure changes suggest that the fishing down of the biomass has been compensated to some extent by recruitment, which means that the fishery may be increasingly reliant on recruitment events (Ziegler et al. 2007). There is also a belief by fishers that stocks in deep water habitats may be buffering against overall stock decline (Ziegler et al. 2006). As it is a live fishery, there is very little fishing at depths greater than 30 m, as the fish suffer barotrauma, so any habitat in these depths could support a 'refuge' population. This belief is supported by anecdotal evidence from fishers who have fished at depths greater than 30 m, stating that catches are dominated by larger fish, suggesting structuring of the population by depth, as seen on New Zealand reefs (McCormick 1989a).

C. spectabilis is known to have high site fidelity to particular reefs (McCormick & Choat 1987, McCormick 1989a & b, Murphy & Lyle 1999), however, there is a poor understanding of the connectivity between the shallow and deep water habitats. Fish seen in deeper water may in fact be part of the same stock moving between habitats, meaning fishing is targeting the overall stock. Understanding the nature and timing of any such movement is particularly important, as the stock assessment model developed for the fishery is based on this assumption of a deep water refuge that partially buffers against stock decline (Ziegler et al. 2006).

Latridopsis forsteri is a schooling species that occurs in coastal waters down to about 60 m, from the central coast of New South Wales, around the south-east of the continent, including Tasmania, to eastern South Australia and also New Zealand. In Tasmania, juvenile *L. forsteri* reside on inshore reefs, moving offshore after maturing at sizes and ages greater than 450 mm and 4 years respectively (Harries & Lake 1995, Murphy & Lyle 1999), presumably to spawn as is the case with the related species *L. ciliaris*, which aggregates to spawn in offshore waters on the east coast of New Zealand (Francis 1981).

L. forsteri is captured by both commercial and recreational fishers in Tasmania, and is an important recreational species, with an estimated 43 t caught by recreational fishers in 2000/01, which was almost double the size of the commercial catch for that period (Ziegler et al. 2008). A substantial decline in commercial catches over the last century has been documented (Harries & Croome 1989, Ziegler et al. 2008), with suggestions that this species has been heavily overfished in Tasmania (Harries & Croome 1989, Barrett et al. 2007). Commercial catches have been stable at around 20 t per annum for the past six years (Ziegler et al. 2008).

L. forsteri appears vulnerable to overfishing in Tasmania, given that both the commercial and recreation fisheries are based almost entirely on juveniles, and the fact that the species exhibits strong recruitment variability (Harries & Croome 1989, Murphy & Lyle 1999). Despite this the fishery is still sustained, perhaps by mature *L. forsteri* resident on deeper offshore reefs providing a refuge population from net fishing, as proposed for *C. spectabilis*, or recruitment being provided by populations in less accessible regions of Tasmania (e.g. west coast) (Buxton et al. 2006).

There is limited data on the movement of *L. forsteri*, and its biology and ecology in general, with what is available suggesting that this species exhibits both high site fidelity (tag recapture study - Murphy & Lyle 1999; dive survey - Edgar et al. 2004), but with some individuals undergoing large scale movements (100's km) (Murphy & Lyle 1999). By examining movement in greater detail, the vulnerability of this species to fishing can be better assessed, and applicable management measures applied, such as 'juvenile area' closures, in order to ensure a significant proportion of the population is protected from exploitation before they reach maturity and contribute to the spawning biomass.

This study used acoustic telemetry to examine the temporal and fine and large-scale spatial movement patterns of both *C. spectabilis* and *L. forsteri* on inshore reefs on the Tasman Peninsula, Tasmania, Australia. The level of site fidelity, period of residency, and scales of movement of individuals of both species was studied to determine the effectiveness of potential management measures for these two vulnerable species, such as spatial and temporal closures.

2.2 MATERIALS AND METHODS

2.2.1 Study site and acoustic receiver deployment

Compact subsurface VR2 'listening stations' (Vemco, Canada) that use a multidirectional hydrophone to detect uniquely coded individual acoustic transmitters and record the date and time each transmitter is detected were used to monitor movements. Thirty-seven VR2's were deployed between 43° 08.41' S 148° 00.06' E and 42° 58.22' S 147° 59.29' E to cover an ~ 20 km stretch of coastline on the Tasman Peninsula, Tasmania, Australia, where both *C. spectabilis* and *L. forsteri* are commercially fished (Fig. 1a). Thirty-two receivers were deployed in July 2006, with the remaining five deployed in January 2007 (Table 1). Receivers were placed such that long-shore movements (Receivers S1-S17, Figs. 1a-d; Table 1), movements from shallow to deep reef (Receivers D1-D11, Figs. 1a-d; Table 1) and movement offshore could all be detected (Receivers O1-O17, Figs. 1a-c; Table 1). Inshore receivers (S and D receivers) were placed to maximise coverage along the coast, and as such many did not have overlapping detection ranges, as determined by range tests (see details below, Table 2). However, the offshore receivers (O receivers) were spaced approximately 1km apart, such as they had closely spaced detection ranges (Table 2, Fig. 2).

Receivers were moored approximately 1.5-2.0 m above the substrate with the hydrophone pointing upwards, and were deployed in one of three ways. Method 1: Attached to a steel poll set in the concrete. These receivers were deployed in depths $\leq$ 30 m and were recovered by divers. The other methods were used in depths > 30 m. Method 2: As per method 1, but with a horizontal rope line attached to the mooring. These receivers were recovered by snagging the horizontal line with a grapple. Method 3: Attached to vertical rope line using an acoustic release (AR60E, Sub Sea Sonics, USA), such that the receivers (and the release) could be brought to the surface by sending a command (acoustic signal) to the release from a surface unit and transducer.

The receivers had a battery life of either eight or fifteen months and were downloaded, had their batteries changed and were re-deployed either once in January/February 2007, twice in January/February 2007 and May 2007, or not at all depending on their battery life, deployment date and position in the array. In November 2007 the study was terminated and all receivers were recovered. Four receivers were not operational after recovery in January/February 2007 and were replaced, with a further two receivers not operational after the final recovery in November 2007 (see Table 1 for details).

Table 1. VR2 and tagging site relationships (see also Fig. 1) and periods of VR2 non-functionality

VR2	Tagging Site	Region	Deployment Date	Period VR2 not functional
S1	-	The Sisters	1/07/2006	
S2	-	Clyde Island	1/07/2006	
S3	R1	Blow Hole	1/07/2006	
S4	R1	Blow Hole	1/07/2006	
S5	R1	Blow Hole	1/07/2006	
S6	-	Patterson’s Arch	1/07/2006	1/07/2006 – 2/02/2007
S7	-	Waterfall Bay	1/07/2006	
S8	R2	Cathedral Bluff	1/07/2006	
S9	R3	Sugarlump	24/01/2007	
S10	R3	Sugarlump	1/07/2006	1/07/2006 – 14/02/2007
S11	R4	O’Hara Bluff	24/01/2007	
S12	R4	O’Hara Bluff	1/07/2006	1/07/2006 – 24/01/2007
S13	R4/5	O’Hara Bluff	24/01/2007	
S14	R6	North Thumbs	1/07/2006	
S15	-	The Thumbs	1/07/2006	
S16	-	Fortescue Bay	1/07/2006	
S17	-	The Lanterns	1/07/2006	
D1	R1	Deep Blowhole	1/07/2006	
D2	R1	Deep Blowhole	1/07/2006	
D3	R1	Deep Blowhole	1/07/2006	
D4	R2	Cathedral Bluff	1/07/2006	
D5	R2	Cathedral Bluff	1/07/2006	1/07/2006 – 9/01/2007
D6	R2	Cathedral Bluff	1/07/2006	
D7	R3	Sugarlump	24/01/2007	
D8	R4/5	O’Hara Bluff	1/07/2006	
D9	R4/5	O’Hara Bluff	1/07/2006	
D10	-	The Thumbs	1/07/2006	
D11	-	The Lanterns	1/07/2006	
O1	-	Outer Curtain	1/07/2006	
O2	-	Outer Curtain	1/07/2006	17/05/2007 – 14/11/2007
O3	-	Outer Curtain	1/07/2006	
O4	-	Outer Curtain	1/07/2006	
O5	-	Outer Curtain	1/07/2006	17/05/2007 – 14/11/2007
O6	-	Outer Curtain	1/07/2006	
O7	-	Outer Curtain	1/07/2006	
O8	-	Offshore Reef	10/01/2001	
O9	-	Little Hippolyte	1/07/2006	

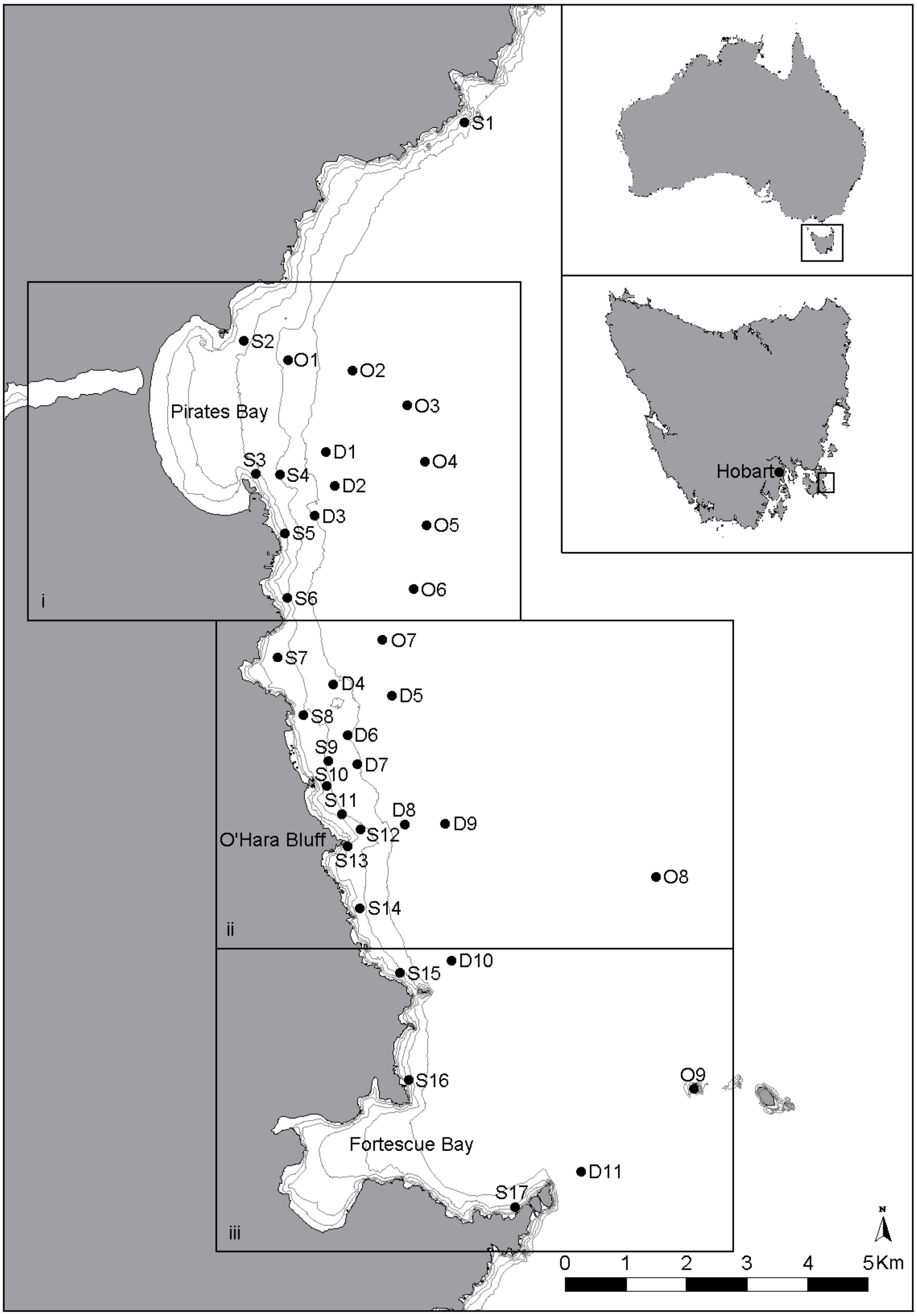


Fig. 1a. Map of Tasmania, Australia indicating location of the study site (Tasman Peninsula) and placement and identification numbers of individual receivers. Lines indicate depth contours, with the first contour at 5 m and all other contours in 10m increments. Detail of inset i, ii and iii shown on Figs. 1b, 1c and 1d, respectively

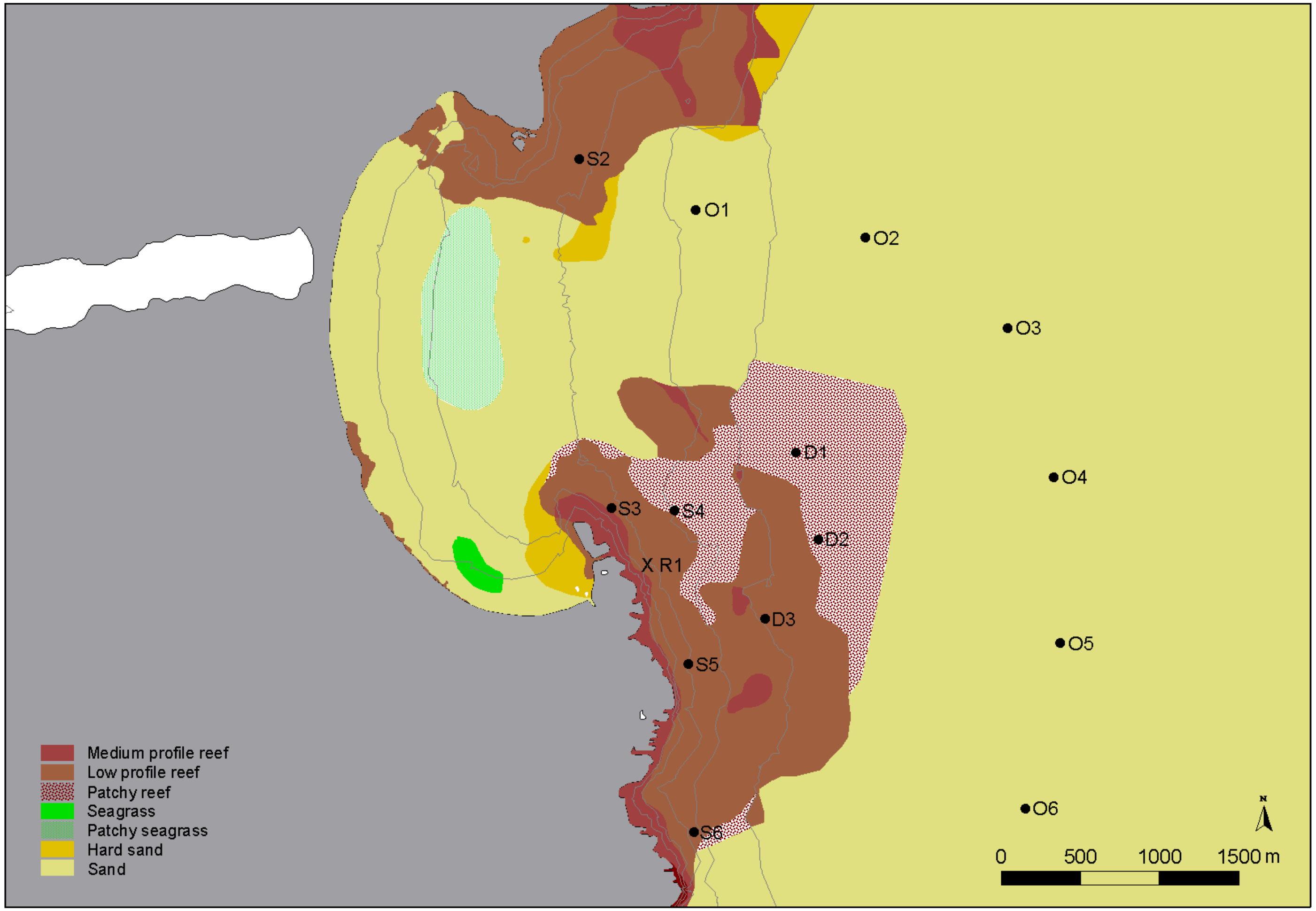


Fig. 1b. Pirates Bay region of the study site. Habitat map indicating placement and identification of individual receivers. Lines indicate depth contours, with the first contour at 5 m and all other contours in 10 m increments. X indicates fish tagging site R1

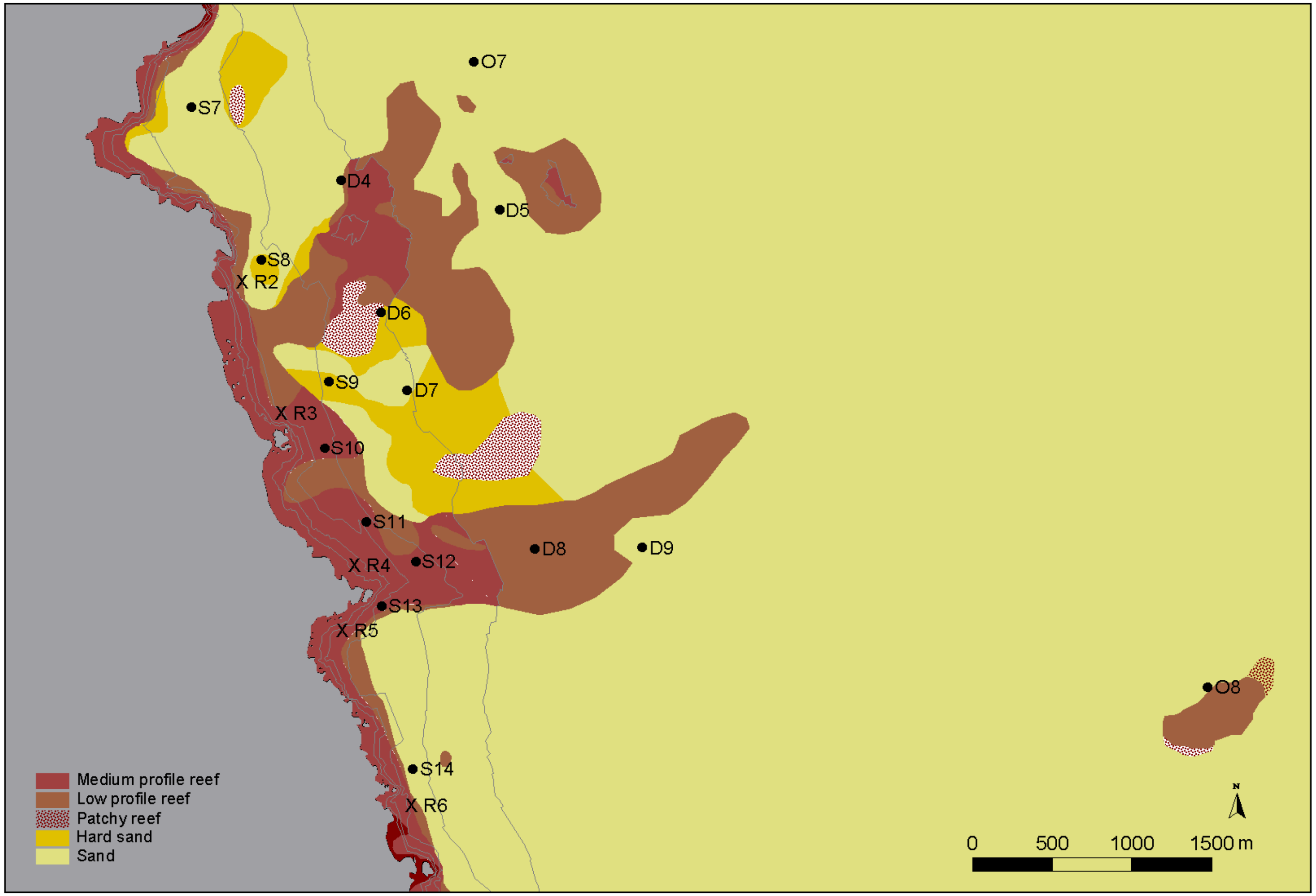


Fig. 1c. O'Hara Bluff region of the study site. Habitat map indicating placement and identification of individual receivers. Lines indicate depth contours, with the first contour at 5 m and all other contours in 10 m increments. X's indicate fish tagging sites R2-R6

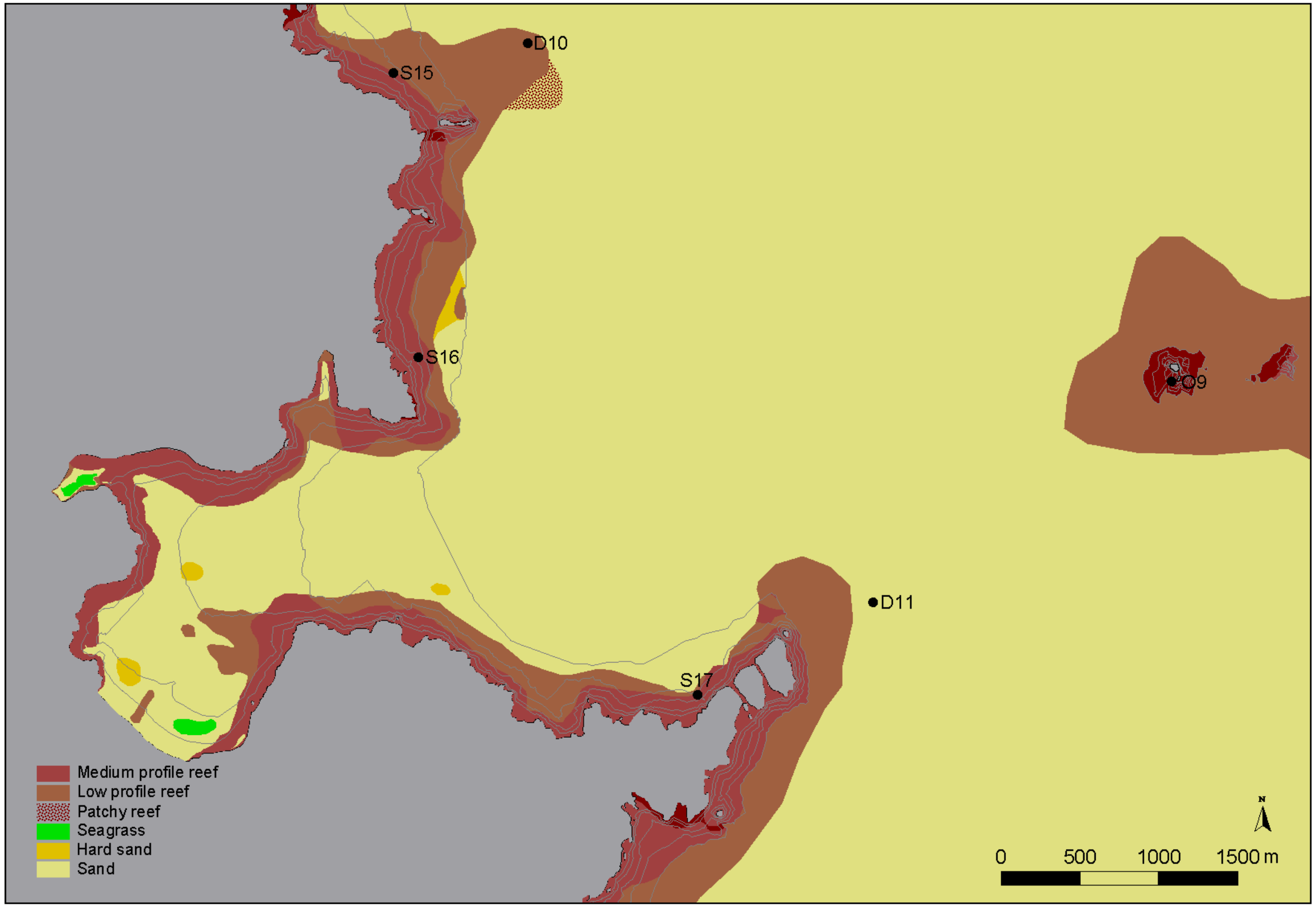


Fig. 1d. Fortescue Bay region of the study site. Habitat map indicating placement and identification of individual receivers. Lines indicate depth contours, with the first contour at 5m and all other contours in 10 m increments.

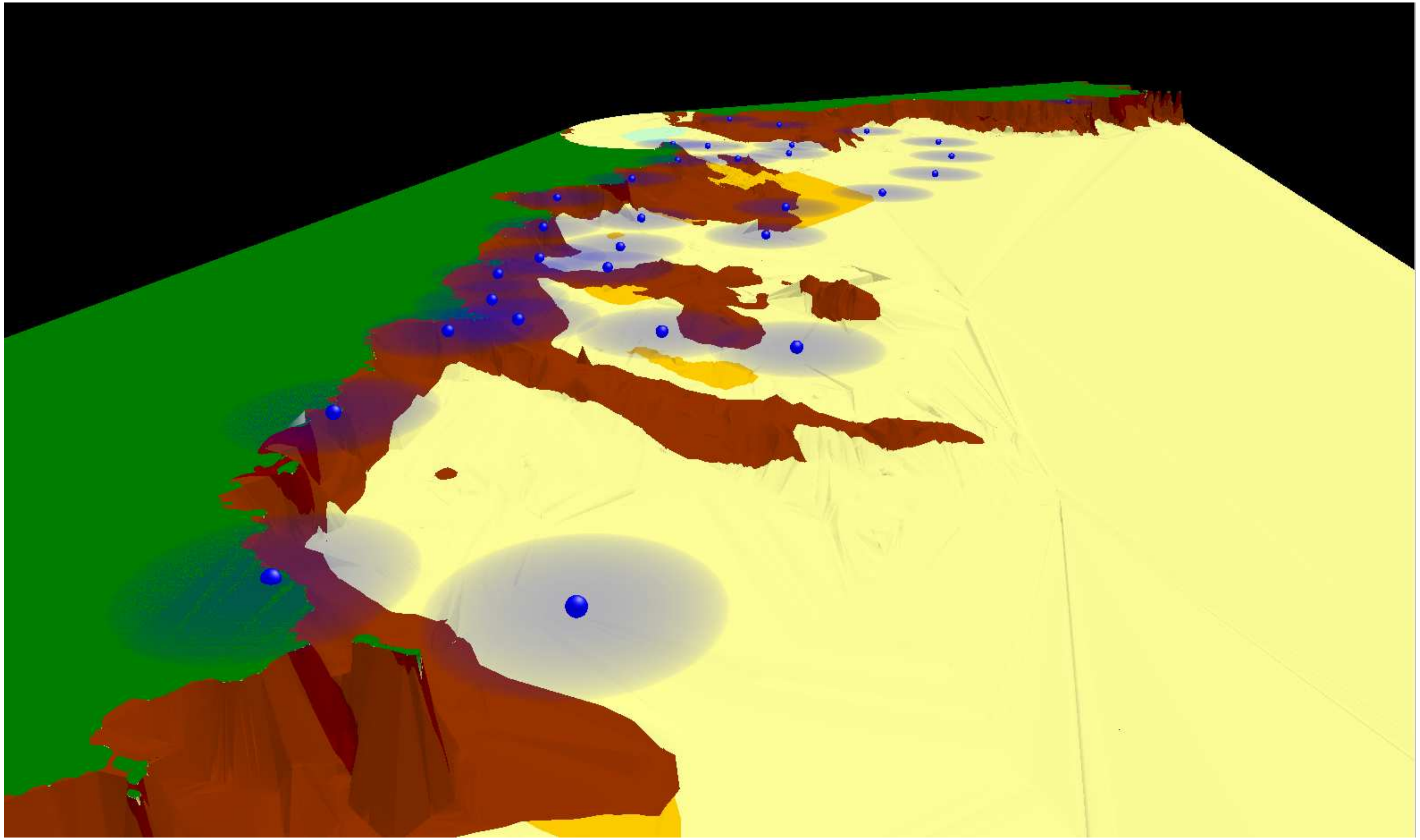


Fig. 2. 3D image of the spatial extent of VR2 acoustic receivers (blue spheres) from The Thumbs (S15 & D10) in the foreground to the Sisters (S1) and their detection ranges (halos) rendered using Eonfusion software (Myriax Software P/L)

Table 2. Pre-deployment receiver range (distance from tag to VR2) testing results from the Tasman Peninsula. '–' signifies the range was not tested at that distance

	% detections			
Range (m)	Inshore Reef	Deep Reef	Inshore Sand	Deep Sand
100	27	77	-	-
200	59	72	-	64
250	24	-	-	-
300	17	18	50	20
350	6	-	-	77
380	-	0	-	-
400	5	-	53	21
450	0	-	80	58
480	-	0	-	30
500	0	-	45	-
530	-	-	-	35
550	0	-	67	-
580	-	0	-	10
600	0	-	44	-

To obtain high-resolution fine-scale movement data for individual fish, a Vemco Radio Acoustic Positioning system (VRAP) was deployed within the VR2 array. The VRAP system is described in detail in O'Dor et al. (1998) and Klimley *et al.* (2001) and works by three surface buoys deployed in an equilateral triangle array detecting acoustic transmitters using multidirectional acoustic hydrophones and transmitting the arrival times via UHF radio modems to a land-based processor (base station), which calculates the position (latitude, longitude) of the transmitters by triangulation and plots them in near real-time. The VRAP was deployed for four separate periods: 5 September – 1 November 2006; 8 January – 14 February 2007; 2-26 April 2007; 11 September – 17 October 2007. For each period an array of approximately 300 m side length was established in the 'Blow Hole' region, with the buoys in ca. 18, 32 & 21m of water respectively (Fig. 3).

2.2.2 Study site bathymetry and habitat classification

The bathymetry and habitat characteristics of the coastline within the extent of the VR2 array from 0-40 m were obtained from SEAMAP Tasmania (www.utas.edu.au/tafi/seamap), with habitat boundaries and attributes determined using an echo sounder and video surveys and a differential GPS unit used to collect positional and depth information (see Barrett et al. 2001 for methodological details). Additional detail of bathymetry and habitats in depths > 40 m and bathymetry within and adjacent to the VRAP triangle were provided by targeted 'mapping' carried out by the 22 m *FRV Challenger* in March 2006 and a 6 m research vessel in October 2006 respectively. A habitat map incorporating bathymetry was produced from all the available data using the GIS software ArcView 3.2 (Esri, USA, www.esri.com). A 3D habitat map was also produced using the data visualisation software Eonfusion (Myriax, Australia, www.eonfusion.myriax.com).

2.2.3 Acoustic transmitters

All Vemco (Canada) coded acoustic transmitters used in this study for both range testing/error determination and fish tracking emitted a unique identifiable code at a frequency of 69KHz, but with varying power outputs (PO) and periods between each code transmission (off-time) depending on the transmitter type.

2.2.4 VRAP positional error testing

To provide reference points for determining the average position error of the VRAP system at various points in the array, four acoustic transmitters were moored in fixed positions approximately 2 m above the substrate within the VRAP array (Fig. 3) and the latitude and longitude of each position recorded. V16-4L coded tags, with a PO of 147 db re 1 μPa @ 1m and a random off time of 180-300 s were used as reference tags for three of the four deployments (October 2006, January 2007 and September 2007). For the April 2007 deployment four V16-5H continuous tags (note that these tags cannot be detected by the VR2s and were used for operational reasons only), with a PO of 159 db re 1 μPa @ 1 m and a pulse period of ca 1.5 s were used as the reference tags.

2.2.5 VR2 range testing

Pre-deployment trials of the receiving range of VR2's at the Tasman Peninsula were conducted in July 2006. Range was determined by mooring a VR2 approximately 1.5-2.0 m above the substrate and then suspending an acoustic transmitter with a PO of 147 db re 1 μPa @ 1 m and a fixed off-time of 5 s (hereafter referred to as the 'test tag') approximately 1m above the substrate at set distances from the receiver for a known time period (Table 2). Four separate range tests were conducted to determine the receiving range of the VR2's on inshore (~ 10-33 m) reef, deep (~ 33-45 m) reef, inshore (~ 23-31 m) sand and deep (~ 38-45 m) sand, as these four habitats comprised the majority of the study area. The detections received at each distance were expressed as a percentage of the total number of detections expected in the time period (hereafter referred to as the 'detection efficiency').

Following establishment of the VR2 array in July 2006, the functional receiving ranges of some of the deeper (35-80 m) receivers (O2, O5 & O6, see Fig. 1a & b) were examined by towing the test tag between the receivers. The tag was towed on a weighted line ~ 30 m behind the *FRV Challenger*, with a crane boom used to trail the line 4 m outboard of the vessel to reduce transmission interference created by the wake and propeller wash. Towing speed was between 2.6-14.2 km hr^{-1} and the tag depth ranged from 2-4 m below the surface. As it was difficult to maintain a constant speed, detection efficiency was not calculated, with only the minimum and maximum detection ranges examined.

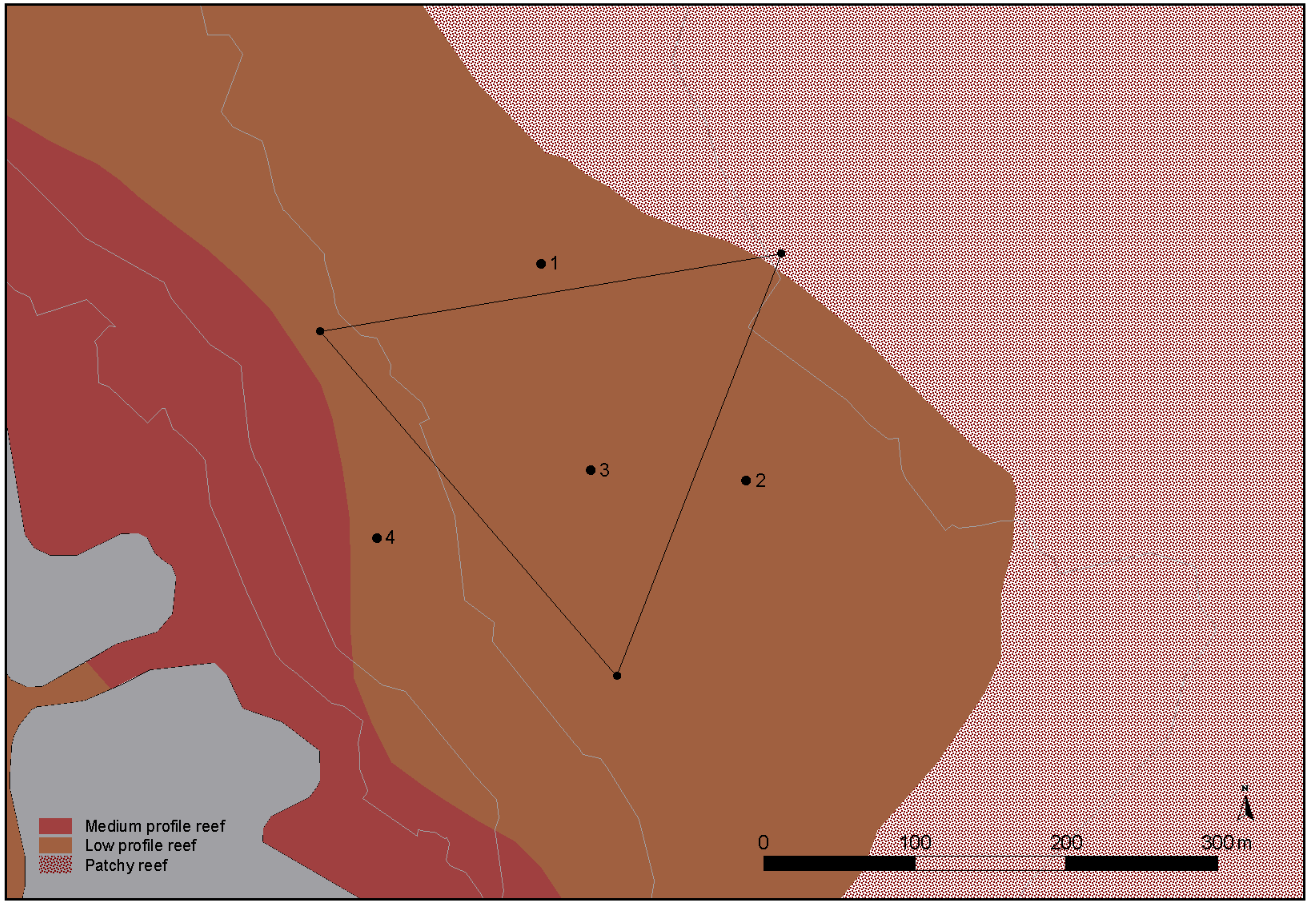


Fig. 3. Location of the VRAP system within the Blow Hole region. Numbered dots indicate the location of the four moored reference transmitters. Lines indicate the 5 m, 10 m, 20 m and 30 m depth contours

2.2.6 Tagging

C. spectabilis and *L. forsteri* individuals were captured at the Tasman Peninsula by a commercial net fisher using 140 mm mesh nets of 20-50 m length and 1.7 m depth between 12 September 2006 and 3 July 2007 in waters ≤ 20 m (so as to avoid barotrauma) within the VR2 array. For all fish the capture position was recorded using a hand-held GPS unit and the fork length (FL) of fish measured. After measurement fish were placed in an anaesthetic induction bath containing 72 mg L-1 AQUI-S (iso-eugenol) (AQUI-S New Zealand Ltd). Once a fish was at a surgical plane of anaesthesia it was transferred to a purpose-built surgical table with aerated water containing AQUI-S at 27 mg L-1 pumped over the gills. Surgery involved making a 10-20 mm incision in the ventral abdominal wall, implanting the acoustic transmitter and suturing the incision with resorbable sutures. Close attention was paid to maintaining the best aseptic technique possible under field conditions.

Post-surgery, fish were tagged with two external T-bar tags (Hallprint, Australia), each marked with a unique five digit identifier, just below the dorsal fin, injected in the tail musculature with 50 mg kg^{-1} of oxytetracycline to protect against infection and transferred to an aerated recovery tank to ensure full recovery from the anaesthetic, after which they were released. Some tagged fish were recaptured by fishers during the study, and in most cases were re-released where they were caught and the capture position and external tag id noted. In a small number of cases tagged fish were reported by fish processors, and these fish were collected, measured, sexed where possible and the acoustic tag removed and re-used if possible.

Forty-three *C. spectabilis* were tagged during the study (see Fig. 1b & c and Table 3 for tagging locations), with 28 tagged between 12-15 September 2006 and 14 on 18 January 2007. Note that one of the 28 fish tagged in September 2006 underwent surgery, but was only tagged with T-bar tags and not an acoustic tag. *C. spectabilis* ranged from 325–575 mm FL (average 419 ± 10mm se) and were either tagged with V9-2H (PO 147 db re 1 µPa @ 1 m, 9 mm diameter, 29 mm length, 2.9 g in water) (17 fish), V13-1H (PO 147 db re 1 µPa @ 1 m, 13 mm diameter, 36 mm length, 6 g in water) (10 fish) or V13P-1H (PO 150 db re 1 µPa @ 1 m, 13 mm diameter, 45 mm length, 6 g in water) (16 fish) transmitters (see Table 3 for fish details). The latter transmitters recorded depth at a resolution of 0.44 m, with an accuracy of ± 10 m, as well as tag id. Fish > 524 mm FL were classified as Male, as only 1% of ~ 5000 sexed *C. spectabilis* measured by TAFI staff > 470 mm FL were female, with the largest ever recorded female 524 mm FL (G. Ewing pers. com.).

Twenty-nine *L. forsteri* were tagged during the study (see Fig. 1b & c and Table 4 for tagging locations), with eight tagged between 13-15 September 2006, seven between 18-19 January2007, eight on 19 March 2007 and six on 03 July /2007. Fish ranged from 280–455 mm FL (average 402 ± 8 mm se) and were either tagged with V9-2H (19 fish) or V9-2L (PO 142 db re 1 µPa @ 1 m, 9 mm diameter, 29 mm length, 2.9 g in water) (9 fish) transmitters (see Table 4 for fish details). All transmitters for both species had a random off-time of 60-180 s.

2.2.7 Analysis

VR2 receivers

Given tagged fish were anaesthetised and may not have behaved normally immediately after release, detections that occurred in the first 24 hr following tagging were not included in the analysis. Similarly, fish that were identified by only a single detection at a particular time or site were not included in the analyses, as there is a high probability that single detections are false positives created by acoustic code collision (see www.vemco.com). Daily fish presence for both *C. spectabilis* and *L. forsteri* at the Tasman Peninsula was determined by grouping all detections for each individual fish for all receivers over the duration that the tag was monitored into daily bins, and if the fish was detected at least once in that day it was considered present for that particular day. The time at liberty and detection period was determined for all fish as the number of days between tagging and removal of the receivers or removal of the active transmitter, including recaptures and the predicted expiry date of the battery and the period in days between the first and last detection respectively. The temporal periodicity in fish detections at the Tasman Peninsula site was assessed using FFT analysis (see Chapter 1 for details).

For those *C. spectabilis* detected at the blow hole region with ≥ 100 detections (16 out of a total of 22 fish with ≥ 100 detections for all regions combined) the percentage of time at liberty (PTL) and the percentage of the detection period (PDP) that individual fish were detected were calculated as a measure of residency and site fidelity respectively. The analysis was undertaken separately for each tagging period (either September 2006 – 7 fish or January 2007 – 9 fish). Percentages were weighted by the length (days) of the PTL and the PDP respectively. For these same 16 fish, Pearson correlation coefficients were used to determine the association between FL and PTL and PDP.

The home receiver for each *C. spectabilis* acoustically tagged was determined as the receiver that had the most detections for that fish. The proportion of available fish (number of individual fish detected scaled by the number of fish available) detected per month at set distances from their home receiver (0-399 m, 400-999 m, 1,000-2,999 m, ≥ 3,000 m), determined by measuring the distance of each receiver visited from the home receiver, was then calculated. Individual fish were only counted once per month per distance category.

Detections were also placed in one of two depth categories (relative to the receiver), 0-30 m and ≥ 40 m (note there were no receivers in depths between 31-39 m), such that the proportion of available fish detected per month at each depth category could be determined. The actual depth of those fish fitted with depth tags was also examined over time.

Table 3. *Cheilodactylus spectabilis* tagged at the Tasman Peninsula array. *Fish carried a depth transmitter. **Sex determined by size.

Fish	Tagging Date	Tagging Site	FL (mm)	Sex & maturity (if known)	Recapture Date	Recapture Site (nearest tag site)	Re-released	Detections	First Detection	Last Detection	Detection Period (days)	Days between tagging and First Detection	Days between tagging and Last Detection	Days Detected	Days at Liberty
BM01	12/09/2006	R1	430					4	18/02/2007	20/06/2007	123	159	281	4	429
BM02	12/09/2006	R1	378					6	20/09/2006	16/01/2007	119	8	126	4	185
BM03	12/09/2006	R1	370	Female	19/03/2007	R3	Yes	4,098	15/09/2006	7/01/2007	115	3	117	110	185
BM04	12/09/2006	R1	380					0							
BM05	12/09/2006	R2	360		27/02/2007	R1	Yes	0							
BM06	12/09/2006	R2	365					3	4/04/2007	4/04/2007	1	204	204	1	204
BM07	12/09/2006	R2	325					0							
BM08	13/09/2006	R1	460					33,528	15/09/2006	28/06/2007	287	2	288	287	428
BM09	13/09/2006	R1	425					9,438	14/09/2006	13/11/2007	426	1	426	312	428
BM10	13/09/2006	R1	410		3/07/2007	R1	Yes	105	26/01/2007	22/04/2007	87	135	221	40	221
BM11	13/09/2006	R1	360		3/07/2007	R1	No	17	6/10/2006	15/11/2006	41	23	63	7	185
BM12	13/09/2006	R1	355		4/06/2007	S of Pirates Bay	No	2,086	17/09/2006	3/06/2007	260	4	263	185	263
BM13	13/09/2006	R1	385		1/9/2007	R1	No	2,743	15/09/2006	5/05/2007	233	2	234	178	353
BM14	13/09/2006	R1	430					5,926	17/09/2006	11/11/2007	421	4	424	403	428
BM15	13/09/2006	R1	370					55,668	15/09/2006	12/11/2007	424	2	425	422	428
BM16	15/09/2006	R6	461					0							
BM17	15/09/2006	R6	372					102	30/11/2006	10/05/2007	162	76	237	51	426
BM18	15/09/2006	R6	362					4	17/09/2006	22/10/2006	36	2	37	2	185
BM19	15/09/2006	R6	367					0							
BM20	15/09/2006	R6	392					5	12/03/2007	15/04/2007	35	178	212	4	426
BM21	15/09/2006	R6	382	Female	13/03/2007 16/12/2007	R6 S of Pirates Bay	Yes No	15	30/09/2006	26/11/2006	58	15	72	13	185
BM22	15/09/2006	R6	412					0							
BM23	15/09/2006	R4	446	Male	24/02/2007	R4	No	No transmitter							

BM24	15/09/2006	R4	397					0							
BM25	15/09/2006	R4	362					18	4/04/2007	29/10/2007	209	201	409	6	409
BM26	15/09/2006	R4	382					0							
BM27	15/09/2006	R5	387					0							
BM28*	15/09/2006	R4	432	Male	18/12/2006	S of Pirates Bay	Yes	0							
BM29*	15/09/2006	R4	530	Male**				1,560	15/12/2006	8/09/2007	268	91	358	89	426
BM30*	18/01/2007	R1	500					3,909	20/01/2007	12/11/2007	297	2	298	282	301
BM31*	18/01/2007	R1	485					1,169	19/01/2007	12/10/2007	267	1	267	84	301
BM32*	18/01/2007	R1	475					829	26/01/2007	16/06/2007	142	8	149	42	301
BM33*	18/01/2007	R1	394					1,614	18/01/2007	28/06/2007	162	0	161	70	301
BM34*	18/01/2007	R1	405					366	26/01/2007	21/08/2007	208	8	215	116	301
BM35*	18/01/2007	R1	410					352	24/01/2007	21/04/2007	88	6	93	43	301
BM36*	18/01/2007	R1	450					801	9/02/2007	5/04/2007	56	22	77	46	301
BM37*	18/01/2007	R1	390					3,255	19/01/2007	3/07/2007	166	1	166	140	301
BM38*	18/01/2007	R1	402					2	22/02/2007	28/02/2007	7	35	41	2	301
BM39*	18/01/2007	R1	365					500	28/01/2007	3/11/2007	280	10	289	70	301
BM40*	18/01/2007	R5	575	Male**				109	26/01/2007	7/05/2007	102	8	109	62	301
BM41*	18/01/2007	R5	535	Male**				6,892	24/01/2007	12/11/2007	293	6	298	266	301
BM42*	18/01/2007	R3	560	Male**				2,085	24/01/2007	29/10/2007	279	6	284	107	301
BM43*	18/01/2007	R3	575	Male**				4	24/03/2007	2/04/2007	10	65	74	4	301

Table 4. *Latridopsis forsteri* tagged at the Tasman Peninsula array. *Fish only detected in first 24 hrs after tagging.

Fish	Tagging Date	Tagging Site	FL (mm)	Detections	First Detection	Last Detection	Detection Period (days)	Days between tagging and First Detection	Days between tagging and Last Detection	Days Detected	Days at Liberty
BT01	13/09/2006	R1	402	494	14/09/2006	16/09/2006	3	1	3	3	185
BT02	13/09/2006	R1	425	3	17/09/2006	17/09/2006	1	4	4	1	185
BT03	13/09/2006	R1	435	5,709	14/09/2006	14/03/2007	182	1	182	124	185
BT04	13/09/2006	R1	415	0							185
BT05	13/09/2006	R1	420	11	15/09/2006	15/09/2006	1	2	2	1	428
BT06	15/09/2006	R4		0							185
BT07	15/09/2006	R4		0							185
BT08	15/09/2006	R2		4,351	16/09/2006	9/09/2007	359	1	359	106	359
BT09	18/01/2007	R5	440	0							301
BT10	18/01/2007	R5	440	661	19/01/2007	19/05/2007	121	1	121	55	301
BT11	18/01/2007	R3	405	331	27/02/2007	4/11/2007	251	40	290	38	301
BT12	18/01/2007	R2	426	65	2/02/2007	5/03/2007	32	15	46	6	185
BT13	19/01/2007	R5	380	0							300
BT14	19/01/2007	R4	405	4	24/01/2007	24/01/2007	1	5	5	1	300
BT15	19/01/2007	R5	315	0							300
BT16	19/03/2007	R4	386	0							185
BT17	19/03/2007	R4	445	0							185
BT18	19/03/2007	R4	390	0							185
BT19	19/03/2007	R4	375	0							241
BT20	19/03/2007	R4	395	0							241
BT21	19/03/2007	R4	355	2	24/06/2007	24/06/2007	1	97	97	1	241
BT22	19/03/2007	R4	395	16	25/03/2007	26/03/2007	2	6	7	2	185
BT23	19/03/2007	R4	385	38	25/03/2007	29/03/2007	5	6	10	5	185
BT24	3/07/2007	R1	425	145*	3/07/2007	4/07/2007	2	0	1	2	135
BT25	3/07/2007	R1	435	64*	3/07/2007	4/07/2007	2	0	1	2	135
BT26	3/07/2007	R1	415	91*	3/07/2007	4/07/2007	2	0	1	2	135
BT27	3/07/2007	R1	455	8,096	4/07/2007	4/11/2007	124	1	124	97	135
BT28	3/07/2007	R1	280	914	4/07/2007	10/08/2007	38	1	38	30	135
BT29	3/07/2007	R1	415	10	5/07/2007	18/07/2007	14	2	15	6	135

Vemco Radio Acoustic Positioning system

An average position was calculated for each transmitter for each five minute period the system was ‘listening’ for transmitters throughout the study using the VRAP software (Vemco), with positions calculated for periods of high environmental noise filtered from the data set, as these can be unreliable. Filtered data was visualised using ArcView 3.2 (ESRI) where obvious erroneous data points, such as those on land, were removed from the data set. Given the low spatial spread of positions, further filtering was not performed. The final data set was visualised using both ArcView 3.2 and Eonfusion software (Myriax Software). An average positional error (accuracy) ± se (precision) for each of the four fixed reference transmitters within the VRAP array was calculated for the October 2006 deployment period based on the difference between the calculated and known position of the transmitters.

The level of site fidelity of each fish positioned within the VRAP was determined using a random walk simulation in the Animal Movement extension of ArcView (Hooge & Eichenlaub 1997), which compares the actual sequence of paths travelled with a random arrangement of the paths (Hooge et al. 2001). For those fish that demonstrated site fidelity and had ≥ 100 individual detections, the kernel probabilistic home range technique (Worton 1989) within the Animal Movement ArcView extension was used to determine the 95% probability contour, which is the area the animal actually uses, and the 50% probability contour, which is the core area of activity (Hooge et al. 2001).

2.3 RESULTS

2.3.1 VR2 Receiver range tests

The pre-VR2 deployment range testing showed the maximum effective detection range of the VR2's on reef to be 200m, with 59% detection efficiency on the inshore reef and 72% on the deep reef (Table 2). The maximum effective detection ranges on sand were 550 m on inshore sand, with 67% detection efficiency, and 450 m on deep sand, with 58% detection efficiency (Table 2). However, the post-VR2 deployment trial in July 2006, where the test tag was towed past selected deep sand receivers, demonstrated that these receivers could detect transmitters at ranges over 800 m.

2.3.2 VR2 acoustic monitoring

General Results

Twenty-four of the 37 receivers had detections, with no fish detected on the most northern (S1 & S2), southern (S17 & D11) or offshore (O1-O7) receivers (note that O2 and O5 were not functional for the last 6 months of the study, see Table 1). Forty-seven of the 71 fish tagged with acoustic transmitters had valid detections, with 32 of 42 *C. spectabilis* tagged (76%) (Tables 3, 5 & 7) and 15 of 29 *L. forsteri* (52%) (Tables 4, 6 & 7) detected respectively. Of the 157,191 individual valid fish detections, 137,213 (87%) were from *C. spectabilis* and only 20,706 (13%) from *L. forsteri*. The majority of fish tagged in the Blow Hole region were detected, with 21 of 22 (95%) *C. spectabilis* and seven of 11 (64%) *L. forsteri* detected respectively, with similar detectability for both the 2006 and 2007 tagged fish (Table 7). Of the fish detected that were tagged at the Blow Hole region, 17 (81%) *C. spectabilis* and four (57%) *L. forsteri* had ≥ 100 valid detections. For those fish tagged in September 2006, the detection rate at other regions was generally poor, with 7 of 16 (44%) *C. spectabilis* detected (Table 7), of which only three (43%) had ≥ 100 valid detections. Of the two *L. forsteri* tagged in September 2006, none were detected. All of the four *C. spectabilis* tagged in 2007 at regions other than the Blow Hole were detected, with three fish having ≥ 100 valid detections. Thirteen *L. forsteri* were tagged at O'Hara Bluff in 2007, with only five detected (38%) and only one having ≥ 100 valid detections.

Nine *C. spectabilis* tagged in September 2006 (including the fish tagged with only t-bar tags) were recaptured in good condition, between 94 and 457 days after tagging (see Table 3). Five of these fish were tagged at the Blow Hole region, with all five detected by receivers, whereas only one of the three fish recaptured from other tagging regions was detected (Table 7). The poor detection rates of those *C. spectabilis* tagged at Cathedral and O'Hara Bluff in September 2006 compared to those tagged in 2007 is most likely a result of the combination of receiver failure, with two receivers failing in the Cathedral Bluff region and one in the O'Hara Bluff region during 2006, set against increased receiver coverage in 2007, with two additional receivers being placed in both these regions in 2007 (Table 1). However, it should be noted that the detection of *L. forsteri* tagged at O'Hara Bluff was poor for both tagging periods, so this is most likely due to fish behaviour. There were no long-term recaptures of *L. forsteri*, however, several fish were recaptured during the tagging periods (i.e. first few days after release) and one unidentified tagged fish was observed on SCUBA behaving normally one day after the tagging period.

Site attachment and residency of Latridopsis forsteri

Six of the 15 *L. forsteri* detected (BT03, 08, 10, 11, 27 & 28) were detected for ≥ 30 days in total (range 30–124 days) (Table 4, Fig. 4) and collectively accounted for approximately 96% of the total detections. Five of these fish (Fish BT03, 08, 10, 27 & 28) were highly site attached when detected, with >98% of detections on the one receiver, which was either in or directly adjacent to the tagging region (see Table 6, Fig. 1). Fish BT11 showed a different pattern, with only 61% of detections at a receiver within its tag region and detection by 11 separate receivers over ~ 5 km of coastline. Three other fish had detections on receivers >4 km apart, fish 10 (~ 5 km), despite being site attached, fish 22 (~ 4.5 km) and fish 23 (~ 10 km) (Table 6, Fig. 1).

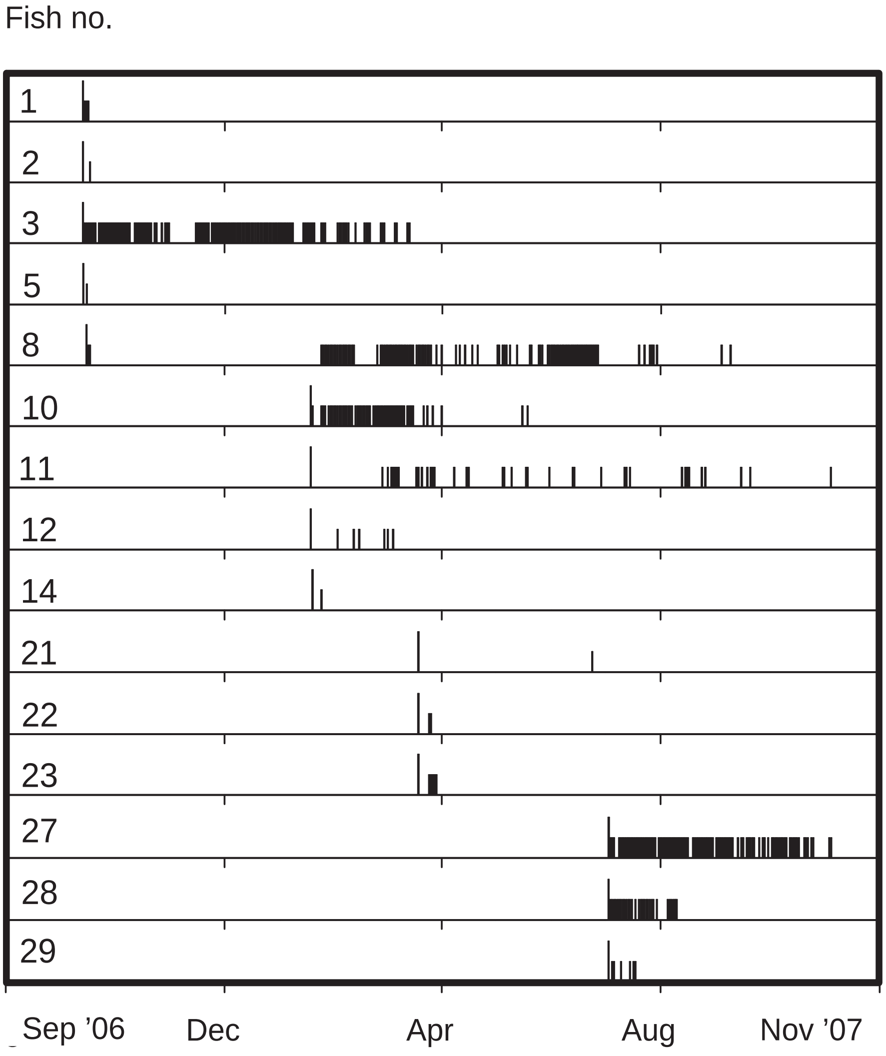


Fig. 4. *Latridopsis forsteri*. Presence/absence of individual fish. The initial line represents the tagging day and each subsequent line represents a day that the fish was detected

Table 5. *Cheilodactylus spectabilis* valid detections per receiver. Values in brackets = % of total detections for those values ≥ 10%

		Blow Hole						Patterson's Arch	Waterfall Bay	Cathedral Bluff	Sugar Lump			O'Hara Bluff				Nth Thumbs	Thumbs	Fortescue Bay
Fish	Tag Region	S3	S4	S5	D1	D2	D3	S6	S7	S8	S9	S10	D7	S11	S12	S13	D8	S14	S15	S16
BM01	Blow Hole	4																		
BM02	Blow Hole		6																	
BM03	Blow Hole									4,098										
BM06	Cathedral Bluff									3										
BM08	Blow Hole	33,292 (99.3)	236																	
BM09	Blow Hole			9,431 (99.9)			7													
BM10	Blow Hole	105																		
BM11	Blow Hole		17																	
BM12	Blow Hole	2,080 (99.7)	6																	
BM13	Blow Hole	74	2,528 (92.2)		141															
BM14	Blow Hole	1,168 (19.7)	4,758 (80.3)																	
BM15	Blow Hole	55,560 (99.8)	108																	
BM17	Nth Thumbs																	91 (89.2)	11 (10.8)	
BM18	Nth Thumbs									4										
BM20	Nth Thumbs																		5	
BM21	Nth Thumbs																	15		
BM25	O'Hara Bluff														18					
BM29	O'Hara Bluff													1,422 (91.2)	2		136			
BM30	Blow Hole	1,686 (43.1)	2,211 (56.6)		12															

BM31	Blow Hole			1139 (97.4)			1	1	4	7	1				10	2	1	3
BM32	Blow Hole	7	13	751 (90.6)			58											
BM33	Blow Hole		1	1546 (95.8)			67											
BM34	Blow Hole		120 (32.8)	184 (50.3)	2	8	52 (14.2)											
BM35	Blow Hole			305 (86.6)		4	43 (12.2)											
BM36	Blow Hole		7	312 (39.0)		28	454 (56.7)											
BM37	Blow Hole			3255														
BM38	Blow Hole							2										
BM39	Blow Hole		31	386 (77.2)		4	79 (15.8)											
BM40	O’Hara Bluff												1	108 (99.1)				
BM41	O’Hara Bluff														6,,892			
BM42	Sugar Lump										862 (41.3)	1,006 (48.3)	217 (10.4)					
BM43	Sugar Lump														4			

Table 6. *Latridopsis forsteri* valid detections per receiver. Values in brackets = % of total detections for those values ≥ 10%

		Blow Hole				Waterfall Bay	Cathedral Bluff				Sugar Lump			O'Hara Bluff					Nth Thumbs	Thumbs	Fortescue Bay
Fish	Tag Region	S3	S4	S5	D3	S7	S8	D4	D5	D6	S9	S10	D7	S11	S12	S13	D8	D9	S14	D10	S16
BT01	Blow Hole			494																	
BT02	Blow Hole			3																	
BT03	Blow Hole	8	5,685 (99.6)	15	1																
BT05	Blow Hole	3	8																		
BT08	Cath-edral Bluff						80						4,271 (98.2)								
BT10	O'Hara Bluff			2		2		1								654 (98.9)	2				
BT11	Sugar Lump						6		13	20	3	12	201 (60.7)	2	3		29	40 (12.1)		2	
BT12	Cath-edral Bluff						6			59											
BT14	O'Hara Bluff																4				
BT21	O'Hara Bluff												2								
BT22	O'Hara Bluff														1						15
BT23	O'Hara Bluff	11				1								4	2				1		19
BT27	Blow Hole			8,094 (99.9)	2																
BT28	Blow Hole	914																			
BT29	Blow Hole		10																		

Table 7. Summary of valid detections for each tagging site at the Tasman Peninsula for both fish species.

September 2006 Tagging		*Cheilodactylus spectabilis*						*Latridopsis forsteri*			
Tag Site	Tag Region	# Fish Tagged	# Fish Detected	# Fish Detected at Tag Region	# Fish With $\geq$100 Detections	# Recaptured	# Recaptured But Not Detected	# Fish Tagged	# Fish Detected	# Fish Detected at Tag Region	# Fish With $\geq$100 Detections
R1	Blow Hole	12	11	10	8	5	0	5	4	4	2
R2	Cathedral Bluff	3	1	1	0	1	1	1	1	1	1
R4	O’Hara Bluff	5	2	2	1	1	1	2	0	0	0
R5	O’Hara Bluff	1	0	0	0	0	-	-	-	-	-
R6	Nth Thumbs	7	4	2	1	1	0	-	-	-	-
2007 Tagging		*Cheilodactylus spectabilis*						*Latridopsis forsteri*			
Tag Site	Tag Region	# Fish Tagged	# Fish Detected	# Fish Detected at Tag Region	# Fish With $\geq$100 Detections	# Recaptured	# Recaptured But Not Detected	# Fish Tagged	# Fish Detected	# Fish Detected at Tag Region	# Fish With $\geq$100 Detections
R1	Blow Hole	10	10	10	9	0	-	6	3 (3 detected in 1st 24hrs not included)	3	2
R2	Cathedral Bluff	-	-	-	-	-	-	1	1	1	0
R3	Sugarlump	2	2	1	1	0	-	1	1	1	1
R4	O’Hara Bluff	-	-	-	-	-	-	9	4	3	0
R5	O’Hara Bluff	2	2	2	2	0	-	4	1	1	1

Site attachment and residency of Cheilodactylus spectabilis

Twenty-two of the 32 *C. spectabilis* detected were detected for ≥ 40 days in total (range 40 – 422 days) (Table 3, Fig. 5) and accounted for approximately 99.9% of the total detections. With a single exception, all of these fish were highly site attached when detected, with > 83% of detections on one or two adjacent receivers, which were either in or directly adjacent to the tagging region (see Table 5, Fig. 1, see also 3D representations of detections – Figs. 6 & 7). Fish BM03 was the exception and was detected at a receiver approximately 3.5 km from its tagging site. This fish was also recaptured at a site within 1 km of where it was last detected. Of the five other fish recaptured with details available of their capture site, four were captured in the area they were tagged (BM10, 11, 13 & 21) and one (BM05) was captured approximately 3.5 km from its tagging site.

Of the 16 *C. spectabilis* tagged at the blow hole region that had ≥ 100 detections, those fish tagged in September 2006 and January 2007 had average PDPs (measure of site fidelity) of 85 ± 6.0% and 53.6 ± 9.4% and PTLs (measure of residency) of 66.3 ± 11.7% and 33.0 ± 8.4% respectively.

A single *C. spectabilis* individual demonstrated large scale movement similar to that for several *L. forsteri*. BM31 was detected consistently at the Blow Hole region from tagging in January 2007 until early May 2007, after which it was not detected again until early October 2007, approximately 9km south at the Fortescue Bay receiver. It was then detected by the long-shore receivers (S receivers) travelling north along the coast and was last detected back at the Blow Hole region two days after detection at Fortescue Bay (Table 5, Fig. 5).

Movement of Cheilodactylus spectabilis during the spawning season

C. spectabilis were predominantly detected between 0 and 1000m from their home receiver throughout the study period, except between December 2006 and April 2007, which encompasses the spawning season, where some fish were detected up to 3000 m from their home receiver (Fig. 8). Similarly, fish were predominantly detected between 0 and 30 m depth throughout the study period, except between December 2006 and May 2007, when around 20% of fish were also detected by receivers in ≥ 40 m depth (Fig. 9). Additionally, 12 of the 15 fish fitted with depth transmitters detected by VR2's moved into water deeper than ~ 20 m and up to ~ 45 m during the spawning season between late January and early May (Fig. 10), with three of these fish classified as male, as they were > 524 mm. These fish did not remain in the deep water, but instead moved into deeper water in the morning and then back into shallower water in the early afternoon (Fig. 11), with the pattern repeated throughout the spawning season (Fig. 12). There was some individual variation in the frequency of these excursions into deep water, for example BM32 repeated the pattern every day, whereas BM37 repeated the pattern every second day (Fig. 13).

Spectral analysis

The dominant biorhythm detected by the spectral analyses (FFT) for both *L. forsteri* (Fig. 14a) and *C. spectabilis* (Fig. 14b) was diel (24 hrs), with both species demonstrating clear diurnal activity pattern based on detections (Figs. 15-17). The pattern for *C. spectabilis* was consistent among seasons (Fig. 16). Note the width of the mode corresponded to daylight period, which varies with season. The pattern for *C. spectabilis* was also consistent among large and medium size classes (Fig. 17), however, smaller fish showed a more gradual increase in detections throughout the day, with a peak towards dusk (Fig. 17).

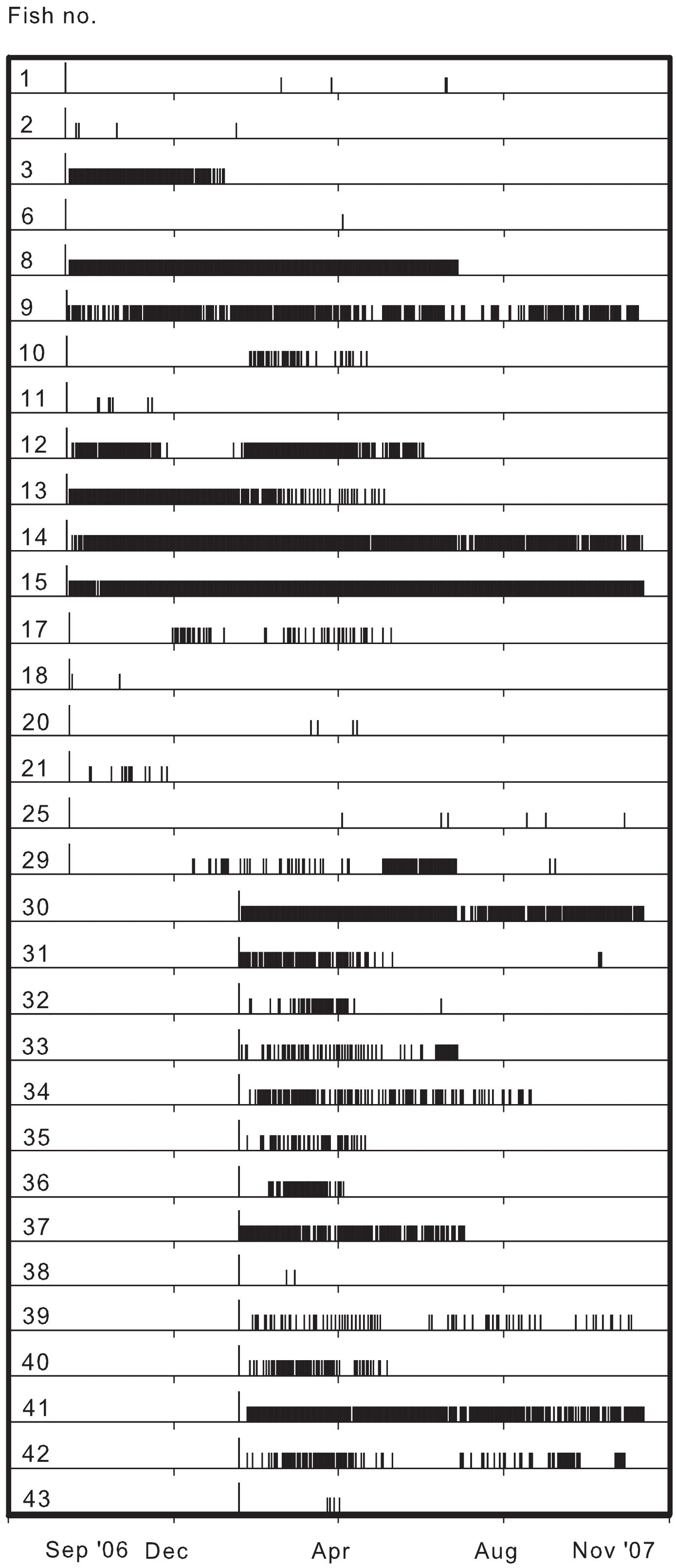


Fig. 5. *Cheilodactylus spectabilis*. Presence/absence of individual fish. The initial line represents the tagging day and each subsequent line represents a day that the fish was detected

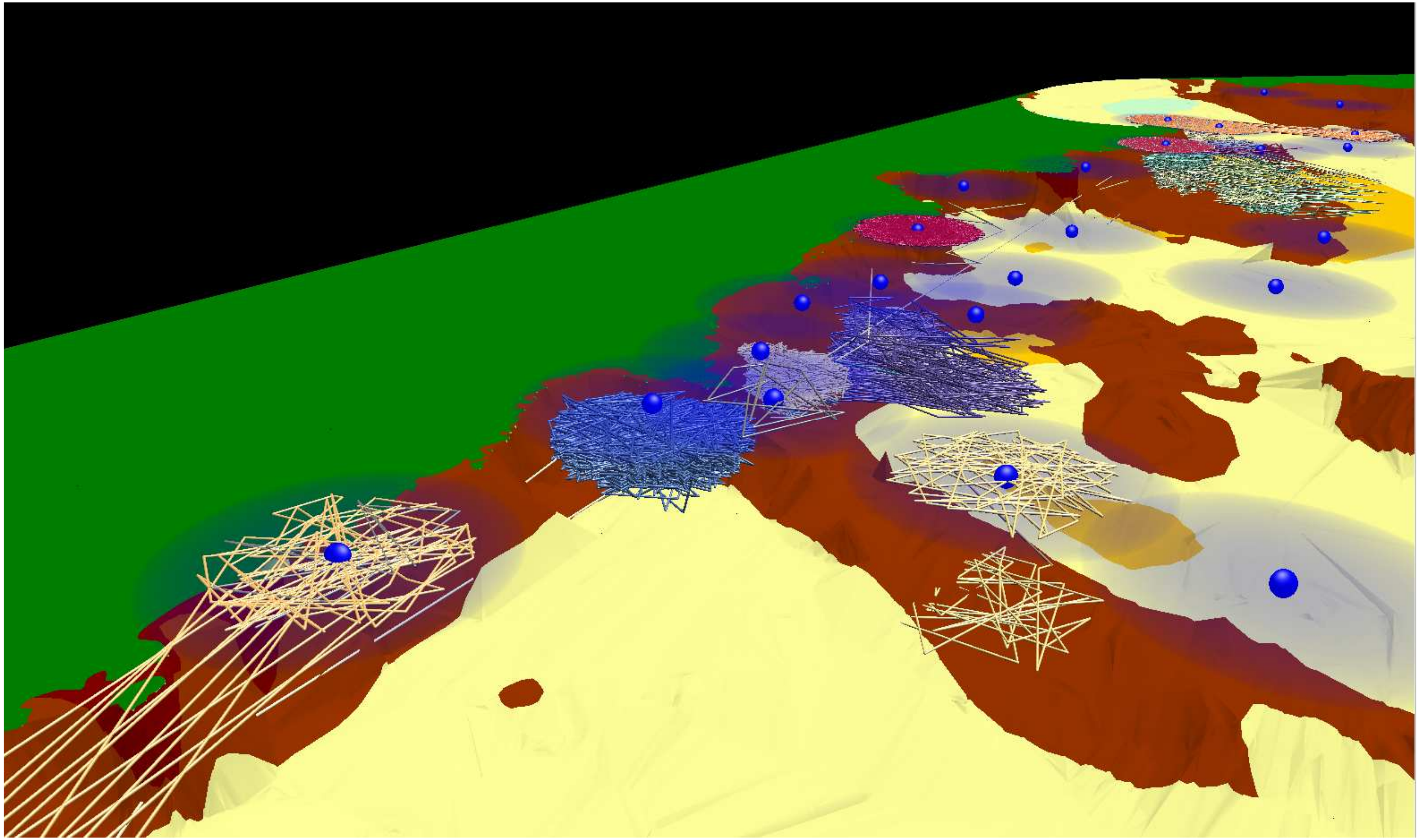


Fig. 6. *Cheilodactylus spectabilis*. 3D image of the spatial and temporal extent of individual fish movement from North of the Thumbs to Pirates Bay rendered using Eonfusion software. Individual fish tracks are uniquely coloured and VR2s are represented by blue spheres

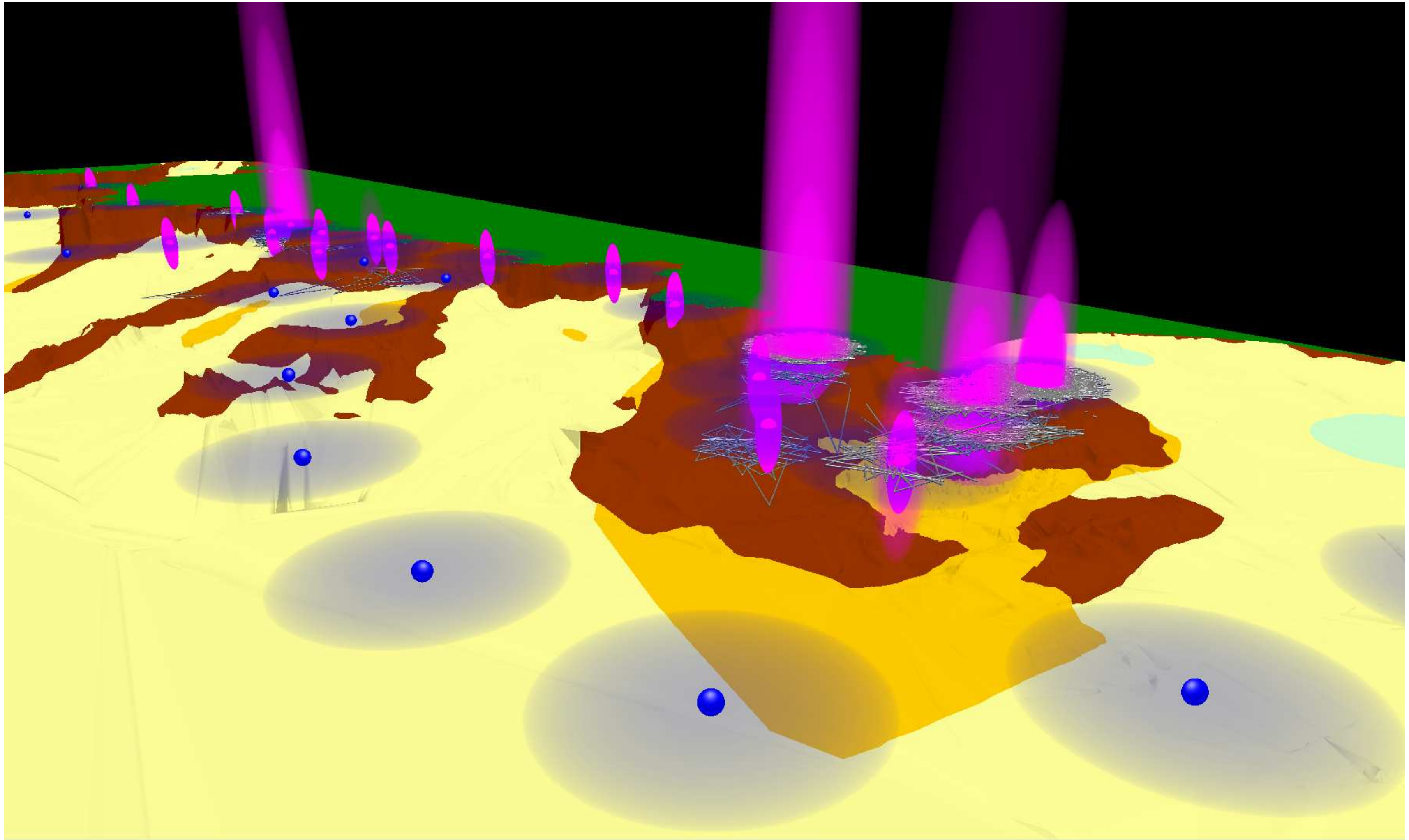


Fig. 7. *Cheilodactylus spectabilis*. 3D image of the quantity of detections at each VR2 with detections from Pirates Bay to the Thumbs rendered using Eonfusion software. The size of the pink halos indicates the quantity of detections in six hr time bins

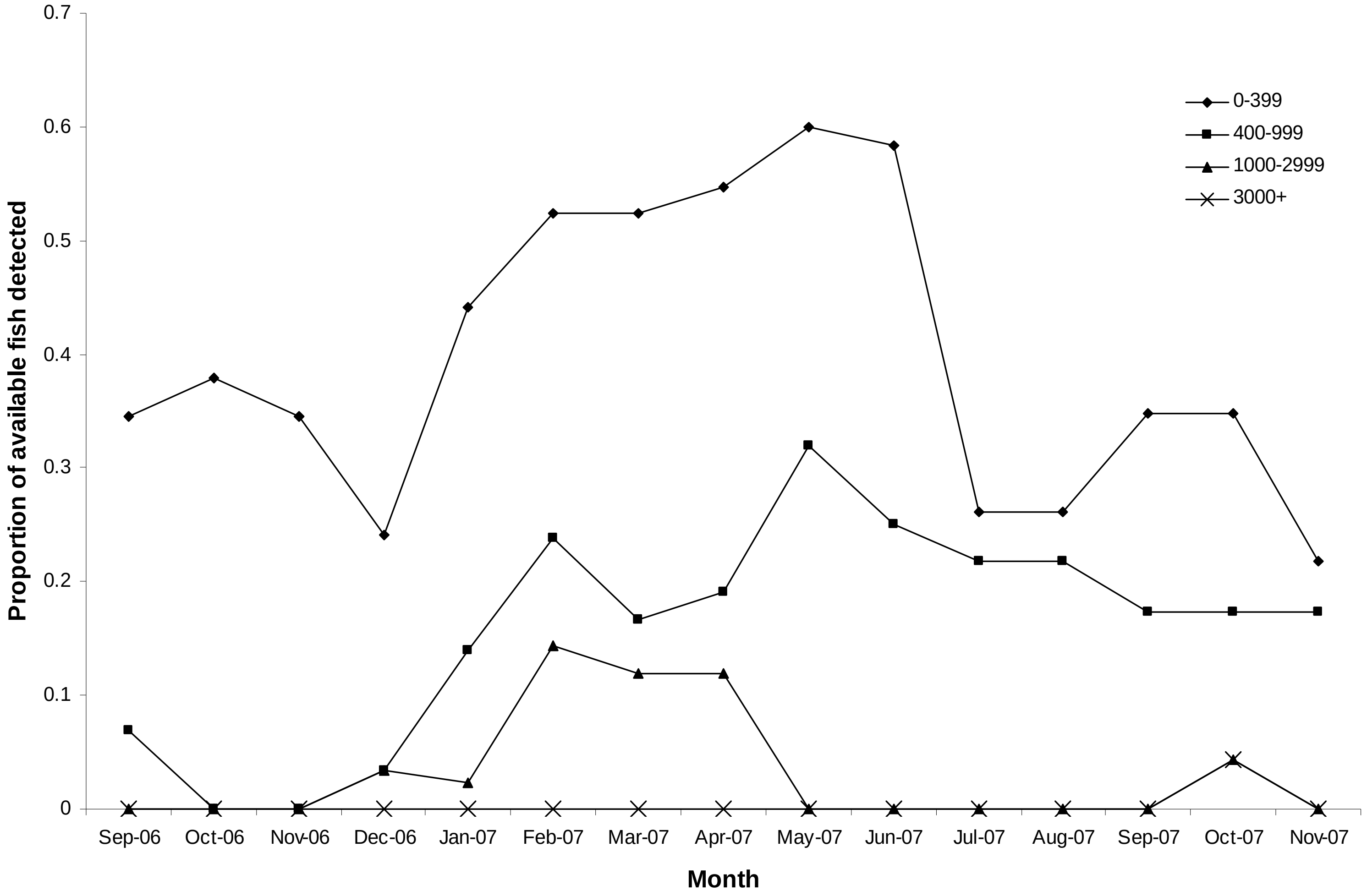


Fig. 8. *Cheilodactylus spectabilis*. Proportion of available fish detected per month relative to the distance from the home receiver

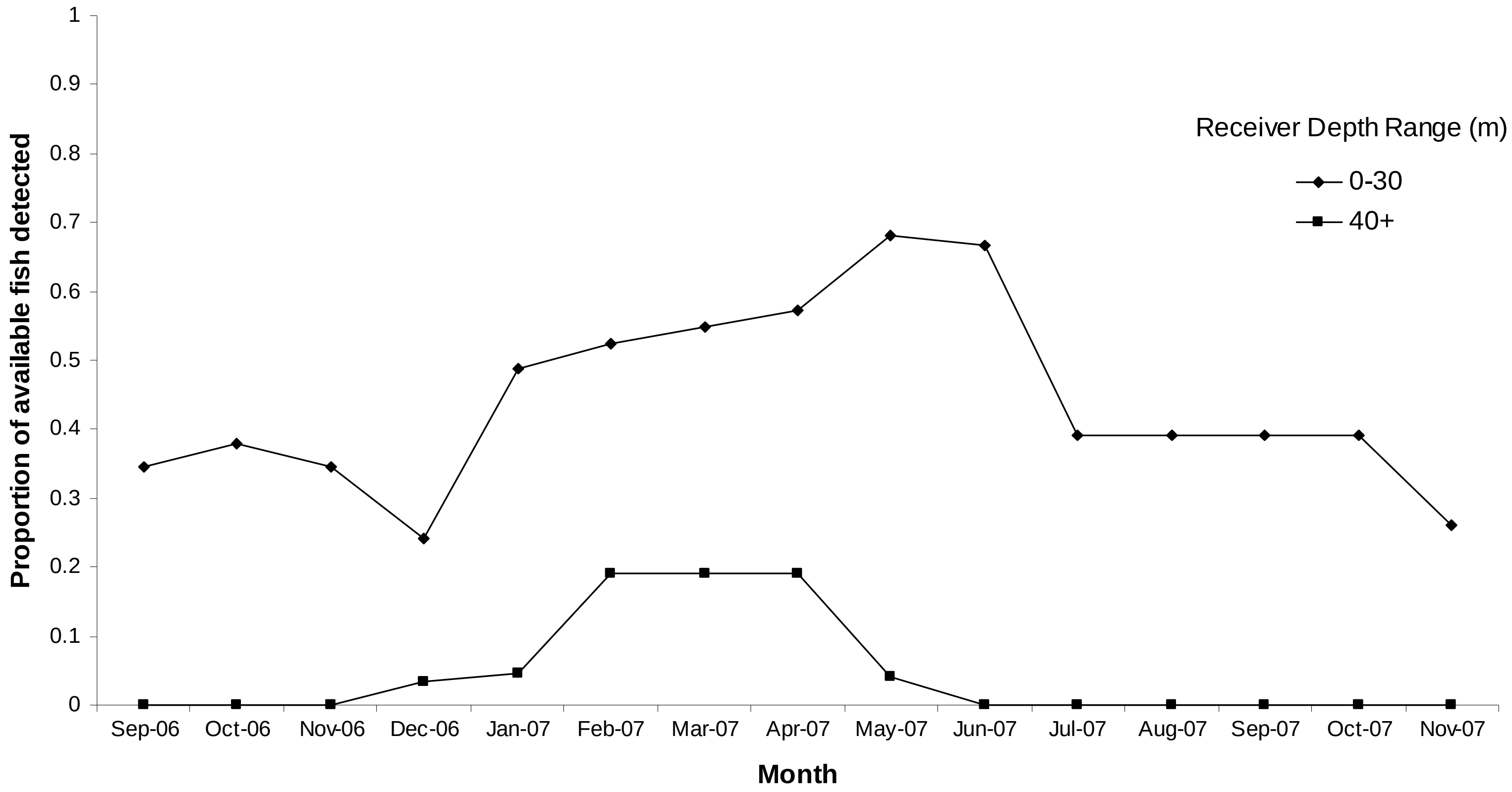


Fig. 9. *Cheilodactylus spectabilis*. Proportion of available fish detected per month relative to receiver depth

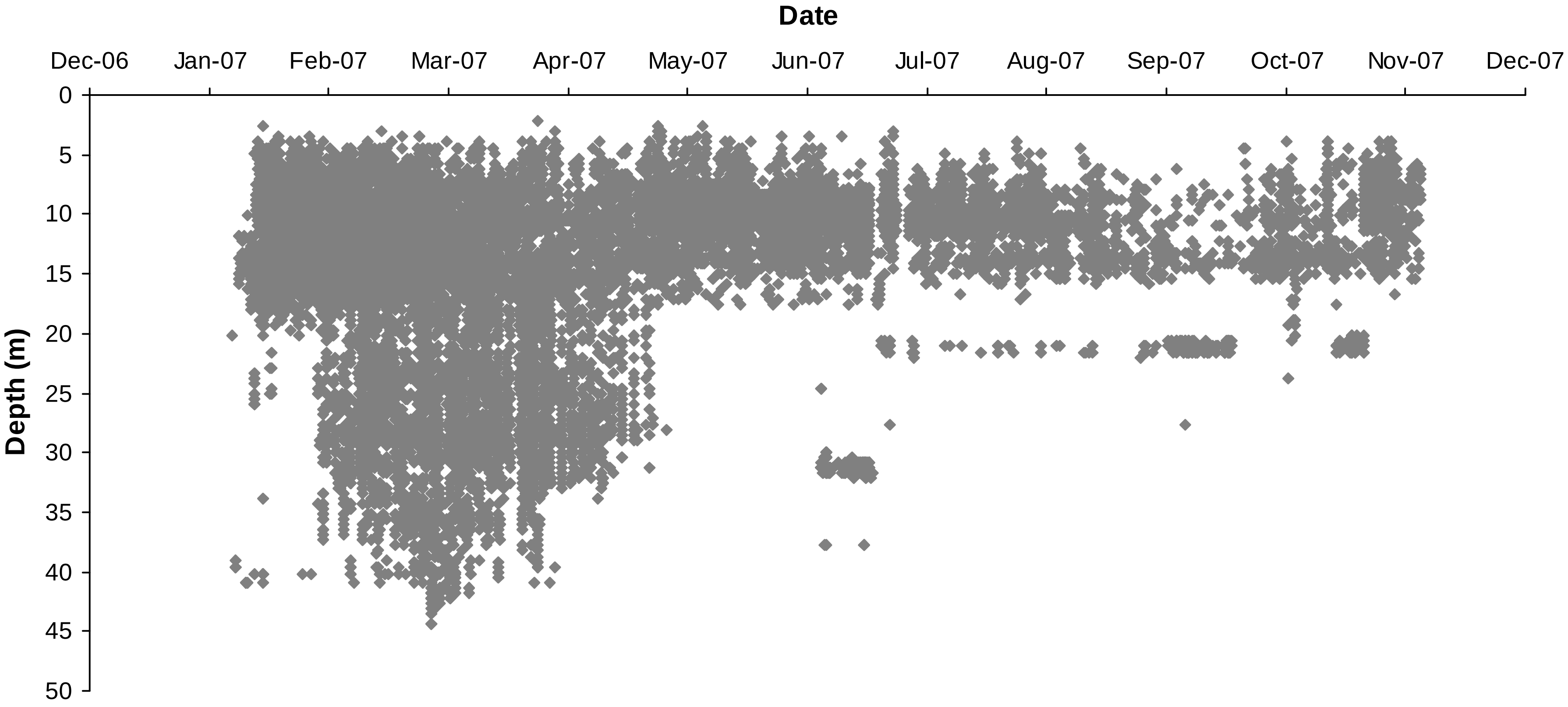


Fig. 10. *Cheilodactylus spectabilis*. Depth of those 13 fish fitted with depth transmitters over time

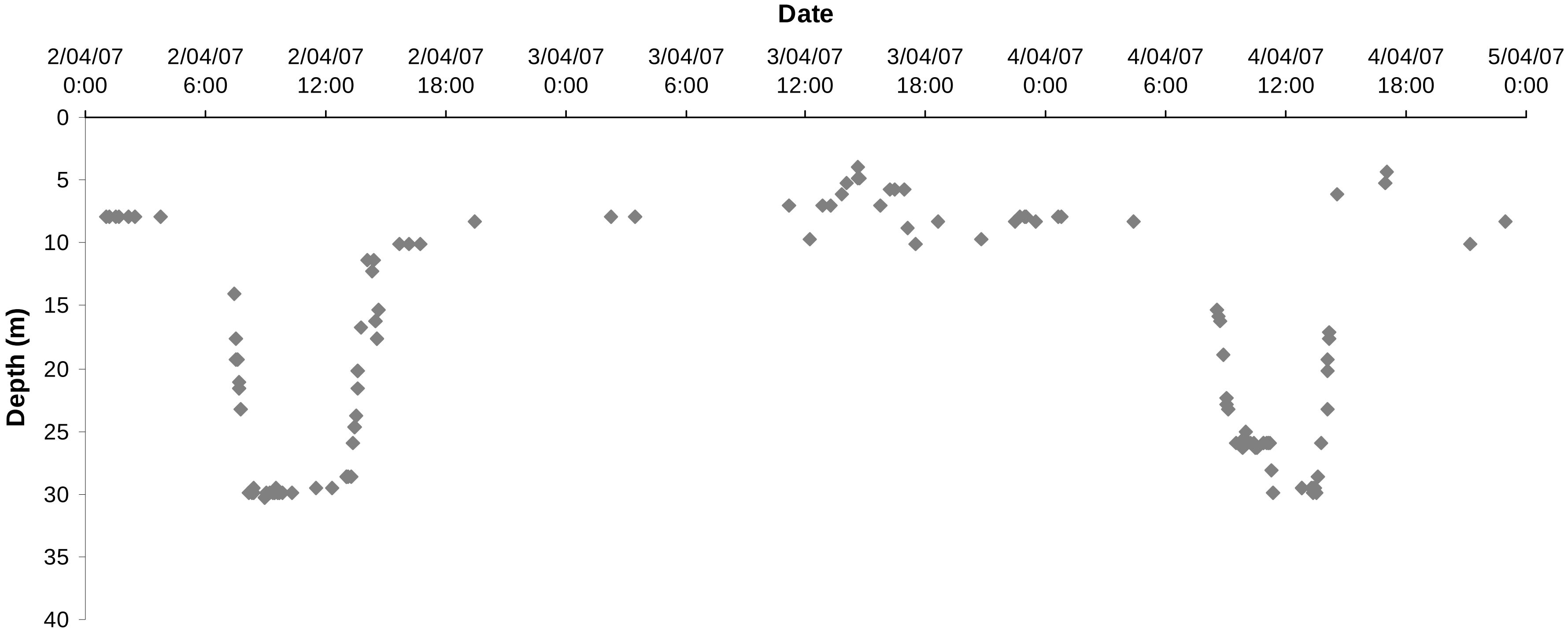


Fig 11. *Cheilodactylus spectabilis*. Depth of BM37 over a 3-day time period in the spawning season

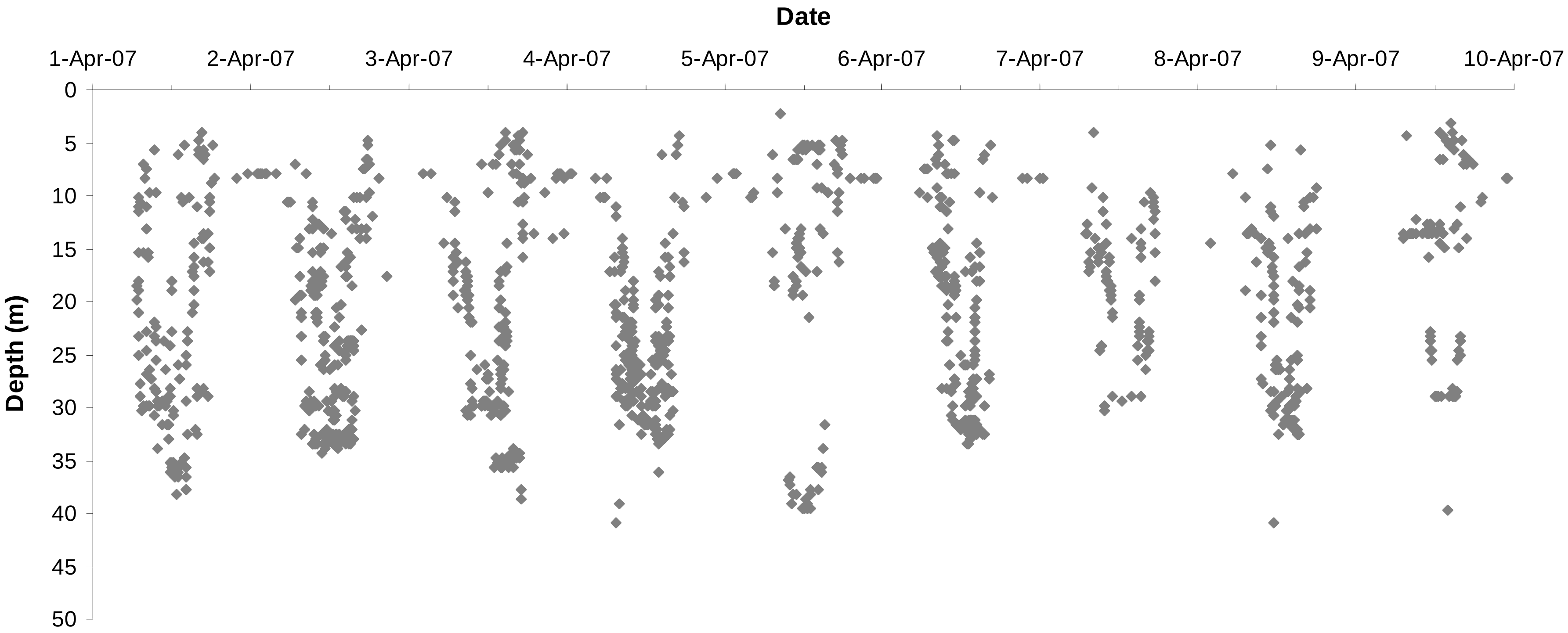


Fig 12. *Cheilodactylus spectabilis*. Depth of those 13 fish fitted with depth transmitters over a 10-day time period in the spawning season

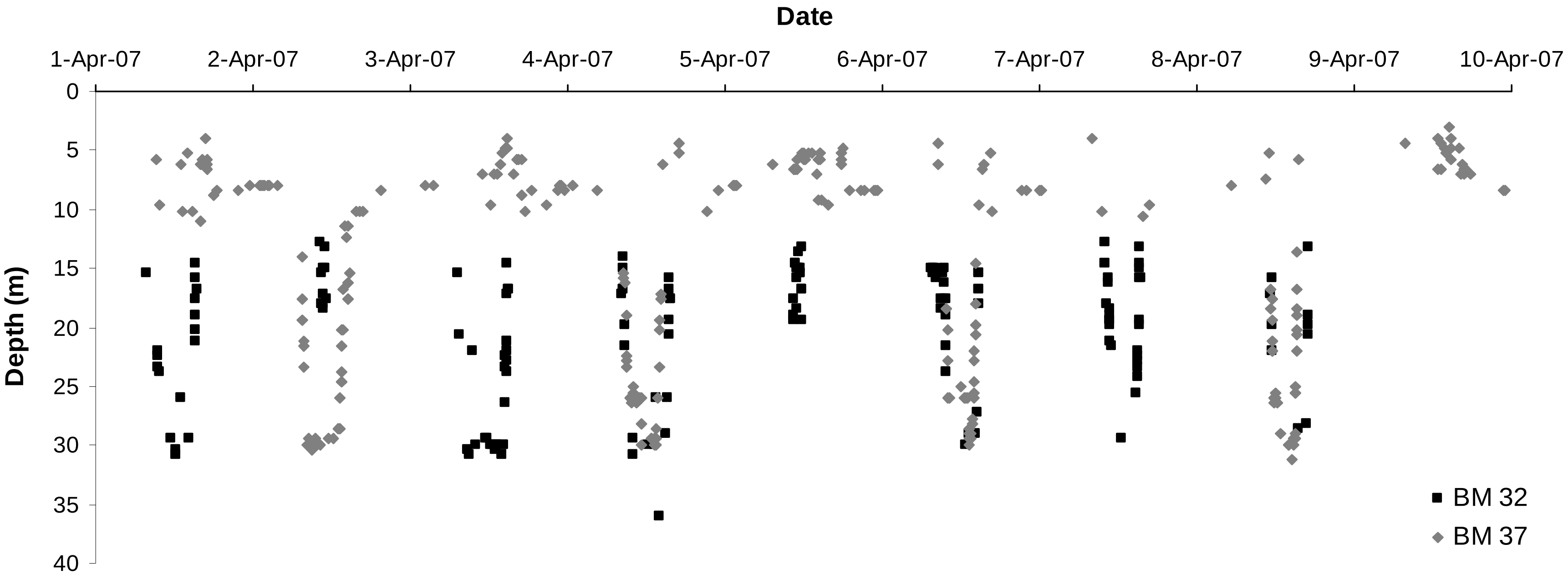


Fig 13. *Cheilodactylus spectabilis*. Depth of BM32 and 37 over a 10-day time period in the spawning season

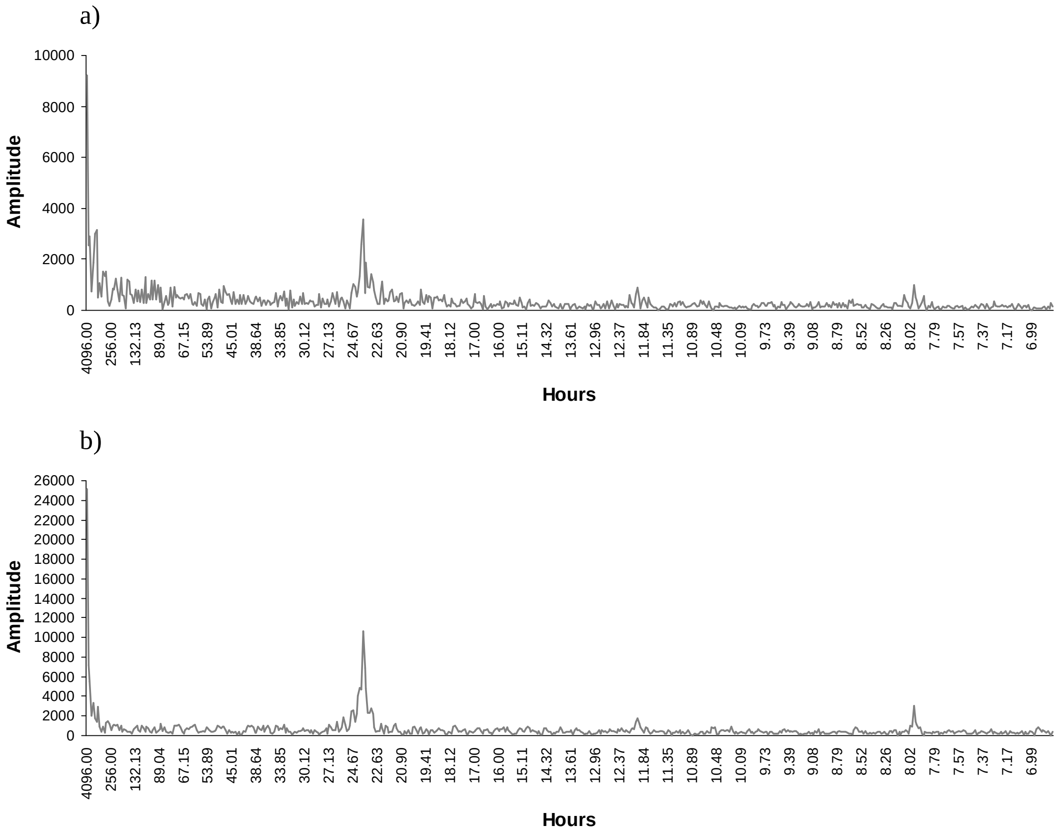


Fig. 14. Fast Fourier analysis of detection data for all fish combined. a) *Latridopsis forsteri*. b) *Cheilodactylus spectabilis*

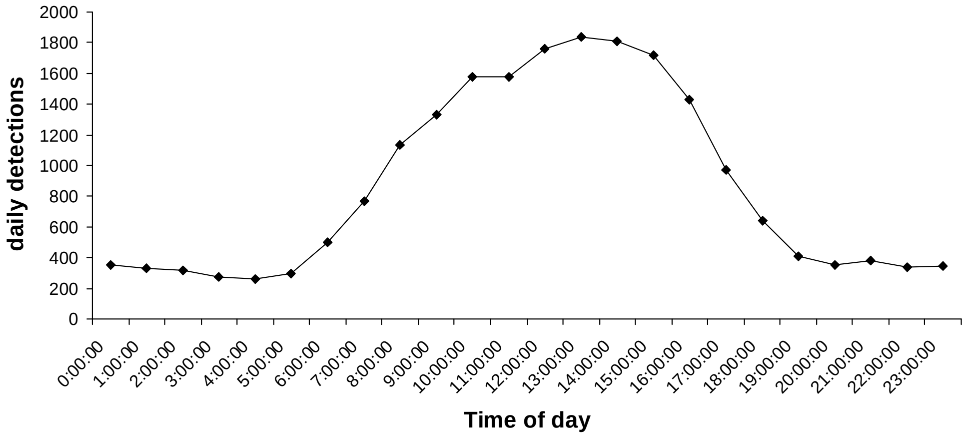


Fig. 15. *Latridopsis forsteri*. Daily detection patterns

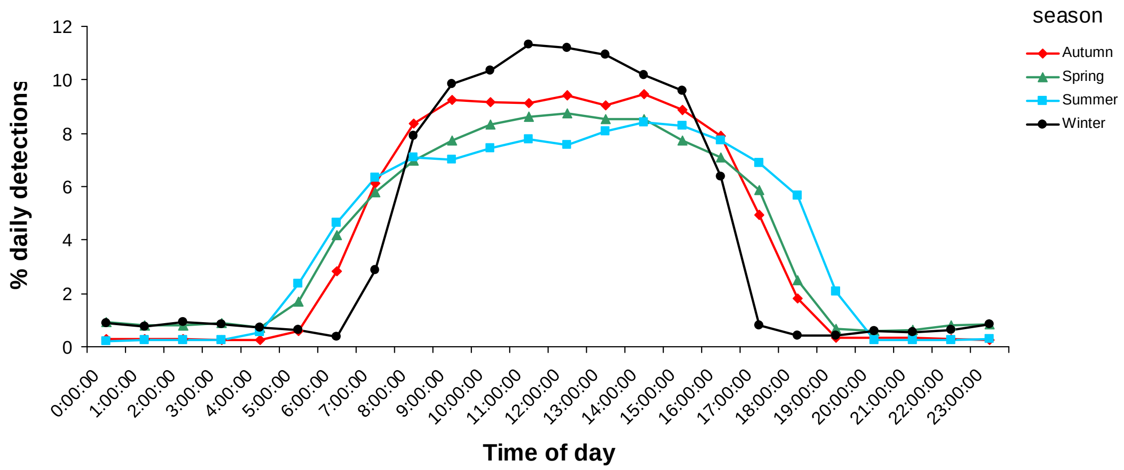


Fig. 16. *Cheilodactylus spectabilis*. Daily detection patterns per season

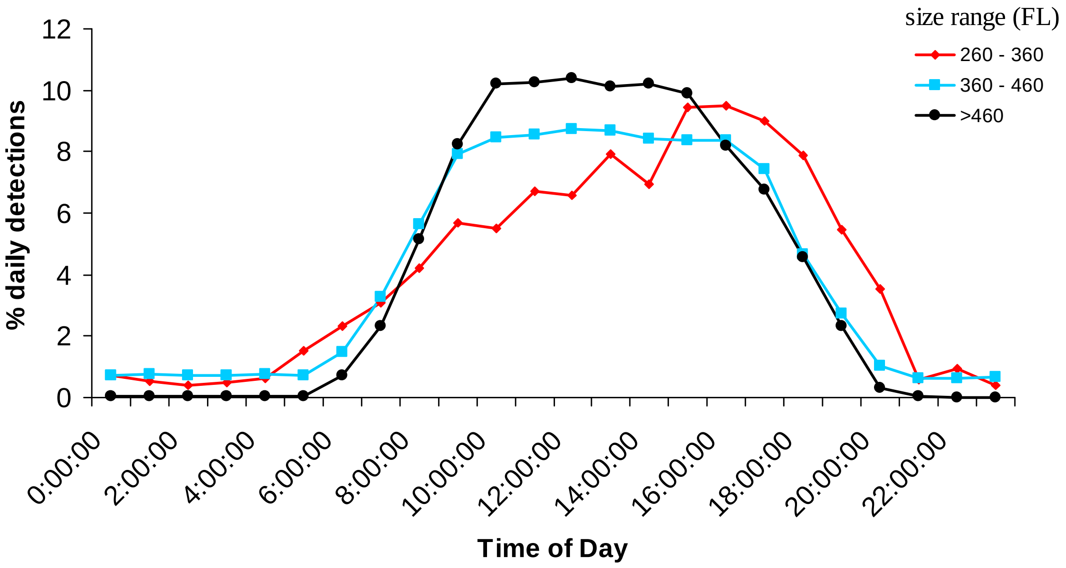


Fig. 17. *Cheilodactylus spectabilis*. Daily detection patterns per size class

2.3.3 VRAP positional error

The average positional error (accuracy) ± se (precision) of the VRAP system differed depending on the location of the transmitter relative to the array of buoys (Fig. 3). Tag 1: 23.0 ± 3.2 m, Tag 2: 11.7 ± 0.6 m, Tag 3: 9.4 ± 0.2 m, Tag 4: 7.8 ± 0.6 m.

2.3.4 VRAP tracking

All fish positioned by the VRAP for one or more of the deployment periods were tagged at the Blow Hole site, with the four *L. forsteri* positioned tagged in September 2006, and nine of the 14 *C. spectabilis* positioned tagged in January 2007 (Table 8). No *L. forsteri* had sufficient data in one or more of the deployment periods to determine home range (≥ 100 individual positions). Three of the *C. spectabilis* (BM13, 14 and 30) had ≥ 100 individual positions in one or more of the deployment periods and were shown by the random walk simulation to have high site fidelity, and as such could have their home ranges determined.

Table 8. VRAP positions per deployment period. *Fish carried a depth transmitter

		VRAP Deployment Period			
Fish	Tagging Date	October 2006	January 2007	April 2007	September 2007
BM01	12/09/2006	1		1	
BM02	12/09/2006	1			
BM08	13/09/2006	30	45	24	
BM09	13/09/2006	1			
BM10	13/09/2006	3	1		
BM12	13/09/2006	5	1		
BM13	13/09/2006	153	65	1	
BM14	13/09/2006	259	581	669	27
BM15	13/09/2006	4	22	7	3
BM30*	18/01/2007		674	327	52
BM32*	18/01/2007		2	8	
BM34*	18/01/2007		2	25	
BM36*	18/01/2007		3		
BM37*	18/01/2007		9		
BT02	13/09/2006	1			
BT03	13/09/2006	12			
BT04	13/09/2006	1			
BT05	13/09/2006	26	1		

The VRAP positions for each deployment period for individual fish tracked were shown to be highly overlapping (e.g. BM13 and 14, Fig. 18), such that the data for individuals could be combined across deployments (Fig. 19). The positions of the individual fish examined were tightly clustered over areas of medium and low profile reef approximately ≤ 100 m in diameter, with three of the four fish examined having overlapping positions and inhabiting approximately 150m diameter of reef (Fig. 19). The calculated home ranges for BM13, 14 and 30 (95% contour) of 1,651 m^2, 2,623 m^2, 1,866 m^2 and core areas (50% contour) of 175 m^2, 868 m^2, 354 m^2 respectively, were very small (Fig. 20a-c). The depth and position data for BM30 (this fish carried a depth transmitter) for January 2007 show that the majority of detections were on or near the bottom (Fig. 21).

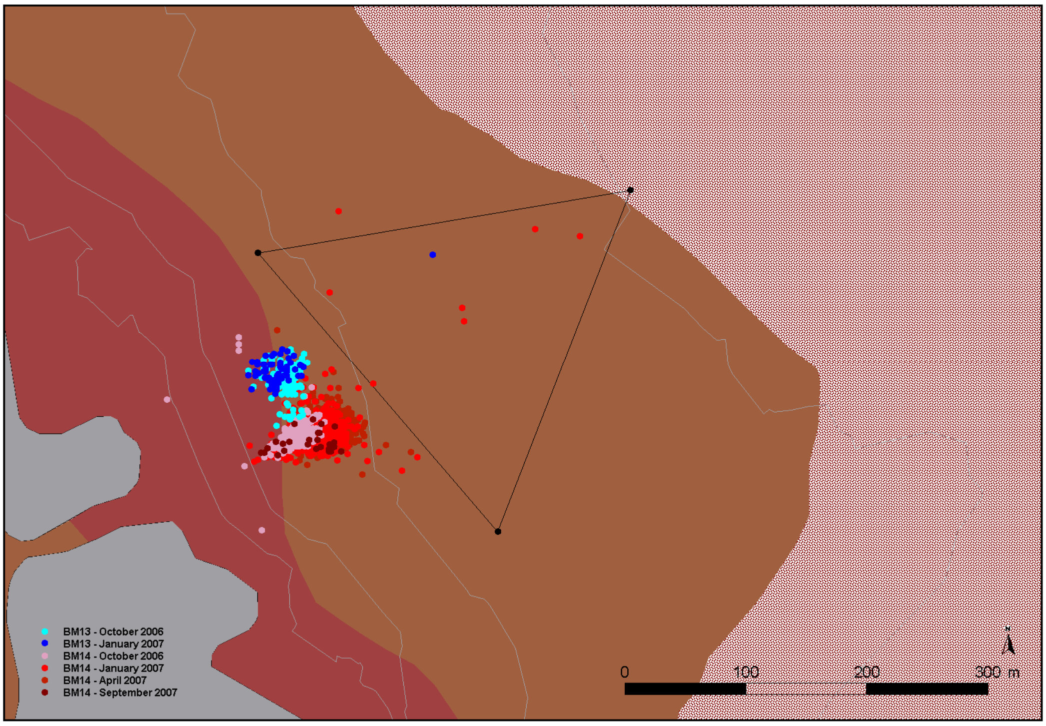


Fig. 18. *Cheilodactylus spectabilis*. VRAP positions (coloured dots) of fish 13 and 14 over multiple deployments. Habitat categories are the same as for Fig. 3

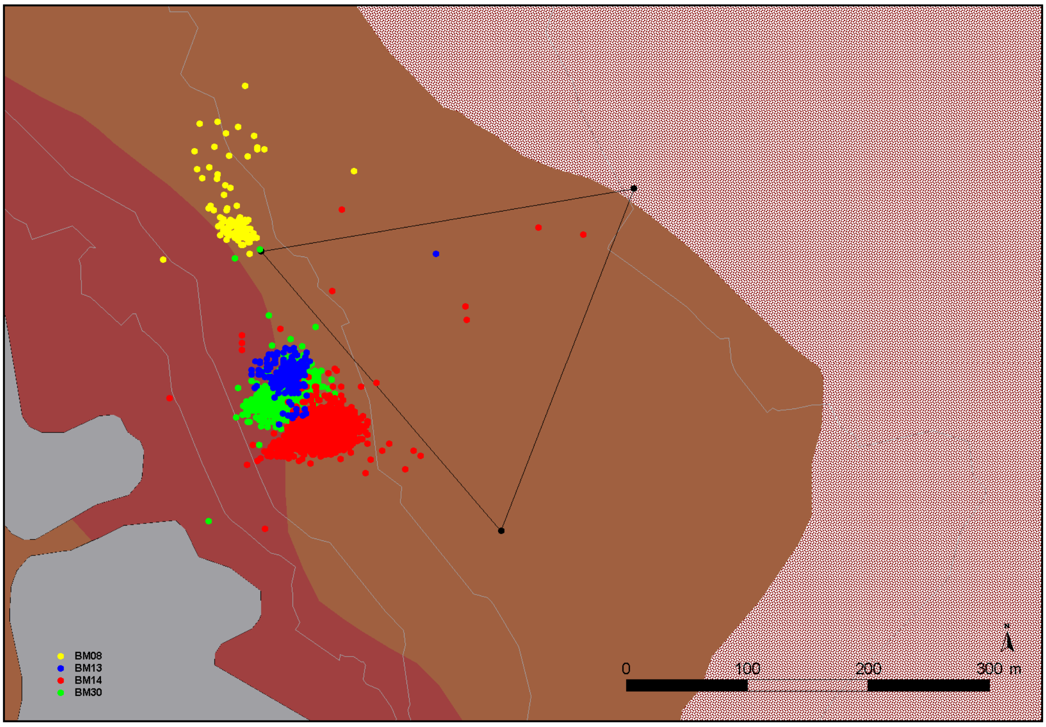


Fig. 19. *Cheilodactylus spectabilis*. VRAP positions (coloured dots) of fish 8, 13, 14 and 30 for all deployments combined. Habitat categories are the same as for Fig. 3

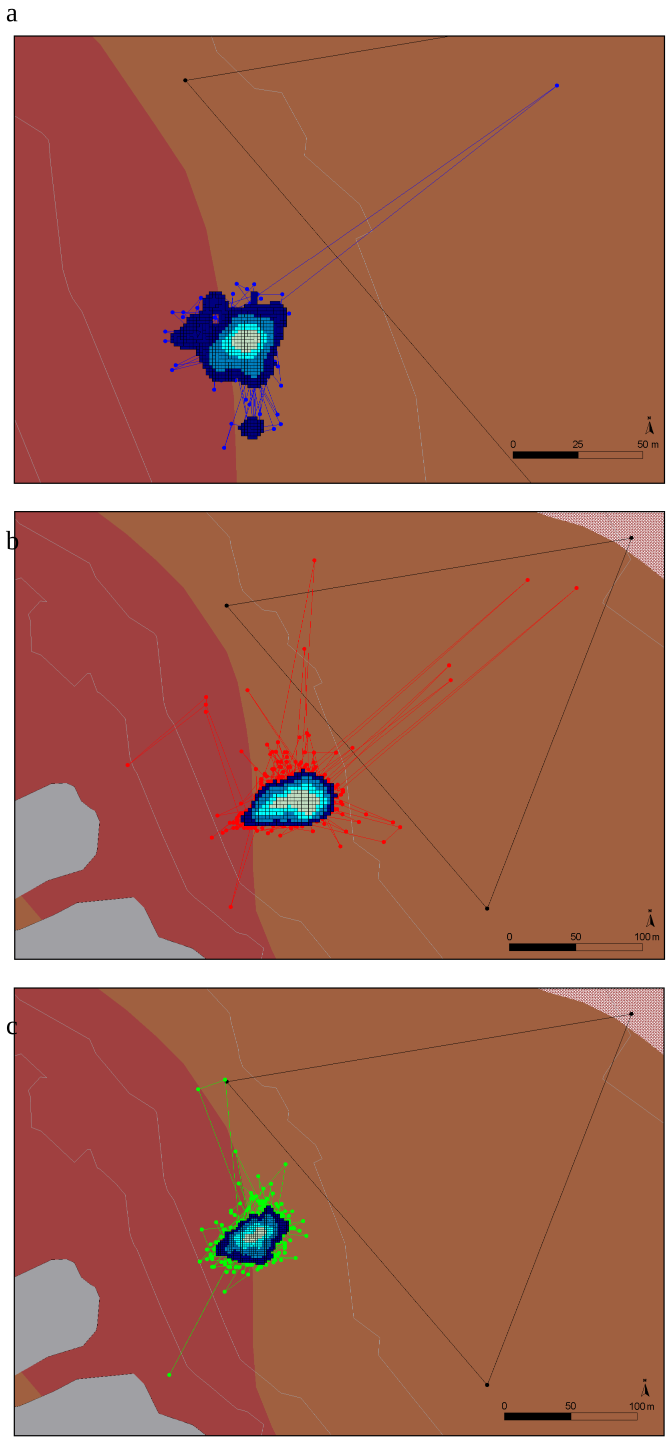


Fig. 20. *Cheilodactylus spectabilis*. Home ranges for fish 13 (a.), 14 (b.) and 30 (c.). Coloured dots represent individual detections, which are joined in sequence by lines. Concentric coloured circles represent the probability contours, with white (inner most contour) representing 1-25%, pale blue 26-50% (activity centre), blue 51-75% and dark blue 76-95% (home range). Habitat categories are the same as for Fig. 3

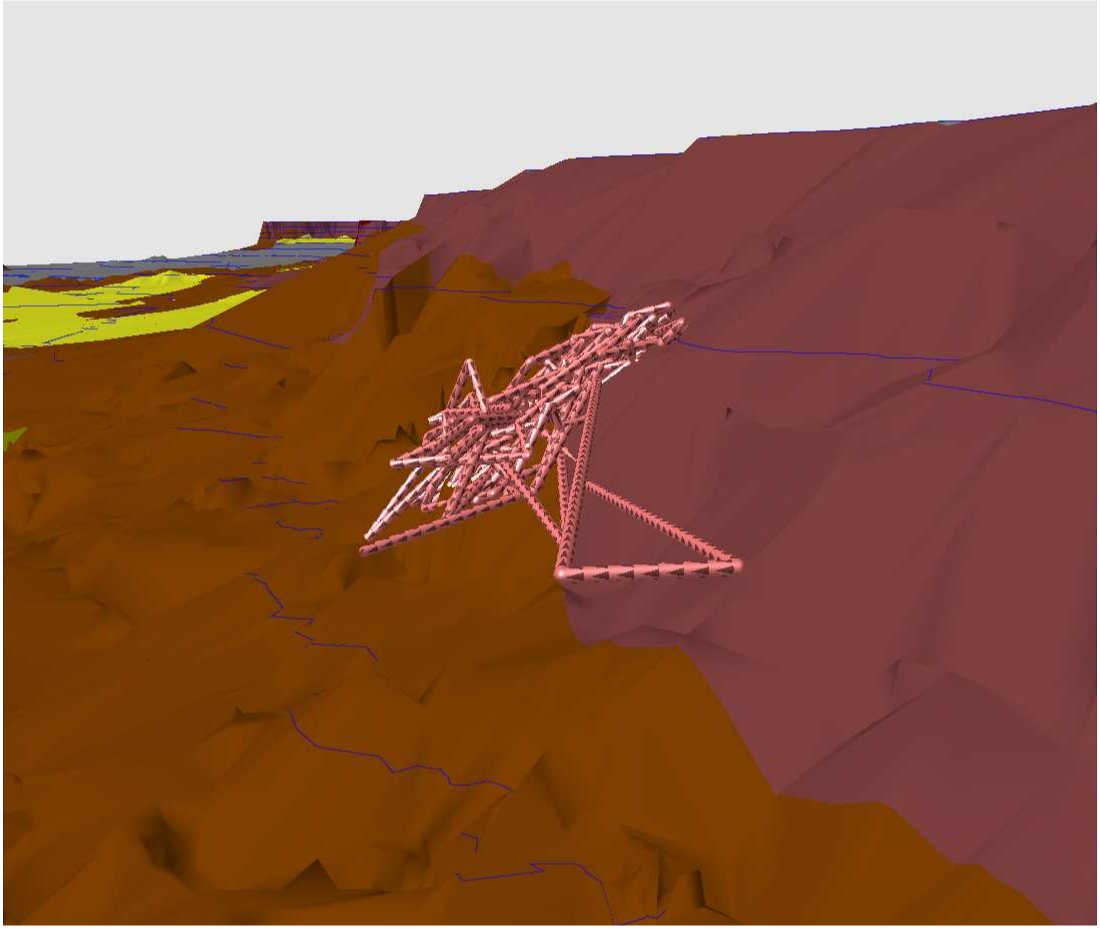


Fig. 21. *Cheilodactylus spectabilis*. 3D representation of the fine-scale (VRAP) movement and depth of fish 30 at the Blow Hole region during January 2007 relative to the bathometry as determined by using Eonfusion software. The blue lines represent the 20 and 30m contours. Habitat categories are the same as for Fig. 1

2.4 DISCUSSION

This study has provided great detail about the movements and behaviour of individual temperate reef fish for periods of up to 14 months for *C. spectabilis*, including a spawning season between February and April, and up to 12 months for juvenile *L. forsteri*, with almost 157,200 individual detections for both species combined. Individuals of both species were not detected on the most northern (S1 &S2), southern (S17 & D11) or offshore receivers (O1-O7), which would have required moving over an approximate 1 km stretch of sand habitat in all cases (see Fig. 1). This suggests that sandy embayments and sandy habitats between reefs may act as a barrier to movement. Open sand was also found to be a deterrent to emigration for six temperate reef fish (labrids and monocathids) on a one ha isolated reef in southern Tasmania (Barrett 1995). However, a previous study of movement of *C. spectabilis* in the north east of Tasmania using tag-recapture methods, suggested that these fish were capable of moving between separate individual areas of reef, separated by soft bottom. Barrett (1995) suggested that the use of natural boundaries should be an important consideration in the design of marine reserves, however, the conflicting results of this study and that of Murphy and Lyle (1999) suggest that this may not always be an effective mechanism for minimising the loss of protected species to adjacent fished areas, with effectiveness likely to vary between regions.

C. spectabilis appear to be highly site attached residents, with the majority of fish detected by VR2's being detected for over 40 days and up to greater than a year by one or two adjacent VR2 receivers within the tagging region, and positions from each VRAP deployment period overlapping for the fish examined. Tag-recapture studies of *C. spectabilis* on the Tasman Peninsula confirm these results, with 78% of 42 recaptured fish captured within 2 km of the tagging site (Murphy & Lyle 1999). Diver observations in New Zealand have also demonstrated *C. spectabilis* to be highly site attached (Leum & Choat 1980, Choat & McCormick 1987, McCormick 1989a & b) and capable of long term (years) residency (McCormick 1989a), with this appearing to be a common trait amongst many Cheilodactylids (Cappo 1995, Lowry & Suthers 1998) and temperate reef fish in general (Buxton and Allen 1989; Barrett 1995, Edgar et al. 2004, Jorgensen et al. 2006). Despite being highly site attached residents *C. spectabilis*, like *P. diacanthus* in the Northern Territory (see Chapter 1), appear to display multiple behaviour modes, including 'movers', with two fish re-captured or detected approximately 3.5 km from their tagging sites and one fish undertaking at least an approximately 18 km return trip (distance from home site to the furthest receiver it was detected on) after being detected at its tagging site for approximately four months. The results of the previous tag-recapture study on *C. spectabilis* support this suggestion, with an individual fish moving over 41 km from its tagging site (Murphy & Lyle 1999). Multiple behaviour modes appear common in reef fish that are monitored over relatively long periods of time (e.g. Attwood & Bennett 1994, Star et al. 2002, Jadot et al. 2002, Edgar et al. 2004, Egli & Babcock 2004).

The combined positional and depth data provided by the depth tag carried by BM30 suggests that these fish are bottom attached, which is not surprising given they are a demersal micro-carnivore (Leum & Choat 1980, McCormick 1998). The fine-scale movement data from the VRAP also demonstrated the extremely small scales that *C. spectabilis* are site attached at, with core areas (50% contour) of between 175-868m^2

and home ranges (95% contour) of between 1651-2623 m^2, such that multiple fish can occupy a small region of reef. These results were consistent with diver observations (pers. obs.). Although small, these home ranges are larger than those estimated by Leum and Choat (1980) for juveniles (140-160 mm SL) of ≤ 100 m^2. However, the three fish examined here were all adults (385-500 mm FL). Adults cover greater area during daily movements than juveniles (Leum & Choat 1980), as the feeding mechanics of larger *C. spectabilis* allows them to exploit a broader range of habitats to feed (McCormick 1998, Metcalf et al. 2008). The three fish examined had overlapping home ranges, with Leum and Choat (1980) noting that large fish are gregarious, with up to 20 large individuals able to occupy a 100 m^2 area. Smaller individuals, however, are solitary and exclude other small individuals from their feeding and shelter sites (Leum & Choat 1980). The home ranges determined for *C. spectabilis* in this study are similar to those for *C. fuscus* (Lowry & Suthers 1998), with adult fish having a maximum mean home range of approximately 3600 m^2. Similarly, the core areas (50% contour) for *C. spectabilis* were much smaller than the home range (95% contour), as was the case for *C. fuscus* (Lowry & Suthers 1998).

The disproportionately high use of particular core areas within a home range appears to be a common trait in site attached marine fish (e.g. Holland et al. 1993, 1996, Meyer et al. 2000, Eristhee & Oxenford 2001, Lowe et al. 2003, Parsons et al. 2003, Jorensen et al. 2006, Abecasis & Erzini 2008), with the use of core areas attributed to patterns of refuging and foraging, although it is still relatively poorly understood (Jorensen et al. 2006). This appears to be the case with *C. spectabilis,* with the core areas used likely to be a result of large fish being associated with reeflets that contain either a cave, gully or ledge for shelter (McCormick 1989b) and intense feeding being confined to a relatively small part of the area regularly traversed (McCormick 1986 in McCormick 1989a).

C. spectabilis were predominately detected at their home VR2 receiver throughout the study period, except during the spawning season. This suggests that these fish become more mobile during the spawning season, most likely as a result of moving to deeper water during this period, as determined by the depth of the receivers that were detecting fish and those fish with depth tags. This increased activity during the spawning season may also explain why *C. spectabilis* tagged at the Blow Hole in September 2006 were more site attached and resident for longer periods than those January 2007 tagged fish, as indicated by the higher average percentage of both their time at liberty and the detection period that they were detected for, given that the September fish were monitored for longer time periods outside of the spawning period. Fishers also report an increase in fish activity during the spawning season.

Like the current study, McCormick (1989b) also showed an increase in fish at depth during the spawning season, with no reproductive behaviour detected outside of deeper sites. The pattern of fish moving into deeper water in the morning and returning in the afternoon on a regular basis appears to be directly related to spawning. McCormick (1989b) found dominant males established territories on the deep reef edge, which females visited during the breeding season, moving into the deep water during the afternoon, with numbers peaking at dusk. However, given three of the fish in the current study were male (> 524 mm), with another three fish most likely male as they were greater than 470 mm, there appears to be a different pattern occurring in Tasmania, with at least some males moving into deeper water during the day and then leaving again. These patterns are being examined in further study commencing in 2009, where all individuals tagged will be sexed. The fact that some individual fish were not repeating the observed pattern every day, but were having ‘days off’, suggests that this may be a result of energetics or simply regeneration of gametes, particularly if it is a pattern displayed by males. This will be further examined in the planned 2009 study.

Both *C. spectabilis* and *L. forsteri* showed a clear diurnal activity pattern, which was consistent among seasons for *C. spectabilis*, but not among size classes, with smaller individuals peaking in their activity towards dusk, after the larger fish had begun to decrease their activity. Leum & Choat (1980) also showed *C. spectabilis* to be day active only and nocturnally quiescent, with all fish observed at night resting in rock crevices or under ledges, which would explain why fish were not detected at night, as the rock would block the acoustic signal (e.g., Matthews 1992, Bradbury et al. 1997). Conversely, *C. fuscus* is predominately night active, with activity peaking at dusk (Lowry & Suthers 1998), as is the case for smaller *C. spectabilis*, which may be related to this group more actively defending their shelter sites than larger fish (Leum & Choat 1980). Very little is known about the activity patterns of *L. forsteri*, however, they are commonly observed during the day (Barrett et al 2007).

With the increasing acceptance of ecosystem-style management, there is a clear need for movement studies utilising acoustic telemetry to examine multiple species, which until recently has been rare (Heupel et al. 2006). However, it needs to be kept in mind that it can be difficult to deploy a tracking array that performs well for multiple types of movement behaviours. For example, the current study worked well for *C. spectabilis,* but not as well for *L. forsteri*.

The relative number of *L. forsteri* detected and numbers of valid detections from those fish tagged at O’Hara Bluff was low compared to those tagged at other tagging sites for the 2007 tagging period when all receivers were in place and functional. This suggests that *L. forsteri* in this region are highly mobile. The fact that 15 of the 29 *L. forsteri* tagged were tagged at O’Hara Bluff, may partially explain why only 52% of tagged animals were detected, with only approximately 21,000 individual detections. In general, *L. forsteri* appear to be relatively mobile, with only approximately one third of detected fish detected for 30 days or more and approximately one third of detected fish being detected over between approximately 4.5-10 km of coastline. Additionally, three fish were only detected in the first 24 hrs after tagging, after which they were no longer detected. Recaptured tagged *L. forsteri* moved an average of approximately 7 km from their tagging site, which generally matches this study, with one fish moving over 143 km, demonstrating that they are capable of undertaking large movements (Murphy & Lyle 1999). Despite this, five fish were highly site attached when detected and were detected where they were tagged. This matches an observation by Edgar et al. (2004) of a single *L. forsteri* individual resighted on SCUBA at distances less than 25 m over 12 months. This suggests that, as for *C. spectabilis* and *P. diacanthus*, there may be several behaviour types of *L. forsteri*, with some individual fish displaying more than one.

BENEFITS AND ADOPTION

For the Northern Territory, this project has provided the foundation for improved management of the *P. diacanthus* fishery via an improved understanding of the temporal and spatial dynamics of aggregations that will significantly enhance the ability to assess the benefits of spatial management to protect the spawning aggregations, including closed area management, and other measures such as reductions/limits catches in the different sectors of the fishery. The improved understanding of the lack of spatial connectivity between key fishing grounds also has implications for the stock assessment and interpretation of catch and effort data for this species.

For Tasmania, this project has provided the foundation for improved management of the *Cheilodactylus spectabilis* fishery through an improved stock assessment process that includes movement information particularly that from shallow to deeper water, and which therefore leads to sustainable catch rates. It will in the same way also lead to improved management of *Latridopsis forsteri*, more particularly with respect to identification of the potential benefits of closed juvenile areas and the scale needed for such closures if they are to be employed.

FURTHER DEVELOPMENT

Various aspects of this project have identified areas that would benefit from further development. These have been classified under (a) Northern Territory and (b) Tasmania.

Northern Territory

Further studies are needed to determine the natal origins of the separate aggregations of adult *P. diacanthus* in the Northern Territory, such as targeted otolith elemental chemistry of both young of the year and adults (e.g. Thorrold et al. 2001), or the use of novel larval mass-marking methods based on maternal transmission of isotopic markers to the otoliths of offspring (Thorrold et al. 2006, Almany et al. 2007). This will determine if there is a high level of spawning site-fidelity, i.e. aggregations are largely self-recruiting, which is important for future management.

The tidal cycle significantly influenced the detection of *P. diacanthus* at Channel Point, however, fine scale (1-2 m) tracking (e.g. VRAP, see Chapter 2), rather than acoustic monitoring as used in this study, combined with activity tags e.g. electromyogram (EMG) telemetered tags (see Cooke et al. 2004), caudal differential pressure tags (see Webber et al. 2001) or acceleration telemetered tags (see www.vemco.com) would be needed to determine exactly how *P. diacanthus* at Channel Point move in relation to the tides.

Tasmania

The pattern of *C. spectabilis* moving into deeper water in the morning and returning in the afternoon on a regular basis in this study appears to be directly related to spawning. McCormick (1989b) found dominant males established territories on the deep reef edge, which females visited during the breeding season, moving into the deep water during the afternoon, with numbers peaking at dusk. However, given three of the fish in the current study were male (> 524 mm), with another three fish most likely male based on size, there appears to be a different pattern occurring in Tasmania, with at least some males moving into deeper water during the day and returning to shallow depths in the afternoon. These patterns are being examined in further study commencing in 2009, where all individuals tagged with acoustic depth tags will be sexed. The fact that some individual fish were not repeating the observed pattern every day, but were having ‘days off’, suggests that this may be a result of energetics or simply regeneration of gametes, particularly if it is a pattern displayed by males. This will be further examined in the planned 2009 study by fitting fish with activity tags.

This study has also highlighted the need for fine-scale assessment for fisheries such as that for *C. spectabilis*, with this species included in a recent FRDC application, which aims to increase the spatial resolution at which fishery-dependent data are reported in small-vessel wild catch fisheries, using electronic data collection methods (Craig Mundy, TAFI). This application builds on work undertaken on the application of electronic data collection for the fine-scale assessment of the abalone fishery in Tasmania (FRDC 2006/029).

With the increasing acceptance of ecosystem-style management, there is a clear need for movement studies utilising acoustic telemetry to examine multiple species, which until recently has been rare (Heupel et al. 2006). However, it needs to be kept in mind that it can be difficult to deploy a tracking array that performs well for multiple types of movement behaviours. For example, the current study worked well for *C. spectabilis*, but not as well for *L. forsteri*. Further study is needed to determine a suitable tracking array for a mobile species such as *L. forsteri.*

PLANNED OUTCOMES

The planned outcomes for this project are long-term ones, as they involve potential changes to fisheries assessment and management in two states. In the Northern Territory, the planned outcome is improved management of the *P. diacanthus* fishery via an improved understanding of the temporal and spatial dynamics of aggregations that will significantly enhance the ability to assess the benefits of spatial management to protect the spawning aggregations, including closed area management, and other measures such as reducing catches in the different sectors of the fishery. The improved understanding gained from this project will also improve the reliability of stock assessment in this species.

In Tasmania, the primary planned outcome is improved management of the *C. spectabilis* fishery through an improved stock assessment process that includes movement information particularly that from shallow to deeper water, and which therefore leads to sustainable catch rates. It will in the same way also lead to improved management of *L. forsteri*, more particularly with respect to identification of the potential benefits of closed juvenile areas and the scale needed for such closures if they are to be employed.

CONCLUSION

This study has provided important information on the connectivity and dynamics of *P. diacanthus* aggregations in the Northern Territory, Australia, including providing crucial information for implementing appropriate management strategies for this vulnerable species. This large sciaenid appears to have high adult aggregation fidelity, with individual fish appearing not to move between aggregation sites, at least within the period of a year. The establishment of separate adult populations at each aggregation site has significant implications for stock assessment and management of the *P. diacanthus* resource in the NT, with the potential for localised depletion, especially if a significant portion of the populations are associated with the aggregation sites. This is also dependant on whether there is a high level of spawning site-fidelity, i.e. aggregations are largely self-recruiting. Until this is determined, the precautionary principle may need to be applied, and the assumption made that individual aggregations support separate populations. As such, closures of all or some of the aggregations during the peak summer spawning period may be a practical method to protect fish moving in and out of the aggregation sites to spawn. Sadovy and Cheung (2003) recommended the seasonal protection of spawning *Bahaba taipingensis*, and important spawning areas for *Argyrosomus inodorus* in Namibia were protected using seasonal closures (Kirchner et al. 2001). However, given *P. diacanthus* appears to form resident spawning aggregations (see Claydon 2004, Sadovy & Domeier 2005), with fish present and caught at the sites year round (Phelan et al. 2008b), the fish would still be highly vulnerable during other periods of the year, potentially negating, or at least reducing the benefits of the seasonal closure (Sadovy & Domeier 2005). As such, other management measures may need to be considered in combination with seasonal closures, such as reducing catches in the different sectors of the fishery (e.g., *A. inodorus*, Kirchner et al. 2001).

This study has provided important information on the temporal and fine and large-scale spatial movement patterns of both *C. spectabilis* and *L. forsteri* on inshore reefs on the Tasman Peninsula, Tasmania, Australia, including providing crucial information for implementing appropriate management strategies for these vulnerable species. Particularly important for *C. spectabilis* is the finding that fish are only moving to depth during the spawning season. This result could mean that the deep water stocks that fishers believe acts as a refuge population (Ziegler et al. 2006), are in fact temporary residents during the spawning season, so the fishery is in fact targeting the entire stock. Further research is needed in this area, with a study examining the movement of *C. spectabilis* into deeper water during the spawning season commencing in 2009.

A consequence of *C. spectabilis* being highly site attached and occupying core areas as small as 175 m^2 is the potential for fishing to result in localised and then serial depletion of this species. Ziegler et al. (2007) hypothesised that recent changes in population characteristics, namely faster growth and earlier maturity in *C. spectabilis*, is related to reduced competition for space, with smaller fish replacing those larger fish removed by fishing, given that *C. spectabilis* populations are partially structured by size (McCormick 1989a). Leum & Choat 1980 found that up to 20 *C. spectabilis* individuals may share small regions of reef, which is consistent with our finding that individuals occupy small core areas and home ranges may even overlap. As such, spatial closures of scales of approximately 1 km^2 or smaller are likely to provide adequate protection for a significant proportion of the stock.

As noted, strong site attachment and limited home ranges can mean that intensive fishing can result in localised depletion and that rebuilding or recovery of areas is likely to depend heavily on recruitment. This being the case there is a need for greater spatial resolution in catch and effort information if localised depletion is to be detected.

Despite *L. forsteri* being a relatively mobile species, given that a third of the fish detected were highly site attached at scales of 100’s m for at least one month, ‘nursery area’ closures implemented at relatively small spatial scales may be successful in ensuring a significant proportion of fish reach maturity before becoming vulnerable to the fishery. Barrett et al. (2007) suggested that closures of reef areas less than 1km in diameter are not sufficient to protect *L. forsteri*, with closures of at least several km of reef most effective. Given the variability of behaviour of *L. forsteri* across spatial scales e.g., fish appeared more mobile at the O’Hara Bluff region of the study site, careful monitoring of the movement of fish at any nursery area would be needed, as their effectiveness may vary with region regardless of size. Given *L. forsteri* were not detected moving across sand boundaries between reefs, natural boundaries may be useful for designing any closure.

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APPENDIX 1: INTELLECTUAL PROPERTY

This is not applicable to this project.

APPENDIX 2: STAFF

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