



## Movement patterns of the draughtboard shark *Cephaloscyllium laticeps* (Scyliorhinidae) determined by passive tracking and conventional tagging

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A combination of passive tracking and conventional tagging was used to provide insight into the movement patterns of the draughtboard shark *Cephaloscyllium laticeps*, the most common catshark in coastal areas of southern Australia. A series of acoustic receivers deployed throughout south-eastern Tasmania as well as a receiver array along an isolated reef, Crayfish Point Reserve (CPR), passively tracked 25 *C. laticeps* from January to July 2003. *Cephaloscyllium laticeps* were present from 4 to 98 days. The majority of the *C. laticeps* stayed within the CPR where most individuals were active throughout the night. They were found actively moving (*i.e.* when a *C. laticeps* was consecutively detected by two or more non-overlapping receivers, suggesting the individual was moving) and spending periods of minor movements (*i.e.* when an individual was consecutively detected by only one receiver, suggesting it was at rest). The length of these minor movements periods, observed both day and night, ranged from 1 h to 5 days. In addition to passive tracking, 1552 conventionally tagged *C. laticeps* were released in the eastern and south-western coastal areas of Tasmania and within the CPR between January 2000 and April 2007. The CPR showed a higher recapture rate, 38%, than eastern and south-western areas where the recapture rates were 10 and 3%, respectively. Within the CPR, 36% of the sharks were recaptured on multiple occasions. The maximum time at liberty ranged from 1 month to 7 years. The majority of the *C. laticeps* were recaptured in the vicinity of where they were released (<10 km), although larger longer-term movements of up to 300 km were recorded. The large amount of multiple recaptures within the CPR, in addition to acoustic tagging results, indicated a high degree of site fidelity for *C. laticeps*. This isolated reef appears to be an important habitat for this species, and therefore, the current protection status of this area is probably beneficial for the conservation of *C. laticeps*.

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Key words: catshark; demersal shark; habitat utilization; rocky reef.

### INTRODUCTION

The draughtboard shark *Cephaloscyllium laticeps* (Duméril 1853) is an endemic Australian shark species that belongs to the Scyliorhinidae family (catsharks). Despite catsharks representing the most speciose family (Compagno *et al.*, 2005), with global

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occurrence and high diversity, the family remains poorly known with very limited ecological information, including habitat utilization and movement behaviour. Previous studies in scyliorhinids showed that they are characterized as slow swimmers (Springer, 1979; Compagno, 1984) and are often found resting in caves either alone or in aggregations (Nelson & Johnson, 1970; Sims *et al.*, 2005). Nelson & Johnson (1970) reported nocturnal activity patterns for the scyliorhinid swellshark *Cephaloscyllium ventriosum* (Garman 1880), and Sims *et al.*, (2001) found differences in the day–night activity between males and females of the lesser spotted dogfish *Scyliorhinus canicula* (L. 1758).

*Cephaloscyllium laticeps* is the most common catshark in the coastal areas of southern Australia (from the Recherche Archipelago, Western Australia to Jarvis Bay, New South Wales), where it is mainly found inshore on the continental shelf down to at least 60 m (Last & Stevens, 2009). *Cephaloscyllium laticeps* forms a significant by-catch component in south-eastern Australia where they are taken in rock lobster traps, demersal trawls, longlines and gillnets (Frusher & Gibson, 1998; Walker *et al.*, 2005). Walker *et al.* (2005) reported a 54% decline in *C. laticeps* caught in Bass Strait, southern Australia, between 1973 and 1976, and 1999 and 2001. Although the cause for this decline is uncertain, the author suggested that it might be due to a change in fishing patterns in an attempt to minimize by-catch of this species rather than a true decline in abundance due to fishing. In Tasmania, however, there is concern that the small amount of by-product that is currently caught has the potential to expand (J. Lyle, pers. comm.). As a precautionary measure, Tasmania has implemented a possession limit of two *C. laticeps* per person, or five sharks per boat per day, to constrain future catches (DPIWE, 2011).

In the past few years, the importance of incorporating fish movement behaviour and habitat utilization as components of marine management and conservation programmes has been recognized (Koehn, 1999; Shumway, 1999; Simpfendorfer & Heupel, 2004). For example, studies on movement behaviour on the broadnose sevengill shark *Notorynchus cepedianus* (Péron 1807) showed that protected coastal areas of Tasmania include essential foraging grounds (Barnett *et al.*, 2011), and for the highly mobile blacktip shark *Carcharhinus limbatus* (Müller & Henle 1839), presence and movement analyses showed that time–area closures for nursery populations may be of greater value (Heupel & Simpfendorfer, 2005). Understanding small-scale movement patterns and habitat utilization is also important to establish if sharks are more vulnerable to capture at certain times of the day and on certain substrata (Rechisky & Wetherbee, 2003; Cartamil *et al.*, 2010). In this context, prior to considering any increased utilization of *C. laticeps*, it is important to understand the mixing of populations between regions. Knowledge of the behaviour of this species can be used to both increase exploitation through targeted fishing or to minimize by-catch by avoidance. Therefore, the aim of this study was to understand habitat utilization and movement patterns of *C. laticeps*, to assist possible future management programmes, by investigating the movement behaviour of this species using passive tracking and conventional tagging. As in other demersal scyliorhinids, high site fidelity, restricted habitat use, distinct diel patterns and short distance movements, were expected for *C. laticeps*. Accordingly, passive tracking was used to identify habitat utilization, diel patterns and short-term movements (<6 months), while conventional tags evaluated short-term and also longer-term movement (>6 months) over larger geographic regions.

## MATERIALS AND METHODS

## PASSIVE TRACKING

*Study site and sampling methodology*

The study covered the south-eastern Tasmania region (Australia) including an isolated reef, Crayfish Point Reserve (CPR) [Fig. 1(a)]. The main study site, CPR, and the adjacent areas of

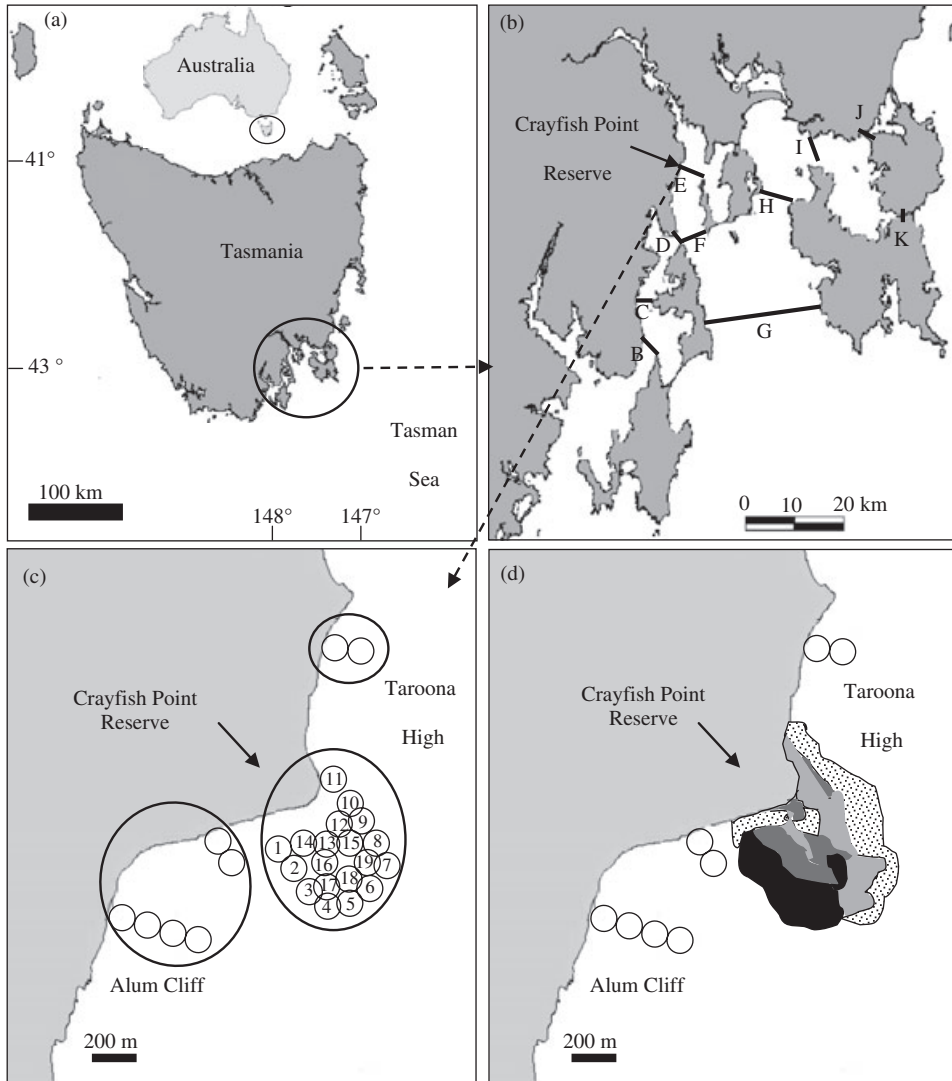


FIG. 1. The *Cephaloscyllium laticeps* study area. (a) Map of Australia. Tasmania is located in the south-east of Australia. (b) Map of Tasmania showing the south-east area and the acoustic receiver positions. Extensive lines of receivers are labelled as: B, Lower mid-channel; C, Upper mid-channel; D, Upper channel; E, Upper Derwent River; F, Lower Derwent River; G, Storm Bay; H, Frederick Henry Bay; I, Norfolk Bay; J, Dunally; K, Eaglehawk Neck. (c) Receiver positions at the Crayfish Point Reserve, Alum Cliff and Tarroona High. (d) Types of substrata for the Crayfish Point Reserve: high profile reef (■), medium profile reef (■), low profile reef (□) and sand (▨).

Alum Cliff and Taroona High are situated in the Derwent River, which runs through the City of Hobart before opening into Storm Bay [Fig. 1(b), (c)]. The Derwent River characterized by a combination of patchy reef (reef elements, including boulders and rocks, intermittently outcropping from unconsolidated sediments) and sand substrata consistently reaches depths of 20–30 m, with a maximum depth of 55 m. The CPR is a small shallow area (total area = 800 m<sup>2</sup>), maximum depth 11 m. Areas of Alum Cliff were characterized by high profile reef (that not only include steep underwater cliffs adjacent to or away from the coast but also include areas of high rugosities where depth variation was >4–10 m over short distances), while the density of the reef decreased in areas within the CPR and towards Taroona High. Low (hard bottom type with very little change in the relief) and medium profile reef (hard bottom type with regularly changes in the relief, depths from 1 to 4 m over short distances) shaped the inner area of the CPR, and Taroona High was characterized by low profile reef and sand (Barrett *et al.*, 2001; Jordan *et al.*, 2001) [Fig. 1(d)]. The flow of the tides will mean that water depth at any location will vary over the tidal cycle, depending on the coastal region; this variation can be in the order of tens of centimetres to metres over a variable 6 hour period (Barrett *et al.*, 2001).

Eighty-two VR2 automated acoustic receivers (Vemco Ltd; www.vemco.com) were deployed from January to July 2003. Fifty-five of these receivers were established as a series of acoustic 'curtains' positioned at the entrances of bays and channels to minimize the possibility of *C. laticeps* moving into or out of these areas without being detected [Fig. 1(b)]. The depth of receiver placement varied from 2 to 55 m. The distance between receivers was chosen to ensure that detection distances had substantial overlap and varied from 729 to 930 m depending on the habitat type. In addition, an array of 27 receivers was established at the CPR and the adjacent areas of Alum Cliff and Taroona High [Fig. 1(c)]. The complexity of these habitats resulted in a reduction of the detection range for the acoustic receivers to a minimum of 60 m (J. Semmens, unpubl. data). Consequently, the receivers were placed 100 m apart, in depths from 2 to 11 m, to ensure sufficient range overlap.

Between January and March 2003, 25 *C. laticeps* were caught in rock lobster traps, fitted with the acoustic transmitters (V8SC-2H, Vemco) and injected with 25 mg kg<sup>-1</sup> of the antibiotic tetracycline dissolved to saturation in sea water. Fifteen *C. laticeps* were caught and released at the CPR and 10 *C. laticeps* were obtained from the east coast of Tasmania and translocated to the CPR. For each *C. laticeps*, total length ( $L_T$ ) (mm) and sex were recorded. Initially, two *C. laticeps* were fitted with transmitters internally. These *C. laticeps* were injected with a local anaesthetic (xylocaine 0.5%, 25 mg in 5 ml), and a 3–4 cm incision was made in the ventrolateral region towards the rear of the stomach cavity. The transmitters were coated in 100% paraffin wax to prevent transmitter rejection and to cover any sharp protrusion on the transmitter surface that might irritate the animal (Heupel & Hueter, 2001). The cavity was closed using surgical glue (Indermil<sup>®</sup> Loctite Corporation; www.loctite.co.uk) and a disposable skin stapler (Royal 35W, United State Surgical Corporation, Ltd; www.ussurg.com). Because *C. laticeps* are benthic, resting on the ventral site of the body, the remaining 23 *C. laticeps* were fitted with transmitters externally. Two 1.1 mm × 38 mm surgical needles were joined to the distal end of the transmitters, and the transmitter was attached to the base of the first dorsal fin by piercing the needles through the fin. Transmitters emitted a unique 69 kHz pulse code that repeated after a random delay of 20–60 s.

### Data analysis

Data recovered from the receivers were stored in a Microsoft Excel database and used to examine presence and movement patterns. Since the receivers were so close together, the raw receiver locations were used to approximate the *C. laticeps* positions. Occurrence of *C. laticeps* within the monitored area was assessed on a daily basis. The presence of a *C. laticeps* was defined as when one receiver recorded at least two detections during a given day (Yeiser *et al.*, 2008). A presence index was calculated for the *C. laticeps* at each group of receivers within the array (*e.g.* Alum Cliff, CPR and Taroona High receivers) as the number of days *C. laticeps* occurred in each group of receivers divided by the total number of days *C. laticeps* were present during the entire study period.

Studies on habitat utilization were restricted only to the CPR, as all this area was covered by receivers. As *C. laticeps* have been observed by personal diving observations to remain

sitting on the substratum for long periods, it was necessary to determine if the hits detected were reflecting active movements or localized minor movements. The definition of active movement required at least two non-overlapping receiver detections, the initial location and the second location after movement. When the *C. laticeps* was detected by the same receiver or set of overlapping receivers for at least 60 min at intervals of  $\leq 1$  min (60+ detections in an hour), the *C. laticeps* was considered to be displaying minor movements. In any case, minor movements indicated that the *C. laticeps* was not actively swimming. To test differences in movement patterns between locations (*i.e.* between different groups of receivers), active movement and minor movement indices were calculated. For each *C. laticeps*, the indices were calculated as the number of hours the animal was actively moving or displaying minor movements in each location (*i.e.* each group of receivers) divided by the total number of hours the *C. laticeps* actively moved or showed minor movement respectively, during the study period.

Home range, based on receiver position, was calculated using 95 and 50% fixed kernel utilization distribution (KUD) (Worton, 1987) using the Movement Analyst Extension tool in Arcview 4.2 (Hooge & Eichenlaub, 2000). The spatial use of the area was estimated using the 95% fixed kernel as an estimate of the extent of the utilized area, while the 50% fixed kernel provided areas of greatest usage (Heupel *et al.*, 2004). Both estimates were examined for each *C. laticeps* per month and by combining all months together. Daily patterns were examined by calculating 95 and 50% KUDs for day and night, and by comparing active movement and minor movement rates. Rates were calculated as the number of active movements or minor movement patterns that occurred per hour, divided by the total number of active movements or minor movement patterns occurring during the 24 h period.

Differences in presence indices, active movement and minor movements indices and daily patterns were compared using the non-parametric Mann–Whitney *U*-test (two data sets were compared) and Kruskal–Wallis test (three or more data sets were compared). Subsequent *post hoc* multiple comparisons for the Kruskal–Wallis test were made using the Mann–Whitney *U*-test on each pair of groups with the adjustment of the *P* value with the Bonferroni correction, adjusting the threshold alpha level divided by the number of comparisons (Quinn & Keough, 2002).

## CONVENTIONAL TAGGING

### *Study site and sampling methodology*

Between January 2000 and April 2007, *C. laticeps* were tagged during routine fishery-dependent and fishery-independent rock lobster catch sampling trips around south-western and eastern Tasmania and in the CPR. The frequency and duration of each sampling trip varied according to the region (Table I). Each *C. laticeps* was tagged with a 35 mm yellow standard Rototag (Daltons, www.dalton.co.uk) externally attached to the second dorsal fin. For each *C. laticeps*, sex and  $L_T$  were recorded.

### *Data analysis*

To calculate short- and long-term site fidelity for the CPR, data were standardized to account for differing effort (number of trap lifts) undertaken in the different surveys, by the following equation:  $P_{ij} = C_j \{ T_i [(S_{ri})(S_{ti})^{-1}] (S_{tj})^{-1} \}$ , where  $P_{ij}$  is the proportion of *C. laticeps* recaptured in trip *i* that were tagged in trip *j*, where  $j > i$ .  $C_j$  is the catch rate (number of *C. laticeps* per trap) of *C. laticeps* tagged during *j*, which was calculated by dividing the number of *C. laticeps* caught and tagged in trip *j* ( $S_{tj}$ ) by the total number of traps set in trip *j*.  $T_i$  is the total number of traps set to capture *C. laticeps* in trip *i*,  $S_{ri}$  is the number of *C. laticeps* recaptured in trip *i* that were tagged in trip *j* and  $S_{ti}$  is the total number of *C. laticeps* caught in trip *i*.

To calculate the expected catchability, the following assumptions were made: (1) catch rate was a function of effort, (2) the CPR had no finite carrying capacity and (3) tagged *C. laticeps* were distributed randomly within the population. Difference in the proportion of *C. laticeps* recaptured per month or per year in the CPR were tested using Kruskal–Wallis test.

All statistical analyses, both passive tracking and conventional tagging, were carried out using SPSS (SPSS® Base 16.0; www.ibm.com/spss\_statistics), with the significance level set at 0.05.

TABLE I. Frequency and duration of fish-sampling trips around Tasmania (Fig. 1). Trip lengths for south-western and eastern Tasmania were 10–15 days each trip, and 5 days for the Crayfish Point Reserve

Year	Number of trips in each area		
	Crayfish Point Reserve	South-western Tasmania	Eastern Tasmania
2000	4 (Jan, Feb, May, Nov)	3 (Jul, Mar, Nov)	2 (Mar, Oct)
2001	8 (Feb, Jun, Jul, Aug, Sept, Oct, Nov, Dec)	1 (Nov)	2 (Mar, Jan)
2002	5 (Jan, Feb, Mar, Apr, May, Nov)	1 (Nov)	1 (Oct)
2003	3 (Jan, Feb, Nov)	2 (Mar, Oct)	2 (Mar, Oct)
2004	3 (Jan, Feb, Nov)	2 (Jan, Oct)	2 (May, Oct)
2005	1 (Jan, Feb)	1 (Oct)	1 (Mar)
2006	1 (Jan, Feb)		1 (Apr)
2007	1 (Jan, Feb)		1 (Apr)

## RESULTS

### PASSIVE TRACKING

Of the 25 *C. laticeps* that were passively tracked (15 females, nine males and one unknown), one individual was never detected and one was only detected twice. Thus, these individuals were excluded from the analysis. Of the remaining 23 *C. laticeps*, six transmitters did not start working until 1 month after attachment, due to the batteries being set to start 1 month after connection (Table II). For the analysis, these six *C. laticeps* were considered to be released at the CPR on the day that transmitters started working and were considered to be initially detected at the CPR, even if the first original detection was outside of the CPR.

#### Presence

Occurrence of *C. laticeps* within coastal areas (entire acoustic array) varied among individuals, with some present for up to 98 days while others were present for only a few days (Table II). The majority of the *C. laticeps* ( $n = 17$ ) remained within the Derwent River [areas E and F, Fig. 1(b)] during the study period. Two females moved beyond the Derwent River towards Storm Bay [area G, Fig. 1(b)] (*C. laticeps* #121 and #148), and four individuals (three females #144, #149, #155 and one male #162) were recorded in the upper Channel area [area D, Fig. 1(b)]. Although more *C. laticeps* were detected in the upper than the lower section of the Derwent River [ $n = 14$ , area E and  $n = 9$ , area F, Fig. 1(b)], *C. laticeps* spent more days in the lower (mean  $\pm$  s.e. presence index:  $0.39 \pm 0.09$ ) than upper section of the river ( $0.18 \pm 0.04$ ) (Mann–Whitney  $U = 28$ ,  $P < 0.05$ ).

Twenty *C. laticeps* were recorded visiting the Alum Cliff area and eight *C. laticeps* the Tarroona High site. Presence index was highest for the Alum Cliff area (mean  $\pm$  s.e.  $0.50 \pm 0.06$ ) followed by the CPR ( $0.43 \pm 0.06$ ) and Tarroona High ( $0.35 \pm 0.08$ ); however, these differences were not significant (Kruskal–Wallis,  $\chi^2 =$

TABLE II. Summary data for *Cephaloscyllium laticeps* tracked in the south-east region of Tasmania. All *C. laticeps* were tagged and released at the Crayfish Point Reserve (CPR). Ten *C. laticeps* were caught on the east coast of Tasmania (EC) and translocated to the CPR, the other 15 were caught at the CPR. For six *C. laticeps*, transmitters started working 1 month after insertion (\*). Two *C. laticeps* were fitted with transmitters internally (†); *C. laticeps* #156 and #143 were excluded from the analysis

Shark identification number	Sex	$L_T$ (mm)	Source	Total days detected
164	F	920	EC	6
163*	F	760	EC	4
162*	M	760	EC	12
161*	M	880	EC	15
160	F	820	CPR	9
159	M	715	CPR	44
158	F	620	CPR	6
157	M	530	CPR	10
156	M	820	EC	—
155	F	600	CPR	12
154	F	820	CPR	55
153	F	630	CPR	10
152	F	750	EC	9
151	M	770	CPR	51
149	F	830	CPR	42
148	M	610	CPR	4
147	M	870	CPR	62
146*	M	750	EC	47
145*	M	660	EC	23
144*	F	650	EC	32
143	F	880	CPR	—
141	F	870	EC	9
140	F	770	CPR	62
121†	F	830	CPR	5
116†	F	770	CPR	98

$L_T$ , total length.

1.88, d.f. = 2,  $P > 0.05$ ). Within the CPR, significant differences in daily occurrences were found (Kruskal–Wallis,  $\chi^2 = 2.30$ , d.f. = 2,  $P < 0.05$ ). The receivers closer to Alum Cliff [1–6, Fig. 1(c)] recorded a great number of *C. laticeps* presences than any other area of the CPR (mean  $\pm$  s.e. presence index:  $0.60 \pm 0.02$ ), followed by the inner receivers [12–19, Fig. 1(c)] ( $0.48 \pm 0.08$ ) (Mann–Whitney  $U = 15$ ,  $P < 0.01$ ) and the receivers closer to Tarooma High [7–11, Fig. 1(c)] ( $0.35 \pm 0.03$ ) (Mann–Whitney  $U = 22$ ,  $P < 0.01$ ). No significant differences in the presence indices between the inner receivers and the ones closer to Tarooma High were found (Mann–Whitney  $U = 10.1$ ,  $P > 0.05$ ).

Within the CPR, the amount of time that *C. laticeps* remained in the area was highly variable, with some *C. laticeps* detected only for a few days (e.g. *C. laticeps* #121 and #160) and others detected for extended periods with limited absence from the study site (e.g. *C. laticeps* #116 and #158), while others were transients for several months with prolonged periods ( $>1$  month) of absence (e.g. *C. laticeps* #148 and

#155) (Fig. 2). Of the 14 *C. laticeps* caught at the CPR (excluding the *C. laticeps* sourced from the east coast), 12 were still present at the CPR after the first month of being released, and 10, six and three after the second, third and sixth months, respectively (Fig. 2).

The majority of the *C. laticeps* that were translocated from the east coast of Tasmania left the CPR after the first month following release. During the first month after release, all nine *C. laticeps* were present at the CPR; by the end of the second month, only two *C. laticeps* (#141 and #146) remained at the CPR, and only one (#146) was recorded by the end of the third month. All the nine *C. laticeps* remained, however, within the Derwent River region during the entire study period.

#### Habitat utilization

Of the 23 tagged *C. laticeps*, 15 (nine females and six males) showed minor movement patterns alternating with active movements. Eight individuals (#164, #163, #162, #161, #160, #158, #153 and #121) were excluded from the analysis as they were intermittently present at the CPR only for a few days during the study period showing only a few active or minor movements. The time spent by *C. laticeps* displaying minor movements varied between 1 and 24 h per day, with a mean  $\pm$  S.E. time of  $6 \pm 1$  h per day (Table III). Eight *C. laticeps* were recorded to display minor movements for  $>10$  h, two *C. laticeps* (#140 and #147) up to 17 and 21 h respectively and one (#149) spent two different periods of 5 and 4 consecutive days slightly moving (Table III).

*Cephaloscyllium laticeps* utilized all areas of the CPR; however, significant differences in the use of the habitat were found, with areas close to Alum Cliff being used more heavily (active movement indices: Kruskal–Wallis,  $\chi^2 = 2.35$ , d.f. = 2,  $P < 0.05$ ; minor movements indices: Kruskal–Wallis,  $\chi^2 = 3.54$ , d.f. = 2,

TABLE III. Total minor movements displayed by *Cephaloscyllium laticeps* at the Crayfish Point Reserve

Shark identification number	Total number of hours of minor movements	Minor movement duration range (h) (mean $\pm$ S.E.)
164	33	1–5 ( $4.3 \pm 0.3$ )
163	15	2–15 ( $8.6 \pm 5.5$ )
162	45	1–9 ( $7.0 \pm 2.1$ )
159	38	1–13 ( $4.5 \pm 1.6$ )
157	30	1–15 ( $5.0 \pm 2.9$ )
155	12	1–12 ( $6.5 \pm 5.5$ )
154	77	1–3 ( $2.0 \pm 0.6$ )
151	25	1–5 ( $2.8 \pm 0.5$ )
149	372	1–24 ( $14.7 \pm 1.7$ )
148	2	2 ( $2.0 \pm 0.0$ )
147	112	1–17 ( $5.1 \pm 0.4$ )
144	6	2 ( $2.0 \pm 0.0$ )
141	9	1–6 ( $3.2 \pm 2.0$ )
140	187	1–21 ( $9.6 \pm 2.7$ )
116	18	3–15 ( $9.0 \pm 6.0$ )



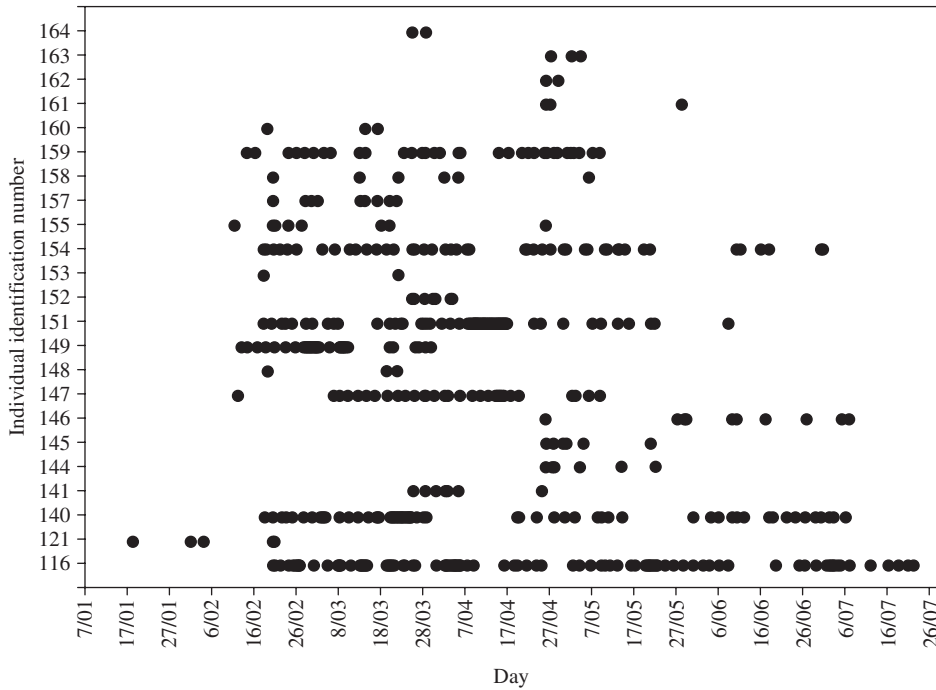


FIG. 2. Plots of individual *Cephaloscyllium laticeps* presence within the Crayfish Point Reserve during the study period.

$P < 0.05$ ). The mean  $\pm$  s.e. active movement index significantly increased concomitant to the complexity of the reef, being  $0.57 \pm 0.02$  in the high-profile reef area closer to Alum Cliff,  $0.26 \pm 0.05$  (Mann–Whitney  $U = 8.31$ ,  $P < 0.05$ ) in the low-density reef of the CPR central area, and  $0.17 \pm 0.01$  (Mann–Whitney  $U = 6.70$ ,  $P < 0.01$ ) in the area closer to Taroona High, where sandy patches were more predominant. No significant differences in movement indices between the central area and the receivers closer to Taroona High were found (Mann–Whitney  $U = 14.31$ ,  $P > 0.05$ ). The area closer to Alum Cliff was also the region where the minor movements rate was significantly higher (mean  $\pm$  s.e.  $0.51 \pm 0.02$ ), followed by the area closer to Taroona High ( $0.38 \pm 0.05$ ) (Mann–Whitney  $U = 8.2$ ,  $P = 0.001$ ) and the central area of the CPR ( $0.11 \pm 0.01$ ) (Mann–Whitney  $U = 9.5$ ,  $P < 0.001$ ). Significant differences in minor movement indices between the central area and the area closer to Taroona High were also observed (Mann–Whitney  $U = 12.1$ ,  $P = 0.01$ ). The utilization and distribution analysis showed extended use of the CPR; all CPR areas fall within each of the 95% KUD estimated for each individual, while the area closer to Alum Cliff was included in the majority of the 50% KUD analysis [Fig. 3(a), (b)]. All individuals showed similar habitat utilization either by month or when all months were combined. For each individual *C. laticeps*, the 95% contour estimates, obtained by combining the entire period it was present at the CPR, showed the entire use of the area. Although the 95% KUDs obtained by separating each month revealed small regions of the CPR not being utilized every month, no major differences were seen in the areas used either by month or when all months

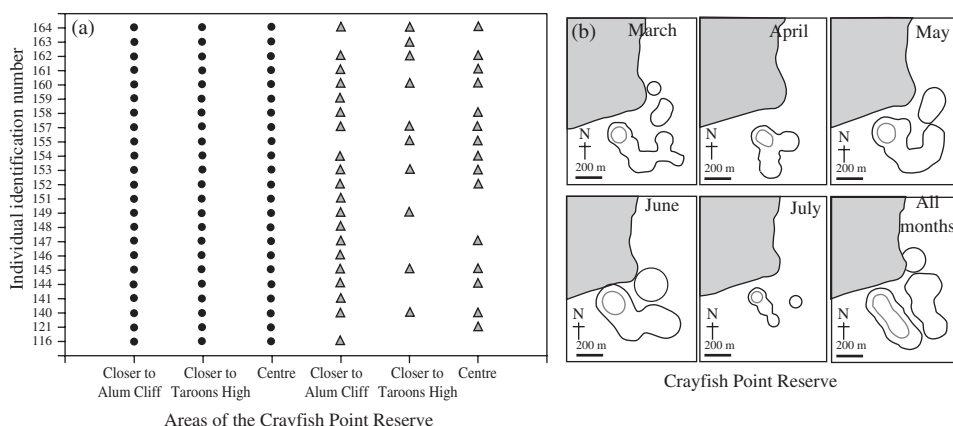


FIG. 3. Estimates of 95 (●) and 50 (▲) % kernel utilization distribution (KUD) for *Cephaloscyllium laticeps* monitored within the Crayfish Point Reserve. (a) Habitats that fall within the 95 and 50% KUDs calculated for each individual. (b) A representative example (#116) of individual and combined monthly estimates of 95 (■) and 50 (□) % KUD contours.

were grouped. In addition, 50% KUDs revealed no difference in the areas occupied either by month or by the combination of the entire study period [Fig. 3(b); note, as all *C. laticeps* showed similar patterns when comparing individual months with all months grouped, only one is shown as a representative example].

For the day–night movement activity patterns, the eight individuals (#164, #163, #162, #161, #160, #158, #153 and #121) that were intermittently present at the CPR were excluded from the analysis. Of the remaining 15 *C. laticeps*, 11 individuals showed greater activity at night, while the other three moved predominantly during the day [Fig. 4(a)]. No shifts in habitat utilization within the kernel area between day and night were detected [Fig. 4(b)]. Periods of minor movements were observed both during day and night. Three animals were excluded from the analysis as they spent <10 h in apparent inactivity. The remaining 12 *C. laticeps* showed minor movement patterns that were slightly higher during the day (Fig. 5). Significant differences (Mann–Whitney  $U = 5.5$ ,  $P < 0.01$ ) was found when day and night minor movements rates were combined: mean  $\pm$  s.d. day rate (0700–1800 hours) =  $0.047 \pm 0.005$ , night rate (1900–0500 hours) =  $0.036 \pm 0.004$ .

#### Conventional tagging

Between January 2000 and April 2007, 1552 *C. laticeps* were tagged in south-west and eastern Tasmania and the CPR. The CPR showed the highest recapture rate, 38% of 364 *C. laticeps* tagged, followed by eastern and south-western areas where the recapture rate was 10% (*C. laticeps* tagged  $n = 622$ ) and 3% (*C. laticeps* tagged  $n = 566$ ) respectively (Table IV). Within the CPR, 64% of the *C. laticeps* were recaptured once and 36% recaptured on multiple occasions (26% of *C. laticeps* recaptured twice, 5% recaptured three times, 4% recaptured four times and 1% recaptured five times). These recaptures did not include recaptures within the same month of tagging. There were no multiple recaptures from the eastern and south-western areas. Time at liberty ranged from 1 month to 7 years (Table IV and refer to Fig. 1 for each location). The

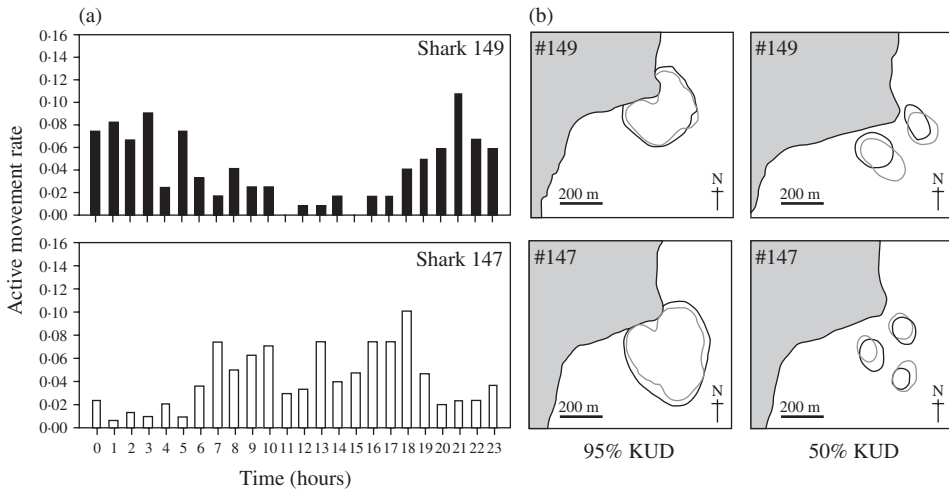


FIG. 4. Representative examples of day and night activity for *Cephaloscyllium laticeps*. (a) Hourly active movement rates for #147 and #149. (b) Estimates of 95 and 50% day (■) and night (□) kernel utilization distribution.

majority of *C. laticeps* were recaptured within 10 km of where they were released (Table IV); however, the maximum distances travelled for *C. laticeps* tagged in the CPR was 75 km, and up to 300 km for *C. laticeps* tagged on the east and south-west coast (Fig. 6).

A high variability of the mean  $\pm$  s.e. values ranging from  $0.004 \pm 0.010$  to  $0.054 \pm 0.165$  was found [Fig. 7(a)]. A decrease in the proportion of recaptured *C. laticeps* was observed after 5 to 6 months and after 11 months of being released, but these drops were not significant (Kruskal–Wallis  $\chi^2 = 9.69$ , d.f. = 5,  $P > 0.05$ ). *Cephaloscyllium laticeps* showed no dispersion away from the CPR over the 7 years since tagging began. The proportion of recaptured *C. laticeps* ranged from mean  $\pm$  s.e.  $0.11 \pm 0.06$  after the first year of being tagged to  $0.085 \pm 0.04$  at the end of the 6 year study period (Kruskal–Wallis  $\chi^2 = 11.2$ , d.f. = 4,  $P > 0.05$ ) [Fig. 7(b)].

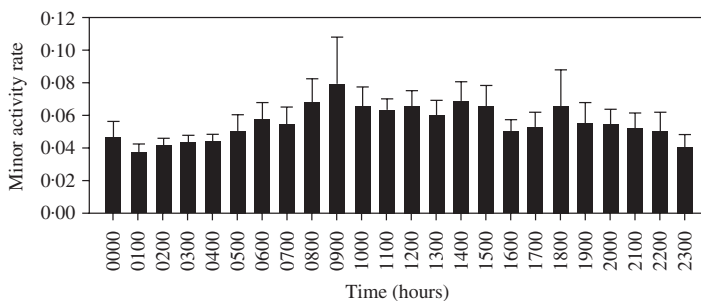


FIG. 5. Hourly distribution of mean + s.e. ( $n = 12$ ) minor movement rate for *Cephaloscyllium laticeps*.

TABLE IV. Summary of *Cephaloscyllium laticeps* conventional tagging in eastern and south-western Tasmania, and in the Crayfish Point Reserve. Note that the distance within 10 km was considered as recaptures in the same area

Area	Tagged ( <i>n</i> )	Recaptures ( <i>n</i> )	Recaptures (%)	Time at liberty	Recaptures in same area ( <i>n</i> )	Recaptures in different areas ( <i>n</i> )
Crayfish Point Reserve	364	137	37.63	1 month to 6 years	122	15
South-western Tasmania	566	19	3.35	4 month to 5 years	17	2
Eastern Tasmania	622	60	9.64	1 month to 7 years	53	7

## DISCUSSION

This study has revealed novel information on specific habitat utilization and movement behaviour of *C. laticeps* that were previously unknown. While mixing between broad regions does occur, the general pattern of movement was of limited dispersion within Tasmania's major coastal regions. Reef substrata were the preferred habitat for this species to use, crepuscular and nocturnal active movement were most common and long periods of resting or minor activity were observed.

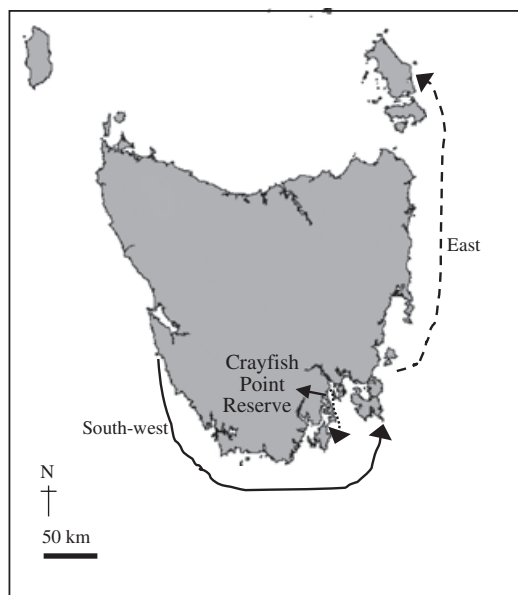


FIG. 6. Examples of maximum reported distances travelled for *Cephaloscyllium laticeps*. Tagged in south-western Tasmania (—▶). Tagged in eastern Tasmania (---▶). Tagged in Crayfish Point Reserve (.....▶). The lines represent the shortest possible route between the release and the recapture position.

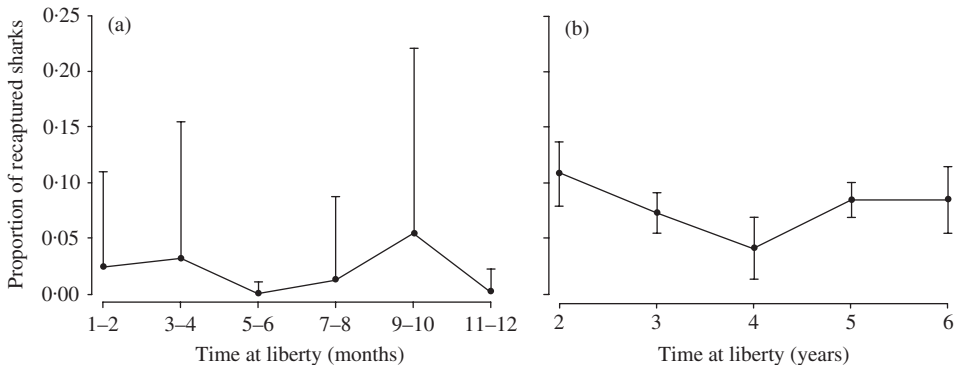


FIG. 7. Monthly ( $n = 90$ ) and yearly ( $n = 47$ ) proportion of recaptured *Cephaloscyllium laticeps* at the Crayfish Point Reserve. Values are mean + s.e.

### Presence and site fidelity

*Cephaloscyllium laticeps* were present within the boundaries formed by the intensive array, the Derwent River and the Upper Channel. Within the Derwent region, the CPR appeared to be towards the upper limit of *C. laticeps* habitat as a greater proportion of *C. laticeps* moved between the CPR and the mouth of the Derwent rather than moving in the other direction. The majority of the *C. laticeps* that were translocated from the east coast of Tasmania did not stay within the release area for longer than 1 month, after which they left the intensive array to be finally recorded around the lower section of the Derwent River. While no significant difference could be detected with the small number of *C. laticeps* tagged, there were indications that *C. laticeps* did show a degree of short-term site fidelity in the use of the coastal habitats in Tasmania. The *C. laticeps* obtained from the CPR were sighted back in the CPR on more occasions and tended to disperse less widely than those obtained from the east coast. It is not known why the translocated *C. laticeps* left the area within 1 month of tagging. It could be possible that they dispersed in search of their natal habitats (Speed *et al.*, 2010). It was also possible that because the CPR is a small marine protected area with a high density of *C. laticeps*, they left to avoid increased competition for limited resources (*i.e.* food and shelter). The preference for high profile reef areas during periods of low activity suggests that the *C. laticeps* may seek refuge from predators, particularly, as the broadnose sevengill shark *Notorynchus cepedianus* (Péron 1807), the largest predator of *C. laticeps*, is highly abundant in these coastal areas (Barnett *et al.*, 2010a, b). If so, then hard structure would be a limited resource in the Derwent Estuary since it mainly consists of mud, silt and sand habitats. Long-term studies would be necessary, however, to clarify if their absence from the CPR was temporary or permanent.

The higher number of research recaptures in the CPR (63%) was most likely a function of the research design. The recapture of the majority of the *C. laticeps* in the vicinity of where they were released was most likely associated with the increased and more frequent sampling undertaken in this region as few (16%) were returned by non-researchers. Surveys in the CPR and the east and south-west coasts revisited the same sites. Thus, it is reasonable to expect that the majority of the recaptures would come from these surveys. In contrast, surveys in south-west and eastern Tasmania

occurred once a year at similar periods and for the same duration; therefore, the fishing effort by researchers in those areas was lower than that for the CPR.

The lack of tag reporting by fishers using traps or nets clearly highlights the problems associated with gathering data on by-catch species and the reporting of recaptured tagged animals that are returned to the sea (*i.e.* no commercial value). During this study, the tagging programme was publicized in fishing industry magazines and explained through talks given to both gillnet and trap fishers. Fishers were familiar with reporting tags as many of the Tasmanian target species have been the subject of tagging studies. Although only a small number of tags were reported, the conventional tag returns indicated a degree of mixing over larger ranges. Large distance movements were recorded between eastern and western Tasmania and between southern and northern Tasmania. Similarly, McLaughlin & O'Gower (1971) found that the demersal Port Jackson shark *Heterodontus portusjacksoni* (Meyer 1793) undertook both short movements around its reef habitats and occasional long ( $10^2$  km) movements. The conventional tag returns have also demonstrated longer-term site affinities with several *C. laticeps* being recaptured in the same location up to 7 years after tagging. Similarly, long-term site fidelity or philopatric behaviour (animals returning to a specific location) has been recorded for other species. The bonnethead shark *Sphyrna tiburo* (L. 1758), *H. portusjacksoni* and *S. canicula* were reported to return to a specific location after periods of absence that can be measured in months or years (Rodriguez-Cabello *et al.*, 1998; Sims *et al.*, 2001; Heupel *et al.*, 2006). The long-term recaptures of *C. laticeps* could be because individuals return to or never leave the specific locations. Either way, these habitats appear to be important for *C. laticeps*. Site fidelity has been attributed to mating, pupping, re-use of natal sites and increase foraging success, as spatial familiarity and increased knowledge of the local prey can improve foraging efficiency (Van Moorter *et al.*, 2009; Speed *et al.*, 2010). *Cephaloscyllium laticeps* inhabit different coastal areas of Tasmania with similar habitat structure (Barrett *et al.*, 2001) and prey availability (unpubl. data). In addition, *C. laticeps* is capable of reproducing throughout the year, with mating and pupping occurring around any of Tasmanian's coastal areas (Awruch *et al.*, 2009). The combination of similar habitat characteristics with the reproductive strategies used by *C. laticeps*, together with this species possible spatial familiarity with the area, suggests no apparent advantages that could drive this species to leave a specific location.

#### *Habitat utilization*

*Cephaloscyllium laticeps* showed preference areas of use within the CPR. Both the KUD results and the greater number of active movements detected on the Derwent mouth side of the CPR (area closer to Alum Cliff, receivers 1–6) suggested that *C. laticeps* were more actively using this smaller region of the CPR. Movements out of the CPR tended to disperse towards the ocean side of the Derwent River rather than further up the river. The main difference between the area close to Alum Cliff and the rest of the CPR was the increased presence of higher profile reef.

The high profile reef was also used by *C. laticeps* for periods of rest or minor movements. Moreover, divers have reported *C. laticeps* resting in rocky crevices by themselves or in groups (pers. obs.). This study indicates that high profile reef was a preferred habitat for this species. The entire Scyliorhinidae family lives in marine habitats, feeding mainly on small fishes and invertebrates (Springer, 1979;

Compagno, 1984). Previous studies in other scyliorhinids showed that *C. laticeps* are characterized as slow swimmers (Springer, 1979; Compagno, 1984) and were often found resting in caves either alone or in aggregations (Nelson & Johnson, 1970; Sims *et al.*, 2005). Periods of inactivity have been reported for *H. portus-jacksoni* (McLaughlin & O'Gower, 1971), the horn shark *Heterodontus francisci* (Girard 1855) (Nelson & Johnson, 1970) and other species of scyliorhinids such as *C. ventriosum*, the nursehound *Scyliorhinus stellaris* (L. 1758) and *S. canicula* (Nelson & Johnson, 1970; Sims *et al.*, 2001, 2005). This was the first time, however, that a continuous period of 5 days displaying apparently minor movements has been documented for any scyliorhinid species. Avoidance of predators, thermoregulation, sexual behaviour and digestion have all been suggested as reasons for periods of inactivity among benthic sharks, especially within the scyliorhinids (Economakis & Lobel, 1998; Sims *et al.*, 2001, 2005; Sims, 2003). Taking into account that no apparent correlation between periods of minor movements and sex was found in *C. laticeps*, and this species is a higher trophic level predator in temperate rocky reef areas, it is most likely that the reason for extended periods of inactivity was due to digestion of prey. Large prey items (*e.g.* 4 kg octopus) are often present in the stomachs of these *C. laticeps* (C. A. Awruch, unpubl. data), and these would be expected to take a considerable period to digest. It is then postulated that long periods of inactivity are likely to be a common behavioural characteristic of this species, and these periods are associated with *C. laticeps* digesting large prey items.

Cooper (1978) and Sempendorfer & Heupel (2004) recommended that the temporal pattern of spatial occupation is crucial for determining whether an animal randomly visits habitat or the habitat is the area usually occupied by it (home range). In species such as neonate *C. limbatus* (Heupel *et al.*, 2004), the bluntnose sixgill shark *Hexanchus griseus* (Bonnaterre 1788) (Dunbrack & Zielinski, 2003) and the temperate rocky-reef teleost red morwong *Cheilodactylus fuscus* Castelnau 1879 (Lowry & Suthers, 1998), changes over time of the home range or seasonal variations in habitat utilization were reported. These seasonal movements were related to survival strategies, feeding activity and reproductive behaviour. In contrast, and similar to other species such as juveniles of the Caribbean reef shark *Carcharhinus perezi* (Poey 1876) (Garla *et al.*, 2006), the coral-reef fish leopard coral grouper *Plectropomus leopardus* (Lacépède 1802) (Zeller, 1997) and the silver seabream *Pagrus auratus* (Forster 1801) (Parsons *et al.*, 2003), *C. laticeps* showed no monthly patterns of habitat utilization throughout the study period. As this species reproduces all year round with no specific pupping grounds (Awruch *et al.*, 2009), and prey are available throughout the year (unpubl. data), there appears to be no reason for *C. laticeps* to show seasonal–monthly variations in habitat utilization.

#### *Day and night activity*

*Cephaloscyllium laticeps* showed a preference for crepuscular and night-time activity in comparison to moving during the day. Similarly, Nelson & Johnson (1970) reported nocturnal activity patterns for the scyliorhinid *C. ventriosum*, and Sims *et al.*, (2001) found differences in the day–night activity between males and females of *S. canicula*. These same activity periods have been reported for other bottom dwelling shark species in their natural environment such as Pacific angelshark *Squatina californica* Ayres 1859 (Standora & Nelson, 1977) and *H. francisci* (Nelson & Johnson, 1970). Movements in *C. laticeps* were probably associated with feeding activity,

as the main dietary items are nocturnally active animals such as the Maori octopus *Octopus maorum*, the Gould's squid *Nototodarus gouldi*, southern rock lobster *Jasus edwardsii* (Hutton 1875) and the white-spotted hairy hermit crab *Strigopagurus strigimanus* (unpubl. data). Although night-time activity was most common, several *C. laticeps* also moved during the day. This has also been observed for other bottom dwelling species such as *H. portusjacksoni* (McLaughlin & O'Gower, 1971), *H. francisci* and *C. ventriosum* (Nelson & Johnson, 1970), which were all found to feed mainly at night with a small number of observations of daytime feeding. Although day and night differences in habitat utilization are common among chondrichthyans (Gruber *et al.*, 1988; Holland *et al.*, 1993; Sims *et al.*, 2001; West & Stevens, 2001; Sims, 2003) for the majority of *C. laticeps*, there were limited differences between the areas utilized during the day and night. This could suggest that the *C. laticeps* had established feeding areas or recognized certain habitat types as more productive regions to locate food.

In conclusion, as a bottom-dwelling species, it was not surprising to find that *C. laticeps* alternated between active movement and minor activity periods. Although the majority of the *C. laticeps* tended to move at night (probably related to movements of their main prey items), they also make opportunistic movements at other times. Both the conventional and acoustic tagging data showed a preference for *C. laticeps* to remain in the general vicinity of tagging. Gradual dispersion rather than established migratory routes appeared to be the general movement pattern but recaptures from conventionally tagged *C. laticeps* did demonstrate that this species is capable of travelling relatively long distances.

With the move to ecosystem-based fisheries management, it is important to consider the sustainability of catches of major by-catch species. Fundamental to management of by-catch will be the need to ensure that populations can be sustained through available habitat. Marine protected areas (MPA) or fishery closures have been reported as an effective spatial tool for fisheries management (Jamieson & Levings, 2001; Stevens, 2002; Baelde, 2005; Blyth-Skyrme *et al.*, 2006). Although sharks are usually highly mobile animals which often have an extensive distribution (Stevens, 2002), MPAs can still play a useful role in their management and conservation, as closed areas effectively reduce fishing mortality protecting parts of the population. As *C. laticeps* showed site fidelity, foraging on reef-dwelling prey and rest in sheltered areas, the implementation of shark refuge areas is likely to be particularly effective in protecting this species.

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