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Patterns of movement and habitat use by leafy seadragons tracked ultrasonically

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Nine adult leafy seadragons *Phycodurus eques* were tracked using ultrasonic telemetry for between 2–10 days around West Island, Australia. All fish except one moved within well-defined home ranges of up to 5 ha (using minimum convex polygon method). Short bursts of movement (at average velocities of 2–17 m h^{-1}) punctuated long periods (up to 68 h) without movement. The exceptional fish moved almost in a straight line away from its tagging location near the end of the tracking period, at a maximum velocity of 146 m h^{-1}. There was no constant diel pattern in movements; some fish moved more at night, others during the day. The time leafy seadragons spent over particular habitats compared to the area of those habitats available at the study site was greater for *Posidonia* seagrass, about as expected for kelp-covered reefs and bare sand patches, and less than expected for *Amphibolis* seagrass and boulders covered with brown algae. In searching for tagging effects, a comparison of movement immediately after tagging showed no difference with subsequent movements for most fish. The lack of tagging effect may be because the transmitter can be attached to the bony appendages away from the body of the fish. There was no sign of damage to fish upon removal of transmitters after tracking.

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Key words: Australia; home range; marine protected areas; pipefish; seahorse; telemetry.

INTRODUCTION

Leafy seadragons *Phycodurus eques* (Günther) are a syngnathid fish endemic to Australia, occurring along the south coast from Perth to east of Melbourne (Gomon *et al.*, 1994). The reproductive biology of leafy seadragons is partly known from aquarium specimens (Kuiter, 1988), but the lack of basic knowledge of their ecology has led the World Conservation Union to list the leafy seadragon on its Threatened Species Red List under the category of Data Deficient (IUCN, 2000).

Leafy seadragons lack a caudal fin and are weak swimmers (Kuiter, 2000). Eggs are reared whilst attached to the underside of the male's tail, so there is no dispersive egg phase. The species is therefore assumed to have low levels of dispersal, making it potentially vulnerable to habitat loss and degradation as well as incidental harvesting by humans (Connolly *et al.*, 2002).

Leafy seadragons are a marine conservation icon in southern Australia, and are a key species in the consideration of marine protected area (MPA) design on exposed coastlines. One of the main considerations when designing MPAs is the extent of movement exhibited by target animals (Kenchington, 1990; Kramer &

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Chapman, 1999). The paucity of information about leafy seadragon movement patterns and habitat utilization makes it difficult to manage this species. Home ranges and movement patterns of other syngnathid species have been measured by determining the position of individual fish that are identified using natural head markings (Gronell, 1984), by tagging individual fish (Vincent & Sadler, 1995; Vincent *et al*., 1995), or by making population abundance estimates over time at different locations (Bayer, 1980; Lazzari & Able, 1990).

The home ranges and movement patterns of syngnathid fishes have been found to be dependent on the sex of the fishes (Gronell, 1984; Vincent & Sadler, 1995) and the pregnancy status of males (Vincent *et al*., 1995), and home ranges for breeding seahorses and for a species of pipefish have been shown to range from 1 to 100 m^2 (Gronell, 1984; Vincent & Sadler, 1995). It has also been shown that some syngnathid species migrate seasonally. The pipefish *Syngnathus fuscus* Storer can migrate hundreds of kilometres offshore into deeper waters during winter (Lazzari & Able, 1990), while the pipefish *Syngnathus leptorhynchus* Girard migrates away from lower estuarine sites in summer (Bayer, 1980), and the seahorse *Hippocampus whitei* Bleeker may move into deeper water in winter (Vincent & Sadler, 1995). Some species of pipefish, however, have been found to stay in the same shallow seagrass beds throughout the year (Howard & Koehn, 1985), exhibiting no seasonal movement.

The only estimate of abundance of leafy seadragons is from West Island in South Australia, where surveys by divers relied on identification of individual fish to estimate an abundance of 57 fish ha^{-1} (Connolly *et al*., 2002). The study noted that although certain individuals were present in the survey area over the course of a year, at other times these fish could not be found and presumably moved outside the survey area.

This study measured movements of leafy seadragons using ultrasonic tracking. The aims were to: (1) describe patterns of seadragon movement, including the area of minimum convex polygon home ranges; (2) compare the proportion of recorded leafy seadragon positions over different habitats within the areas of the available habitats; (3) determine whether the degree of movement or habitat use differs at different times of day; (4) test for tagging effects on fish movement by comparing movement immediately after tagging with movement at other times.

MATERIALS AND METHODS

This study was undertaken in the shallow waters (5–20 m deep) around West Island and the adjacent Wright Island in South Australia (Fig. 1). Adult leafy seadragons were located by SCUBA divers and tagged *in situ* using commercially available ultrasonic transmitters (cylinder: 30 mm long and 8 mm diameter). The transmitters have a slight negative buoyancy, weighing 3 g in water. To make them neutrally buoyant, a small amount of syntactic foam was moulded on to each transmitter whilst ensuring they remained streamlined to minimize drag. Transmitters were attached to bony appendages on the back of fish using polyfilament dacron line, firmly enough to prevent them from rubbing the fish or snagging on vegetation, but without damaging appendages. The transmitter was slung between the single nape appendage and the two back appendages (Connolly *et al*., 2002) using three lines from the transmitter.

Nine fish were tracked from a boat for between 2 and 10 days in summer and winter (two summers and one winter over a 13 month period). Fish were tracked for varying

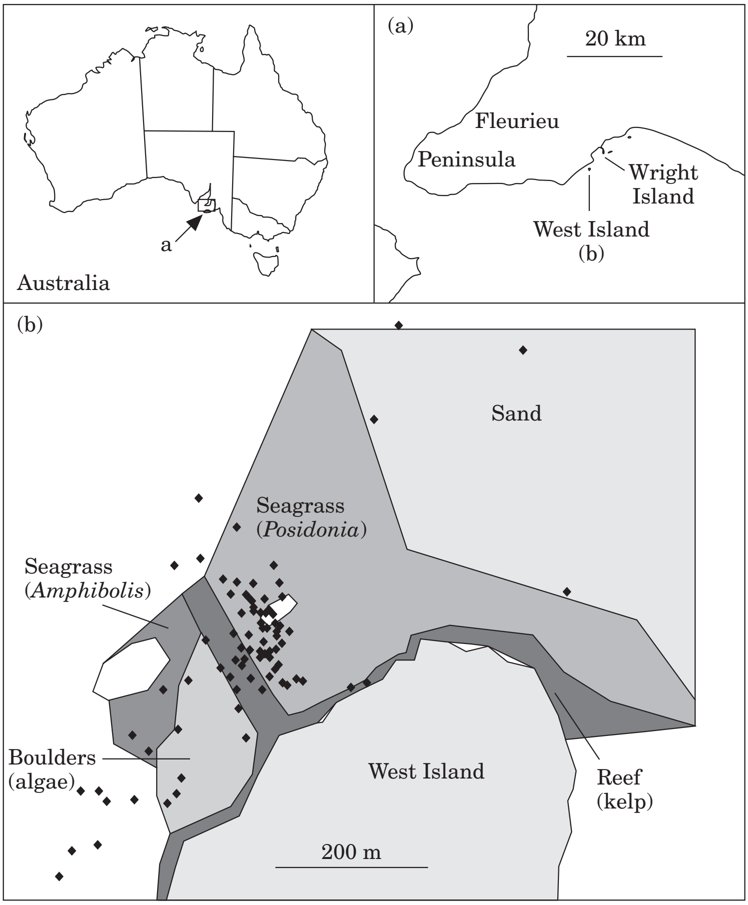

FIG. 1. Regional map showing (a) location of West Island in South Australia, and (b) details of the island with habitat types in the study area. Leafy seadragon recordings are marked (◆).

periods depending on when during a field trip they were first sighted. The location of fish was determined every 3 h (weather permitting) using a directional hydrophone, a receiver and GPS, as an observation frequency of less than one per day has been shown to reduce the accuracy of determining home ranges (Ovidio *et al*., 2000). Although the transmitters can potentially be detected at up to 200 m, in the vegetated habitat at the study site, with interference from strong water movement (swell surge and waves), they gave a reliable range of *c.* 60 m. A total of 200 position recordings (Fig. 1) were made with a precision of *c.* 5 m, calculated as the maximum distance a transmitter could be moved by a diver in 7 m water depth without detection of movement by the surface crew. The following movement parameters were calculated in Geographic Information Systems (GIS) for each fish: (1) minimum convex polygon home range (Worton, 1987), (2) distance moved between successive observations, (3) fish velocity between successive observations, (4) distance from point of initial tagging, and (5) cumulative distance travelled by the fish. All parameters were calculated based on an assumption of straight-line distances between position recordings, and as such represent minimums.

The vegetation along a 50 ha area of the northern shore of West Island was mapped prior to the tracking programme using GIS software based on diver information and truthing points for significant underwater landmarks and areas. The vegetation was categorized into five broad habitat types (Table I), and the habitat at each sighting was determined using GIS (Fig. 1). On one occasion, two fish were tracked at Wright Island

TABLE I. Habitat categories and descriptions

Habitat category	Description of habitat
Boulders/brown algae	Boulders in sand, covered in brown algae (mainly *Cystophora* spp.)
Reef/kelp	Shallow water, granite boulders covered in kelp (*Ecklonia radiata*)
Sand	Unvegetated sand
Seagrass—*Amphibolis*	Seagrass meadows dominated by *Amphibolis antarctica*, with smaller patches of *Heterozostera tasmanica* and *Posidonia sinuosa*
Seagrass—*Posidonia*	Seagrass meadows dominated by *P. sinuosa* with smaller patches of *H. tasmanica* and *A. antarctica*

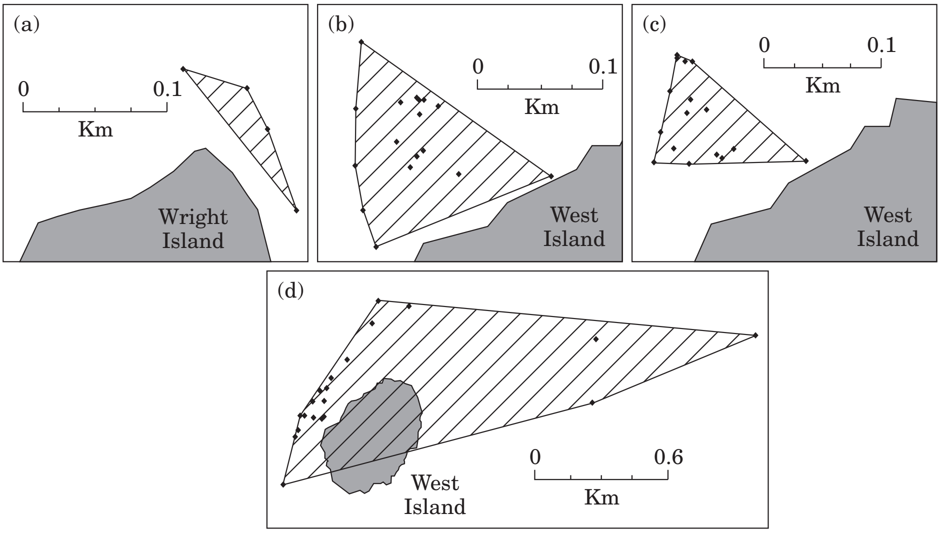

FIG. 2. Recorded positions (◆) and minimum convex polygon home ranges for fish (a) 2, (b) 3, (c) 4, and (d) 6.

when none could be found at West Island, but the habitats at Wright Island were not mapped so no determination could be made of habitat use at these sightings. Nor could the habitat be determined for fish tracked at West Island when they moved outside the mapped area. The proportion of fish positions recorded over different habitats was compared with the area of each habitat available in the study area.

Differences in the mean distance travelled between observations at three times of day (day, night and the transition between day and night) were tested using a one-way ANOVA for each fish separately.

RESULTS

MOVEMENT

Most fish moved within a well-defined home range over the 2 to 10 day periods of tracking [e.g. fish 2, 3 & 4; Fig. 2(a), (b), (c)]. Home ranges were <2 ha for seven fish, nearly 5 ha for another, while the remaining fish (fish 6) moved over a much larger area of 88 ha [Fig. 2(d) and Table II). The distances moved by fish from the tagging location typically did not increase steadily over time [Fig. 3(a), (b), (c)], providing evidence that fish were remaining in a defined area and not simply moving in a straight line through the study site. Fish 6 was exceptional in this regard, moving large distances away from the tagging location near the end of the tracking period [Figs 2(d) and 3(d)].

Most fish had a pattern of movement in which long periods without apparent movement were punctuated by periods of movement [e.g. Fig. 3(b)]. The longest period over which no movement was detected was 68 h for fish 1, with 17 position recordings during that time (Table II). When fish did move between recordings, average velocities for fish other than fish 6 ranged from 2–17 m h^{-1}, with a maximum velocity of 43 m h^{-1} (Table II). Fish 6 moved at an average of 44 m h^{-1} and maximum of 146 m h^{-1}.

TAGGING EFFECTS

Any effect on the fish of attaching the transmitter was searched for by comparing the distance moved at the initial recording after tagging with the average and maximum distance moved at all other recordings (Table III). Five of the nine fish moved further immediately after tagging than they did on average at other times. All except two of these fish (fish 2 and 9), however made larger movements than the initial movement at other times of the tracking period (Table III). Comparisons of distance from tagging location gave similar results. Only for one fish (fish 2) was the maximum distance recorded away from tagging location recorded immediately after tagging (Table III).

HABITAT USE

The number of fish positions recorded over different habitats was significantly different from the total area of each habitat available in the study area at West Island ($\chi^2=160$, d.f.$=4$, $P<0{\cdot}001$). Fish were recorded disproportionately more often over *Posidonia* seagrass than would be expected based on the area of that habitat, and less often over *Amphibolis* seagrass and boulders covered with brown algae (Fig. 4). Fish occurred over kelp covered reef and bare sand about as frequently as would be expected based on area.

TIME OF DAY

Only fish 3 showed a significant difference in distance moved at different times of day (Table IV). This fish moved further in the day than at night and an intermediate distance on the transitions between night and day. The ratio of habitats occupied did not differ between day and night for any fish (χ^2 test, $P>0{\cdot}05$ for each fish), nor when data from all fish were combined (χ^2 test, $P=0{\cdot}5$).

DISCUSSION

In the 2 to 10 day periods over which leafy seadragons were tracked in this study, all except one fish remained in well-defined home ranges. The sizes of home ranges were relatively homogeneous, even at different islands and in different seasons. The exceptional fish (fish 6) behaved as a transient. The sizes

Table II. Summary of leafy seadragon tracking and movement. Home range areas are for minimum convex polygon method. S, summer; W, winter. Average velocity assumes straight line movement between recordings, and excludes recordings where no movement was detected

Fish number	1	2	3	4	5	6	7	8	9
Period of tracking (days)	7	2	8	8	9	8	2	10	2
Season	S	S	S	S	W	W	S	S	S
Number of recordings	23	6	55	41	24	20	5	22	4
Home range area (ha)	0·03	0·18	0·64	1·38	0·74	88·14	1·74	0·91	4·71
Cumulative distance travelled (m)	221	225	819	943	712	5163	767	692	669
Greatest linear movement between consecutive recordings (m)	104	91	129	152	198	881	510	93	328
Time between recordings of greatest linear movement (h)	5	2	3	43	6	64	17	9	18
Number of recordings with no movement since previous recording	17	2	39	24	13	0	0	7	0
Longest period without moving (h)	68	13	18	24	43	0	0	51	0
Number of recordings during longest period without moving	7	1	6	7	4	0	0	3	0
Average velocity (m h^{-1})	2·0	4·3	5·1	5·7	5·6	44·0	16·6	3·6	13·8
Maximum velocity (m h^{-1})	21·2	14·2	43·0	37·8	37·2	145·6	29·6	8·9	19·3

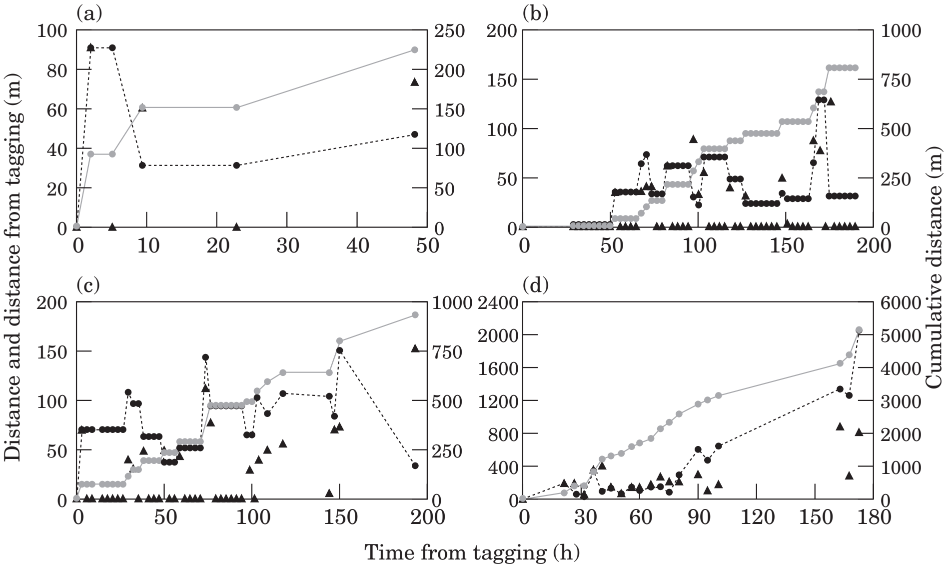

FIG. 3. Movement patterns (▲, distance; – – – distance from tagging; —— cumulative distance) for fish (a) 2, (b) 3, (c) 4, and (d) 6. Distance, the straight line distance moved between successive observations.

TABLE III. Comparison of distances moved at initial recording after tagging with subsequent recordings

Fish number	Distance moved per observation interval (m)			Distance from tagging location (m)		
	Initial Mean	Post initial Mean	Post initial Maximum	Initial	Post initial Mean	Post initial Maximum
1	0	11	104	0	18	81
2	91	33	74	91	51	91
3	0	16	129	0	41	131
4	70	22	152	70	77	152
5	55	30	198	55	66	216
6	188	276	881	188	442	2049
7	57	237	510	57	183	387
8	40	32	72	40	45	53
9	328	170	290	328	387	490

of the home ranges measured for leafy seadragons were much greater than for tropical reef fishes of similar sizes, the movement of which tends to be limited by reef patches and strong intra- and inter-specific competition for space (Eristhee & Oxenford, 2001). Using the two formulae presented by Kramer & Chapman (1999) relating total fish length (L_T) to maximum home range length and home range area, leafy seadragons had longer home ranges for their body length than expected for tropical reef fishes (mean 245 m compared to the expected 169 m), and larger home range areas than expected (mean 1·29 ha compared to the expected 0·19 ha) (unpubl. data). This may be partly explained by leafy

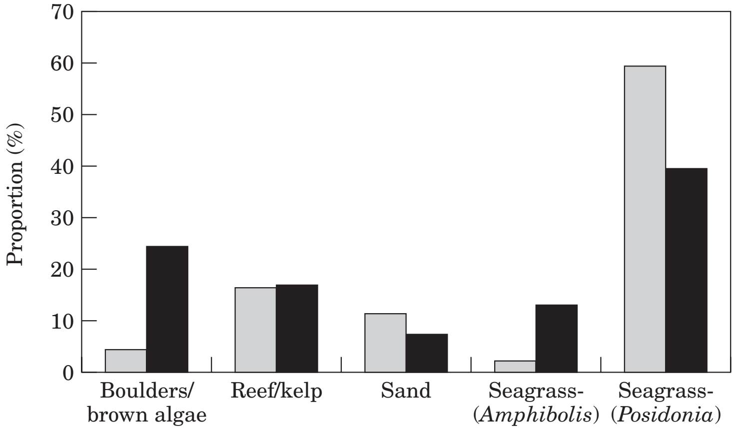

FIG. 4. Habitat use of fish based on the proportions of fish occurrences (☐) and each habitat type available (■).

TABLE IV. Summary of effect of time of day on leafy seadragon movement. The sum of the number of observations is lower than the total number of observations due to the exclusion of recordings with >12 h between them. Transition means movement between two recordings either side of the light–dark boundary

Fish number	Number of observations Day	Night	Transition	Mean distance travelled (m) Day	Night	Transition	*P* (ANOVA)
1	8	2	8	14	0	11	0·880
2	2	—	2	46	—	30	0·800
3	19	20	14	26	3	18	0·045*
4	20	10	8	28	12	14	0·346
5	8	2	9	69	0	9	0·069
6	7	2	7	185	256	283	0·630
7	—	—	2	—	—	91	—
8	5	1	9	28	54	39	0·696
9	1	—	—	51	—	—	—

seadragons using multiple habitats, as fishes with home ranges over two habitats tend to have larger home ranges than those over a single habitat (Kramer & Chapman, 1999).

There appeared to be no differences in movement patterns of leafy seadragons between summer and winter observations, although this was not tested statistically because there were too few winter observations. Leafy seadragons were found in the study area in both seasons, however, and do not show the seasonal migration from inshore to offshore waters described in some other species (Lazzari & Able, 1990). Mating of leafy seadragons has never been observed, but breeding occurs over summer months, and individuals are thought to reach adulthood after 1–2 years. More detailed work focussing on movement patterns of fish around mating times would help to determine how the genders interact and how this affects movement.

The pattern of punctuated movement shown by leafy seadragons has been described in other marine fishes tracked ultrasonically, and is often associated with day-night movements. Ultrasonically tracked sole *Solea vulgaris* Quensel, red morwong *Cheilodactylus fuscus* Castelnau, whitesaddle goatfish *Parapeneus porphyreus* Jenkins and Bermuda chub *Kyphosus sectatrix* (L.) showed greater movement at night than day (Lagardere *et al*., 1988; Lowry & Suthers, 1998; Meyer *et al*., 2000; Eristhee & Oxenford, 2001), while coral trout *Plectropomus leopardus* (Lacepède) showed greater movement during the day (Zeller, 1997). The pattern of punctuated movement shown by leafy seadragons is not explained by time of day; some fish moved more during the day while others moved more at night. Diel patterns of movement are often related to predator avoidance. Leafy seadragons may be so well camouflaged that they do not need to hide or remain still during the day.

Some marine fishes, especially those with little swimming ability, move with tidal flow as a means of conserving energy (Szedlmayer & Able, 1993; Almeida, 1996). Tidal currents around West and Wright Islands are very weak, and there is in any case no indication of tidal periodicity in seadragon movement. Rather, it is non-tidal water currents around the islands that are likely to affect fish movements. The pattern of punctuated movement in leafy seadragons might be a result of such currents, either when fish actively use the currents to move or are swept passively by the currents when they are too strong to swim against. The currents around the islands have never been measured, however, and the lack of consistency in periods of movement and inactivity by leafy seadragons means that currents would have to be measured at frequent, short intervals to detect relationships between currents and fish movements. Leafy seadragons are sometimes found within the vegetation canopy but at other times are above it, and any influence of current might be found to interact with the vertical position of the fish.

The exceptionally large movements by fish 6 resemble those of a transient individual moving through the area without a well-defined home range. Whilst it has been shown here that home ranges of different individuals at the study site overlap, and no observations were made of territorial defence by leafy seadragons, the possibility remains that fish 6 was moving through the study site looking for unoccupied habitat but encountering negative interactions with other seadragons. Alternatively, the tracking period for this fish may have occurred while it was relocating its home range (Kramer & Chapman, 1999). Still another possibility is that fish 6 simply had a much larger home range than other individuals. There is no way of testing these different explanations with the current data, but the exceptional movement patterns of this one individual demonstrate an alternative pattern to that of other fish, and one that may be important in rates of dispersal of this species.

The tagging of leafy seadragons did not appear to affect movement; neither the comparison of movements immediately after tagging with those later in the tracking period nor inspections of graphs displaying movements over time gave any indication of different movement patterns after tagging. Tagging effects have been shown in other marine fishes, especially when the tag has been surgically attached (Szedlmayer & Able, 1993; Lowry & Suthers, 1998; Zeller, 1998; Meyer *et al*., 2000; Eristhee & Oxenford, 2001). Although the possibility remains that small tagging effects in leafy seadragons went undetected, there was no evidence of damage to fish upon removal of transmitters, and the effects of tagging may be less in this species because of the method of attaching to bony appendages away from the body of the fish.

Leafy seadragons spent more time over *Posidonia* seagrass and less over *Amphibolis* than expected based simply on the area of habitat available. This might result directly from habitat selection by leafy seadragons or indirectly from fish positioning themselves in response to other factors such as water movement or prey abundance. The more protected water in the lee of West Island, for example, where leafy seadragons spent much of their time, coincides mainly with *Posidonia* seagrass habitat. The presence and type of vegetation might also affect the success of leafy seadragons in capturing mysid shrimp, their main prey (Kuiter, 2000). Flynn & Ritz (1999) showed using synthetic seagrass that the large mysid swarms occurring in unvegetated habitat become dispersed into smaller groups over vegetation. They demonstrated that the capture rate of mysid prey by seahorses increased in vegetated habitats, and was different even between different densities of seagrass. Leafy seadragons may have higher success rates of prey capture over vegetation but near unvegetated areas where large mysid swarms occur. Studies of prey availability would be a useful start in determining the reasons underlying leafy seadragon distribution.

Ultrasonic tracking of adult leafy seadragons has provided for the first time reliable measures of movement and habitat use. These results are immediately applicable in current attempts to design a marine protected area in Encounter Bay, which includes West and Wright Islands. Only further telemetry studies at other sites can confirm whether the patterns obtained here are representative of elsewhere. Gender and pregnancy status might affect movement and these should be incorporated into future work if possible. The other important information needed to ensure sensible management of this species and its habitat is the degree of movement in the juvenile phase. Even in this relatively large species of syngnathid fish, juveniles are too small to be tracked ultrasonically. Dispersal of juveniles will perhaps best be calculated using measures of genetic differentiation to estimate historical dispersal. Nevertheless, the sizes of home ranges determined for adults in this study suggest that even marine protected areas on a local scale (1–10 km linear dimension) might be useful in places where leafy seadragons are a key species.

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