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Year-round presence of dugongs in Pumicestone Passage, south-east Queensland, examined in relation to water temperature and seagrass distribution

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Abstract. Pumicestone Passage is a narrow waterway that lies to the north of and adjacent to Moreton Bay, and between mainland Queensland and Bribie Island, Australia. Anecdotal reports have suggested that the Passage is home to dugongs year-round despite winter water temperatures that are known to cause dugongs to migrate elsewhere. To examine the pattern of distribution and abundance of dugongs within the passage on a year-round basis, eight years of sightings data collected by a charter boat operator were examined. Dedicated aerial surveys of the passage were also conducted at two-monthly intervals over two years, and more intensively over a single winter. Dugong sightings were examined in relation to water temperatures and seagrass prevalence. The number of dugongs sighted in the area on any one survey varied from 0 to 13. Dugongs were seen in all months of the year and in each of the eight winters, indicating that Pumicestone Passage is used year-round despite winter water temperatures dropping to below 18°C from June to August inclusive and below 16°C in June. All dugong sightings occurred in the southern part of the passage, south of Tripcony Bight. Dugongs were associated with shallows that support *Halophila* and *Halodule* species of seagrass, food species that are favoured elsewhere in their range. The northern part of the passage also supports seagrasses that are eaten by dugongs and has water temperature ranges that are not appreciably different to those of the southern passage. However, the narrow channels and very shallow nature of the northern passage provides little to no deep-water refugia for dugongs and the seagrass beds are less extensive. This study suggests that southern Pumicestone Passage requires protection concomitant with it being a year-round refuge of the vulnerable dugong.

Introduction

One of the largest concentrations of dugongs in south-east Queensland waters is found in Moreton Bay (Preen 1993; Lanyon *et al*. 2002; Lanyon 2003). Aerial surveys of Moreton Bay in 1995–96 indicated a year-round population of 850–1000 dugongs (Lanyon and Morrice 1997; Lanyon 2003). Preliminary results from an ongoing mark–recapture program suggest that the population in 2004 was larger than 750 dugongs (J. M. Lanyon, unpublished data). More than 95% of this population is concentrated in the eastern part of the bay, over the extensive seagrass beds of the Amity and Moreton Banks and through the intervening Rous Channel (Preen 1993; Lanyon 2003). These seagrass beds lie 8–10 km from the developed western shores of the bay and Brisbane city. During summer, dugongs remain closely associated with these seagrass banks. In winter, when water temperatures in the eastern bay fall below ~18–19°C, dugongs undertake intermittent and short-term movements between these banks and the oceanic waters of nearby South Passage, where water temperatures may be 4–5°C higher than in the bay (Preen 1993; Lanyon 2003). At these higher latitudes of the dugong's range, including Moreton and Shark Bays, water temperature is thought to be a major determinant of distribution (Anderson 1986, 1994; Preen 1993; Bryden *et al*. 1998).

Historically, dugongs were probably found in significant numbers in the western inshore regions of Moreton Bay (Flinders 1814; Thomson 1967; Peterken 1994). However, increased boating traffic (Welsby 1931) and loss of suitable feeding grounds through coastal development (Preen 1993; Peterken 1994) is thought to have led to an easterly contraction of their range. Although dugongs are still found in the western and southern parts, their distribution in these areas is patchy and sporadic and numbers are generally low (i.e. 2–5% of the total population) (Lanyon 2003). One of the few inshore areas that still support dugongs is Pumicestone Passage at the northern end of Moreton Bay, a narrow and shallow waterway that runs between Bribie Island and mainland Queensland.

The first documented account of dugongs in Pumicestone Passage was made by Matthew Flinders on 25 July 1799 (Collins 1804) as he navigated up the passage to the Glasshouse Mountains. Further written records of dugongs in the region were in relation to the local dugong fishery that

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operated sporadically out of Bribie Island from 1877 to the early 1900s (Thomson 1967; Petrie 1975). This fishery eventually closed because of unsustainability in the face of decreasing dugong numbers (Peterken 1994). According to anecdotal reports from local people, the number of dugongs in the Pumicestone Passage region has continued to fall since the cessation of commercial harvesting so that the numbers of dugongs regularly using Pumicestone Passage today are significantly fewer than 50 years ago.

Local residents have reported that small numbers of dugongs are present in Pumicestone Passage on a year-round basis. Since the annual minimum average water temperature in the Passage drops as low as 15.8°C (QDEH 1993), we might expect dugongs to move out of the area in the colder winter months, as they do elsewhere in Moreton Bay and elsewhere in Australian waters (e.g. Anderson 1986, 1994; Marsh *et al*. 1994).

This paper reports on the results of a series of boat-based and aerial surveys of Pumicestone Passage to determine whether dugongs were present in the passage year-round. The distribution and abundance of dugongs in the passage were examined in relation to the distribution of seagrasses and surface water temperatures.

Methods

Study site

Pumicestone Passage is located in south-east Queensland, just north of Brisbane (between 153°02′ and 153°10′E, and 26°48′30″ and 27°06′00″S) on the east coast of Australia. The passage is a shallow (to 7-m depth), 45-km-long channel that runs roughly north–south between mainland Queensland and Bribie Island (Fig. 1). The southern end of the passage opens into Moreton Bay and the northern end into the Sunshine Coast just south of Caloundra. The passage is 1–5 km wide and covers a total area of ~63 km^2. About 80% of the passage is less than 2 m deep. This narrow waterway is flanked by extensive intertidal mudflats and seagrass beds, and is fringed by mangrove along most of its length. At the southern end of the passage are the towns of Bongaree and Toorbul with fringing coastal development, and a bridge from the island to the mainland. These towns support some recreational boating. The remainder of the passage remains relatively undeveloped and is accessible only by water.

Boat-based surveys

Dugong sightings were collected by observer(s) aboard the 'Ferryman' charter vessel over an eight-year period from 1 March 1993 to 29 December 2000. This vessel is a 14-m catamaran with a beam of 4.3 m that operates a tourist charter service within Pumicestone Passage. Sightings of dugongs were recorded by one key observer, the skipper, from the bow of the boat. This observer scanned the front and either side of the vessel to a horizontal distance of 25–30 m while the boat was in motion. Additional observers were sometimes present. In all, 1056 trips were undertaken in this eight-year period (i.e. at a mean frequency of 2.56 trips per week), of which 984 trips had full datasets that are included in this analysis.

Each charter trip commenced at Bellara (just north of the main bridge between the mainland and Bribie Island) in southern Pumicestone Passage and completed a north–south circuit. Three categories of boat trip, differing in duration and length, were made: (1) Bellara to north of Poverty Creek (Type 1: 3-h duration, 14-km round trip), (2) Bellara to the north of Thooloora Island (Type 2: 4 h, 22 km), (3) Bellara to The Skids (Type 3: 6 h, 34 km) (Fig. 2). All trips followed the main boating channels, but different routes were taken on the north-bound and south-bound trips. Although the same basic route was taken for each of the three types of trip, minor variations to the route sometimes occurred depending on weather, water conditions and tides. In addition, small detours sometimes resulted on each trip type when dugongs and other marine animals (e.g. dolphins) were sighted just off course. Each trip commenced at mid-morning (1000 hours) of each day.

Data recorded on each charter trip included number of dugongs per group, number of dugong calves (identified as a small individual accompanying an adult), map grid reference for dugong sightings (on a 0.5- by 0.5-km grid), wind speed, Beaufort sea state, and general weather conditions. Differences in the numbers and densities of dugongs between boat-trip types and months were tested using analysis of variance with and without Beaufort sea state as a covariate. Sightings data were log-transformed (ln(x)) to stablise the variance (Draper and Smith 1981). A map summarising dugong distribution and cumulative sightings was produced using Arcview 3.2® GIS software.

Aerial surveys

Two types of aerial survey were conducted: (1) aerial surveys that were part of a dugong monitoring program for Moreton Bay and covered only the southern part of Pumicestone Passage, and (2) dedicated surveys of the entire length of the Passage.

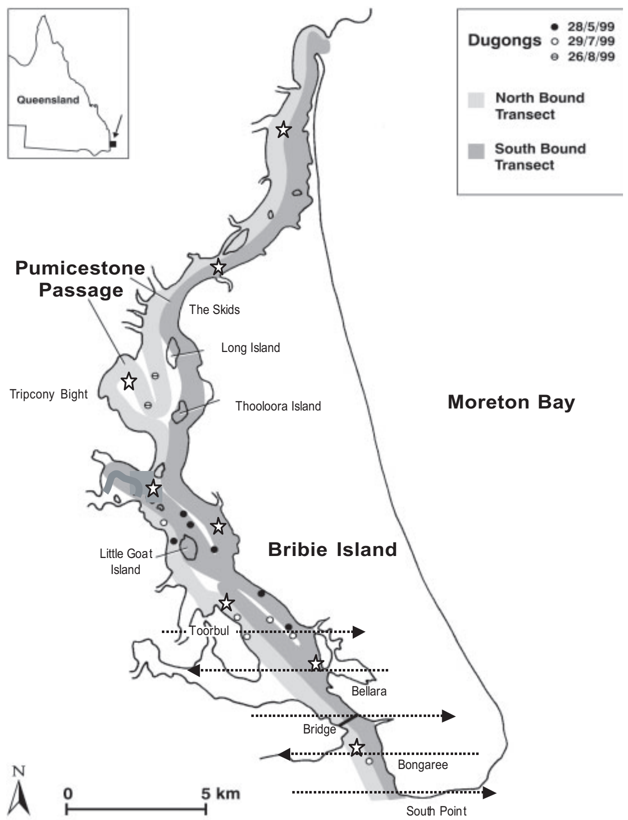

Fig. 1. Map of Pumicestone Passage showing aerial-survey transects for (i) dedicated surveys of the entire passage in winter, and (ii) surveys of the southern passage year-round. North- and south-bound winter aerial-survey transects are indicated by shaded grey bands. Dugongs sighted during the winter surveys are indicated by the symbols in the legend. East–west transects of the southern passage are indicated by dotted lines with the arrow heads showing direction of travel. Positions of water-temperature monitoring stations are indicated by stars.

Aerial surveys of the southern part of the Passage (north to Toorbul: Fig. 1) were conducted at high tide in mid-morning on 11 occasions during 1995–96, at roughly two-monthly intervals. These surveys formed part of a broader monitoring program for dugongs in Moreton Bay (Lanyon and Morrice 1997; Lanyon 2003). The surveys, comprising five east–west transects (Fig. 1), were flown at an altitude of 274 m and only when weather conditions were excellent (fair weather, cloud cover ≤4 oktas, winds ≤10–15 kn and a Beaufort sea-state ≤2). The methodology for these surveys is summarised in Lanyon (2003). Six of these 11 aerial surveys coincided with Ferryman 'boat surveys' of the passage.

Dedicated aerial surveys of the entire length of Pumicestone Passage were conducted on three mornings during winter 1999: 28 May, 29 July and 26 August. The entire passage from South Point, south Bribie Island, to the northern Bribie Island spit just south of Caloundra were covered by roughly north–south transects running along the length of the passage (Fig. 1). Each survey comprised ~2-h flying time and was flown at high tide when dugongs would most likely be over the shallow intertidal areas. Surveys were conducted only when weather conditions were excellent. Surveys were flown in mid-morning to avoid glare and to take advantage of generally light winds. Each of these three aerial surveys was timed to coincide with Ferryman 'boat surveys' of the Passage.

These surveys used a different methodology to other dugong surveys (e.g. Marsh 1995; Lanyon 2003) because of the nature of the area to be surveyed. Pumicestone Passage is a long narrow passage where a census count was attempted instead of sampling via linear strip transects. A four-seater Cessna 182 high-wing aircraft was flown at an altitude of 274 m at a constant ground speed of <185 km h^{-1} (90 kn). A line transect of infinite width (but in reality up to ~500 m) was surveyed from either side of the aircraft. The survey crew comprised the pilot-navigator, a tandem team of two observers on the starboard side (survey leader in front) and an observer behind the pilot on the port side. All observers were experienced in aerial survey of dugongs.

Transects were navigated so that the starboard observers scrutinised a strip of water from the extreme high-water mark (which fell just in the observers' field of view under the plane) out towards the centre of the passage. The port observer checked the mouths of creeks flowing into the passage. In narrow areas of the passage, one of each of a north- and south-bound transect resulted in complete observer coverage of the water. In wider areas of the passage or where islands occurred, extra transects were flown to cover the entire water area (Fig. 1). Observers recorded, in order of priority, the numbers of dugongs (including calves), dolphins, and sea turtles as per Marsh and Saalfield (1989) and Marsh *et al*. (1994). The survey leader recorded all sightings directly onto a large-scale navigational chart.

Dugong counts from both types of aerial survey were uncorrected raw counts because correction factors have not been developed for these shallow, murky water conditions. These counts were likely to be underestimates because an (unknown) number of animals was unavailable to observers owing to water turbidity.

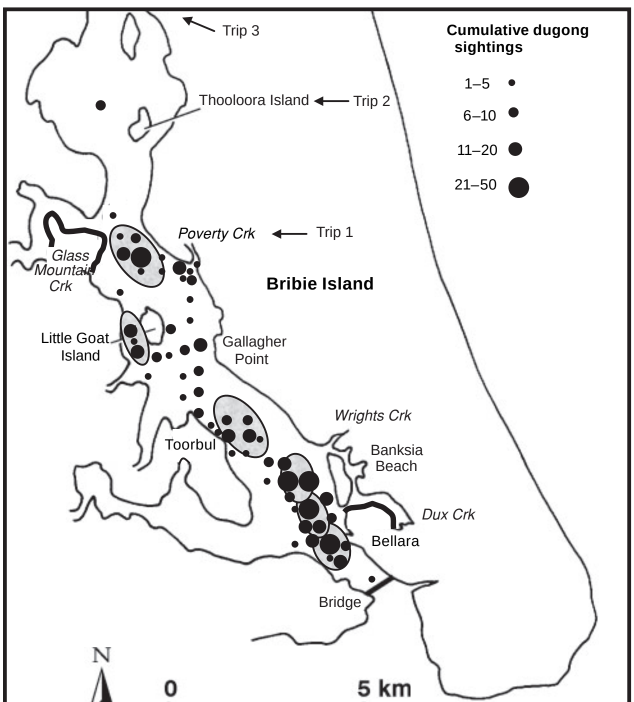

Fig. 2. Map of southern Pumicestone Passage showing cumulative dugong sightings from eight years of boat surveys. Arrows indicate the northern limits of boat trip Types 1–3. Major seagrass beds that are associated with dugong 'hotspots' and are described in the text are indicated by shaded areas.

Seagrass distribution

A seagrass survey was conducted in mid-winter (24 June) towards the end of this study to map seagrasses present in areas that were most frequented by dugongs, and to coincide with the period when abundances of the dugong's preferred species were likely to be lowest (Lanyon and Marsh 1995). Within each of these 'dugong areas', seagrass species composition and abundance (percentage cover) were visually assessed along three 10-m-wide transects running across a depth profile. Seagrass community compositions from this survey were compared with seagrass community maps prepared in the late 1980s by the Queensland Department of Primary Industries (Hyland *et al*. 1989).

Water temperature

Surface water (0.2-m depth) temperatures sampled at eight sites along the entire length of Pumicestone Passage at no more than 7-km intervals (Fig. 1) were made available by the Pumicestone Region Coastal Monitoring Program (Preda *et al*. 2000; R. King, unpublished data). These water-temperature sampling sites cover the full latitudinal distribution of dugong sightings in the passage and are coincident with the most frequently used dugong areas (see Results). Water temperatures were recorded at all eight sites on each sampling day, of which there were at least 2–3 per month. Temperature data were collected for three years from March 1997 through to April 2000. Water temperatures for these sites along the passage were not available in the period March 1993 to March 1997. However, Bureau of Meteorology records for this region indicate that mean, minimum and maximum daily winter air temperatures in these years were not appreciably different from those of the three sampled years (Bureau of Meteorology, personal communication).

Results

Boat-based surveys

Boat trips

The number of charter trips per year ranged from 96 to 144 (mean 123 ± 5). There was no significant difference in total number of trips among years (F = 0.85, d.f. = 7,200, P = 0.543), nor among months of year (F = 0.615, d.f. = 11,276, P = 0.815) so that boat-survey effort was evenly distributed through time. There was a highly significant difference in frequency of trip type over the eight-year period (F = 61.56, d.f. = 2,581, P < 0.001). The most common trip type was the medium-length 22-km round-trip (Type 2): 552 out of 984 (56%). The most infrequent (n = 153, 16%) was the longer (6 h, 34 km) trip (Type 3). Trip Type 1 (14 km) accounted for 279 (28%) of trips. There were no consistent differences among years or months/seasons (years pooled) (Fig. 3) in terms of frequency of different types of boat trip undertaken.

Dugong sightings

Over an eight-year period, a total of 519 dugong sightings was made during 984 charter boat trips (Fig. 2): 497 individual sightings were of adult dugongs, and 22 sightings were made of calves. Dugongs were sighted on 26% of trips (260 of the 984 trips).

The number of dugongs sighted on any one boat trip ranged between 0 and 13. The number seen per trip type varied between 0 and 13 for the shorter trip (Type 1), 0–7 for the medium trip (Type 2) and 0–3 for the longest trip (Type 3). There were significantly fewer dugong sightings per individual trip on the longest trip (Type 3), i.e. 0.27 ± 0.05 dugongs per trip, compared with 0.58 ± 0.04 on Type 2 and 0.49 ± 0.07 dugongs on Type 1 (month × trip type interaction, $F = 0.797$, d.f. = 22,971, $P = 0.73$, transformation ln(Y); trip-type effect: $F = 0.4923$, d.f. = 2,971, $P = 0.007$; month effect $F = 1.251$, d.f. = 11,971, $P = 0.248$). Similarly, when only those trips on which dugongs were sighted were considered, there were fewer dugongs seen on trip Type 3 than on the shorter trips (Fig. 4). This trend of fewer dugongs seen on the longest trip was unexpected since the longest trip also traversed the southern areas covered by the shorter trips. Possible reasons for this trend include either (1) sustained observer effort was lower in this longer trip, (2) sightings were affected by rate of travel, which increased with trip length (e.g. mean travel rate of 4.66 km h^{-1} for trip Type 1 compared with 5.66 km h^{-1} for Type 3), and/or (3) dugongs were present in lower densities in the more northern areas of the passage.

Sightings were also examined in terms of number of dugongs per kilometre travelled per trip in an attempt to reduce the bias of trip duration and trip length. A highly significant trend of decreasing 'density of sighting' with increasing trip length was apparent ($F = 8148.61$, d.f. = 1,2034, $P < 0.001$). Fewer dugong sightings were recorded per kilometre (0.008 ± 0.002) on the longer trip (Type 3) than on Type 2 (0.026 ± 0.002) and Type 1 (0.032 ± 0.004). These differences among trip types are probably due to differences in observer effort and/or regional differences in dugong densities.

Dugongs were sighted in all months of the year, and in most months of each year. Dugongs were sighted in 87 (92.5%) of the 94 months. The longest period over the eight years in which dugongs were not seen in the passage was 70 days (18 March 1994 until 28 May 1994). On four other occasions, dugongs were not recorded over one entire calendar month: July and December 1996, June and November 1999. There was no significant difference in mean number of dugongs sighted per trip per month ($F = 1.251$, d.f. = 11,71, $P = 0.248$, transformation ln(Y)) (Fig. 5), suggesting that dugongs were equally likely to be found in winter months as in warmer (summer) months. The probability of sighting a dugong on an individual boat trip was not significantly affected by Beaufort sea state (Beaufort as covariate in two-way ANCOVA: month × trip type interaction, $F = 0.619$, d.f. = 22,970, $P = 0.913$, transfomation ln(Y); trip type effect, $F = 4.569$, d.f. = 2,970, $P = 0.01$; month effect, $F = 1.149$, d.f. = 11,970, $P = 0.31$).

In all, 284 groups (a group being defined as ≥1 dugong) were sighted over the eight-year period. Group size varied between 1 and 13. Only one herd (defined as ≥10 dugongs) was sighted (of 13 animals on 8 March 1995), comprising 0.35% of total number of groups. Mean group size for all trips combined was 1.82 ± 0.07. There was no significant difference in size of dugong groups sighted on different trip types ($F = 0.002$, d.f. = 1,566, $P = 0.964$): trip Type 1 had a mean group size of 1.857 ± 0.18 (range 1–13); Type 2: 1.824 ± 0.077 (range 1–7); Type 3: 1.68 ± 0.138 (range 1–3). Modal group size was always one.

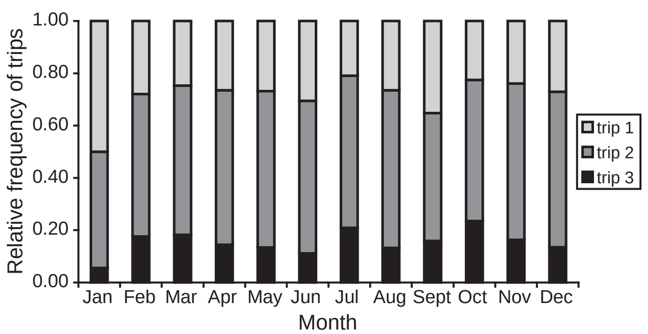

Fig. 3. Frequency distribution of boat trips of Types 1–3 conducted per month (8 years' data pooled).

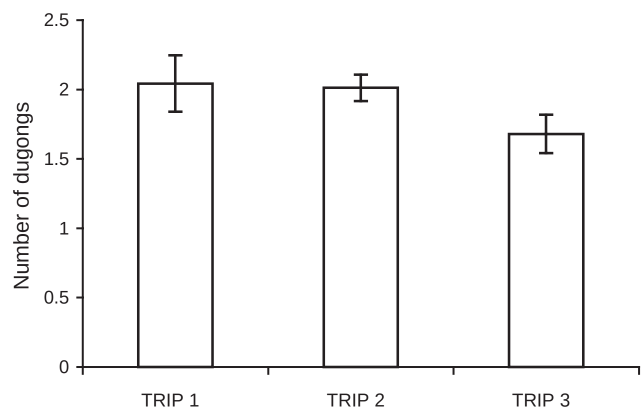

Fig. 4. Mean (±s.e.) number of dugongs sighted per boat trip Types 1–3, for trips on which dugongs were seen.

Twenty-two sightings of calves were made over 22 trips, i.e. the maximum number of calves sighted during any one trip was one. Similarly, the maximum number of calves in any one group was also one. Calves were sighted on all trip types: 7 sightings on trip Type 1, 13 on Type 2 and 2 on Type 3. In 50% of calf sightings, calves were with one adult animal; at other times they occurred within groups of up to five animals (Fig. 6). In total, 10% of all sightings of pairs of dugongs were adult–calf pairs, presumably cow–calf. Sightings of calves were made in seven out of the eight years (i.e. in all except 1995). Calves were sighted in all seasons: 5 in each of summer and autumn, 4 in winter and 8 in spring. All calves were sighted within the southern part of the passage, south of the mouth of Glass Mountain Creek.

Dugong habitat

All dugongs were sighted in the southern half of Pumicestone Passage (Figs 1, 2). All but one of the dugong sightings were made within 14 km of Bellara, i.e. within the area traversed by the shortest boat trip: Type 1. In fact, all dugong sightings recorded during trip Type 3 (longest trip) fell within the area covered by trip Type 1, except one sighting which was in the more northern trip Type 2 zone. No dugongs were seen in the most northern area covered by trip Type 3 only (i.e. more than 22 km north of Bellara). The most northerly sighting occurred in Tripcony Bight, in the shallow channel just north of Thooloora Island.

Individual dugong sightings were distributed at intervals between Bongaree Jetty in the south, to Thooloora Island in the north. When sightings were pooled across years, several areas showed up as more frequently supporting dugongs. These 'hotspots' included (from south to north) seagrass beds located (1) mid-passage offshore from Banksia Beach to northern Bellara (includes (from south to north) seagrass beds off northern Bellara, off the mouth of Dux Creek and off Wright's Creek): 223 sightings, (2) mid-passage east of Toorbul: 136 sightings, (3) fringing southern and western Little Goat Island: 42 sightings, and (4) mid-passage between Poverty and Glass Mountain Creeks: 51 sightings.

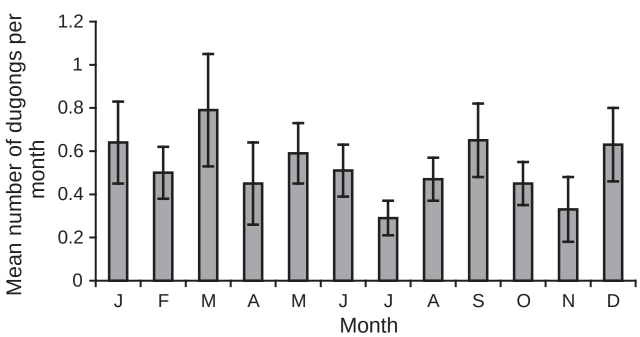

Fig. 5. Mean (±s.e.) number of dugongs sighted per month during eight years of boat surveys of Pumicestone Passage.

Aerial surveys

Southern Pumicestone Passage: year-round surveys

During the 11 aerial surveys, one (five surveys) to two dugongs (one survey) were sighted in the southern Passage. All were solitary. Two sightings occurred in spring, two in summer, two in autumn and one in winter.

The three single dugongs sighted on each of three separate surveys in 1995 (April, May and December) were all found in the same position, just south of the main bridge at Bellara. The three sightings in 1996 occurred on the seagrass bed close to Dux Creek, west of Banksia Beach (February, 2 dugongs; August, 1 dugong), and on the bed east of Toorbul (October, 1 dugong), i.e. hotspots (1) and (2) from boat surveys (see above).

On 6 of the 11 days on which these aerial surveys were conducted, the Ferryman charter boat conducted a Type 2 trip within 24 h so that boat and aerial surveys overlapped in space and time. On two days the single dugong spotted by one survey type and not the other fell just outside the other's survey range. On two days, neither survey sighted a dugong. On one day, the boat found one dugong that the plane observers missed and *vice versa* on the other day.

Entire Pumicestone Passage: winter surveys

Dugongs were sighted in Pumicestone Passage on each of the three winter surveys: six dugongs on each of 28 May and 29 July and two dugongs on 26 August 1999: a mean of 4.66 ± 1.33 dugongs per survey. All sightings were of solitary animals.

All sightings occurred in the southern half of Pumicestone Passage, between Tripcony Bight in the north and Bongaree in the south (Fig. 1). On 28 May, sightings occurred west of Banksia Beach, around little Goat Island and west of Poverty Creek. On 29 July, sightings occurred at Bongaree, west of Banksia Beach, inshore at Toorbul and north of Little Goat Island. On 26 August two dugongs were sighted in Tripcony Bight.

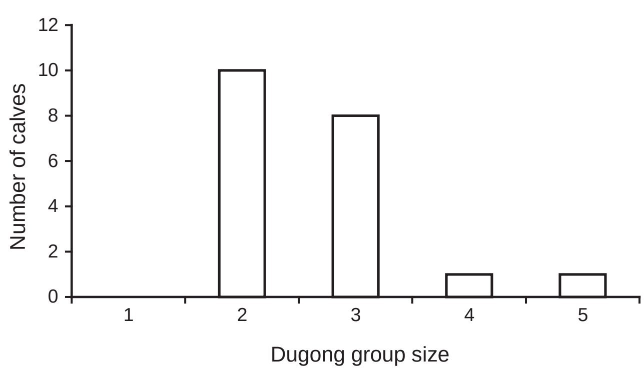

Fig. 6. Number of dugong calves and the sizes of groups (2–5) in which they occurred, sighted within Pumicestone Passage during boat surveys.

On each of the three days on which these aerial surveys were conducted, the Ferryman charter boat conducted a Type 2 trip (Bellara to north of Thooloora Island/Tripcony Bight). Observers on the boat did not report any dugong sightings on these dates, despite the boat visiting the areas in which dugongs were sighted from the air.

Seagrass distribution

With the exception of the dugong sightings made in the immediate vicinity of Bellara Bridge, all sightings were associated with, or close to, a seagrass bed. Each of the seagrass beds near which dugongs were sighted lies within 1.2 m of lowest astronomical tide datum. Deeper areas between them appeared to be unvegetated (i.e. bare mud). Seagrass composition at each of these beds followed a distinct pattern of depth zonation.

Banksia Beach to northern Bellara. This area comprised an elongate offshore heterogenous seagrass meadow. The upper reaches of the bed comprised a medium to dense region of *Zostera capricorni* and/or *Halodule uninervis* and *H. pinifolia* (25–80% cover; patches exposed at low tide) extending down to mixed lighter beds of *Z. capricorni* and *Halophila ovalis* (10–40% cover). Deeper and adjacent to this band were sparse *H. ovalis* and denser *H. pinifolia* (10–60% cover). The deeper subtidal areas comprised sparse *H. ovalis* (up to 20% cover) grading into bare mud.

East of Toorbul. The upper reaches of this offshore bed comprised medium to dense *Z. capricorni* (30–60% cover). Adjacent to this area was a mixed band of patchy *Z. capricorni*, *H. ovalis* and/or *H. uninervis* (combined 10–50% cover). Sparse subtidal beds of *H. ovalis* (up to 20% cover) and *Halophila decipiens* (<5% cover) graded to bare mud.

South and west Little Goat Island. Little Goat Island supported narrow intertidal seagrass beds between the mangrove and mud supralittoral region and the muddy tidal channel. The upper reaches of the bed comprise patchy and often dense *Z. capricorni* (20–80% cover). A sparser mixed bed of *Z. capricorni* and *H. ovalis* was found lower down in the intertidal region and was replaced by sparse *H. ovalis* (with possibly some *H. ovata*), *H. pinifolia* with, less frequently, *H. decipiens* on the outer edge of the banks (combined <20% cover).

Between Poverty and Glass Mountain Creeks. This seagrass bed lying in the middle of the passage had extensive upper bands of patchy dense *Z. capricorni* (20–90% cover). The lower zone comprised lighter and patchy *Z. capricorni* and *H. ovalis*, followed by an outer patchy 'ribbon' of *H. uninervis* (up to 70% cover) and *H. ovalis* (up to 20% cover). Patchy sparse *H. ovalis* (up to 15% cover) graded down into bare mud.

Water temperature

Over the three years 1997 to 1999 inclusive, surface water temperatures ranged from a recorded daytime minimum of 15.4°C in winter (June 1999) to 30.8°C in summer (January 1998). Mean monthly water temperatures were highest in January of each year and lowest in June and/or July (Fig. 7). Yearly variation of temperature followed a bimodal distribution, with peaks in January and November. Mean monthly water temperatures of 18°C and below were measured at each of the eight temperature stations in June and July of each year, and at six sites in August. Winter temperatures of <16°C were recorded in at least six of the eight sites in June of each year. The other two sites had minimum temperatures of 16.0–16.4°C. There was no difference in water temperature at sites along the length of the passage (F = 0.474, d.f. = 7,354, P = 0.853).

Discussion

Pumicestone Passage is one of the few areas in the Moreton Bay region, apart from the eastern banks, that still supports more than one or two dugongs. The number of individual dugongs sighted in Pumicestone Passage at any one time varied between 0 and 13, although most sightings were of up to six individuals. This agrees with previous observations of small groups of up to 12 dugongs in the central sections of the passage (QDEH 1993). The greatest numbers of dugongs sighted at any one time in this study were made during the frequent boat surveys but sighting success was highly variable so that mean number of dugongs sighted at any one time was generally low. This high variability in number of dugongs sighted was most likely due to a combination of factors including availability of dugongs to the observers (i.e. number of dugongs present in the passage and their locations relative to the survey vessel), dugong sightability (due to water turbidity, position of dugong in the water column), weather conditions and observer error and effort. Further, the number of dugongs sighted during any one survey was likely to be an underestimate. Dugongs spend >96% of their time underwater with a short (up to 2 s) surface interval when undertaking normal shallow-water feeding dives (J. M. Lanyon, unpublished data). In very muddy waters such as are found in

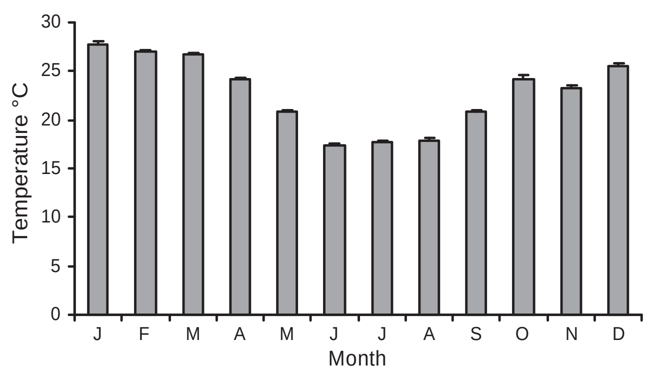

Fig. 7. Mean monthly water temperatures (°C ± s.e.) measured at each of eight water-sampling stations at up to 7-km intervals along Pumicestone Passage.

Pumicestone Passage, dugongs are difficult to see unless they are at the water surface. This gives the observer a narrow window of opportunity in which to spot dugongs. In the case of an aerial survey, a fast-moving aircraft must coincide its transit with the brief surfacing behaviour of a dugong, whereas a boat must be in close proximity, in this case within 30 m, to a surfacing animal.

Each of the survey methods used here recorded small numbers of dugongs in Pumicestone Passage, but there was a low level of agreement between survey methods. Although each of the three winter aerial surveys found dugongs in the southern passage (6, 6 and 2 dugongs respectively), boat surveys run simultaneously and over the same area found none. This result suggests that boat surveys, in particular, may be consistently underestimating the number of dugongs, despite traversing the major dugong areas. On the basis of the maximum number of dugongs sighted in Pumicestone Passage through boat survey, this area would appear to support up to 2% of the dugong population of the Moreton Bay region at any one time, given an overall population estimate of 750 (Lanyon 2003).

Dugongs were seen year-round in Pumicestone Passage, including in the winter months when water temperatures dropped to below 16°C along the length of the passage. These temperatures are lower than the apparent thermal threshold for dugongs (Anderson 1986, 1994; Preen 1993; Allen *et al*. 2004). In other parts of their range, dugongs respond to water temperatures of less than 18–19°C by moving into warmer waters. For example, in Moreton Bay when water temperatures drop to 16–17°C, dugongs on the eastern banks move to oceanic waters that remain 4–5°C warmer than in the bay (Preen 1993). A similar response to falling temperatures has been suggested for the dugongs of Shark Bay, Western Australia (Anderson 1986, 1994). This propensity of at least some dugongs to stay within Pumicestone Passage despite low water temperatures sustained over 2–3 consecutive winter months appears anomalous. These waters are the coldest yet reported in which dugongs have been found. The sporadic sightings of dugongs in more southern waters off the coast of New South Wales have all occurred in the warmer months of the year when water temperatures are 18.9–25°C (Allen *et al*. 2004). The finding from this study suggests the possibility that dugongs in Moreton Bay and elsewhere may not be moving directly in response to falling water temperatures but to some correlate of dropping water temperature such as declining availability of forage.

All dugongs were sighted in the central and southern half of Pumicestone Passage, from Tripcony Bight to the south. Although boat survey effort was most intense in southern Pumicestone Passage, the conspicuous lack of dugongs in the northern half of the passage on both the longest boat trips and the aerial surveys of the entire passage, suggest a southerly concentration. Further, more than 95% of all sightings were of dugongs associated with seagrass beds. Four ‘hotspots’ were identified, from boat and aerial surveys, as those areas where frequencies of dugong sightings were greatest. Not surprisingly, these areas supported shallow seagrass beds comprising species that are favoured by dugongs elsewhere in their range. In particular, the two seagrass beds most frequented by dugongs (offshore from Banksia Beach, and east of Toorbul) supported extensive shallow seagrass communities of *Halophila ovalis* and *Halodule uninervis*, in a species composition and density preferred by dugongs (Preen 1993; Lanyon 2003). The other two ‘hotspots’ of south-west Little Goat Island and Poverty Creek also had seagrass stands of these preferred species but these were less extensive.

The reason for the dugongs’ concentration in southern Pumicestone Passage is unclear. There are 1648 ha of seagrasses in Pumicestone Passage (Hyland *et al*. 1989) and seagrasses are distributed along the entire length of the passage. Although seagrasses were not surveyed in the northern part of the passage for this study, previous surveys (e.g. Hyland *et al*. 1989; Marine Botany Department, University of Queensland, unpublished data) indicate that there is no appreciable difference between northern and southern Pumicestone in terms of seagrass availability. The northern half of the passage supports a large number of seagrass beds that appear to be dominated by *Z. capricorni* and *H. ovalis* (Hyland *et al*. 1989). Since *Z. capricorni* is amongst the less preferred species of the dugong and may be actively avoided in some areas (Preen 1993; Lanyon 2003), the northern seagrass beds may appear to be less than ideal dugong habitat. However, there were appreciable differences between the seagrass communities in the southern passage described by Hyland *et al*. (1989) and those found by this study, suggesting that either (1) temporal (e.g. seasonal) changes in abundance may account for the differences, (2) seagrass beds have changed composition in the intervening period, or (3) that the survey of Hyland *et al*. (1989) did not document the less conspicuous or sparser components of the seagrass community. It is also possible that dugongs do not frequent northern Pumicestone Passage for other reasons. The narrow and shallow nature of the passage may make it difficult to traverse and access fringing seagrass beds. Further, low proximity to deep-water refugia may limit the distribution of dugongs, as has been found elsewhere in Moreton Bay (Preen 1993; Lanyon 2003). Alternatively, if dugongs access Pumicestone Passage from central Moreton Bay (i.e. from the southern entrance), they may merely be waylaid by suitable habitat in the southern section.

Conclusions and recommendations

The southern part of Pumicestone Passage has been identified as habitat for a small number of dugongs year round. Within the passage, dugongs are regularly associated with only a few seagrass beds. Two of the main southern feeding areas lie in the middle of the passage and are flanked by boating channels. In Moreton Bay over the past four years, most anthropogenic mortalities of dugongs have been caused by boat strike: in 2003 alone, nine dugongs were struck in the narrow boating channels in southern Moreton Bay (Moreton Bay Marine Parks staff, personal communication). Dugongs feeding over the shallow seagrass areas of Pumicestone Passage are presumably similarly vulnerable to boating traffic. Further, the lack of deep-water refugia in Pumicestone Passage would suggest that dugongs in the shallow narrow channels are also vulnerable to boat strike.

A further threat to dugongs in Pumicestone Passage is loss of the limited seagrass habitat through coastal development. It is reasonable to suggest that changing shorelines, dredging activities and other coastal development activities could result in altered sedimentation and subsequent changes in seagrass distribution (Walker and McComb 1992; Lee Long *et al*. 2000) within the passage. The southern region of Pumicestone Passage is home to the greatest concentration of dugongs and the most rapid coastal development.

Since only a few areas within Pumicestone Passage support dugongs, measures should be taken to protect and conserve these seagrass meadows through mitigation of threatening processes. Further, careful boating to reduce risk of boat strike should also be encouraged. At this stage it is unclear whether the dugongs of Pumicestone Passage constitute a permanent subgroup separate to the dugongs of the greater Moreton Bay region or if the group comprises transitory assemblages of dugongs. This could be elucidated through expansion of local mark–recapture and genetic-relatedness studies already established elsewhere in the Moreton Bay region (Lanyon *et al*. 2002).

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References

Allen, S., Marsh, H., and Hodgson, A. (2004). Occurrence and conservation of the dugong (*Sirenia*: Dugongidae) in New South Wales. *Proceedings of the Linnean Society of New South Wales* **125**, 211–216.

Anderson, P. K. (1986). Dugongs of Shark Bay, Australia – seasonal migration, water temperature, and forage. *National Geographic Research* **2**, 473–490.

Anderson, P. K. (1994). Dugong distribution, the seagrass *Halophila spinulosa*, and thermal environment in winter in deeper waters of eastern Shark Bay, Western Australia. *Wildlife Research* **21**, 381–388.

Bryden, M., Marsh, H., and Shaughnessy, P. (1998). 'Dugongs, Whales, Dolphins and Seals: a Guide to the Sea Mammals of Australasia.' (Allen and Unwin: Sydney.)

Collins, D. (1804). 'An Account of the English Colony in New South Wales.' (T. Cadell and W. Davies: London.)

Draper, N., and Smith, H. (1981). 'Applied Regression Analysis.' (Wiley: New York.)

Flinders, M. (1814). 'A Voyage to Terra Australis. Volumes I & II.' (G. & W. Nicol: London.)

Hyland, S. J., Courtney, A. J., and Butler, C. T. (1989). Distribution of seagrass in the Moreton region from Coolangatta to Noosa. Queensland Department of Primary Industries Information Series 1989.

Lanyon, J. M. (2003). Distribution and abundance of dugongs in Moreton Bay, Queensland *Wildlife Research* **30**, 397–409. doi:10.1071/WR98082

Lanyon, J. M., and Marsh, H. (1995). Temporal change in the abundance of some tropical intertidal seagrasses. *Aquatic Botany* **49**, 217–237. doi:10.1016/0304-3770(94)00435-O

Lanyon, J. M., and Morrice, M. G. (1997). The distribution and abundance of dugongs in Moreton Bay, south-east Queensland. Report, Queensland Department of Environment, Brisbane.

Lanyon, J. M., Sneath, H. L., Kirkwood, J. M., and Slade, R. W. (2002). Establishing a mark–recapture program for dugongs in Moreton Bay, south-east Queensland. *Australian Mammalogy* **24**, 51–56.

Lee Long, W. J., Coles, R. G., and McKenzie, L. J. (2000). Issues for seagrass conservation management in Queensland. *Pacific Conservation Biology* **5**, 321–328.

Marsh, H. (1995). Fixed-width aerial transects for determining dugong population sizes and distribution patterns. In 'Population Biology of the Florida Manatee'. (Eds T. J. O'Shea, B. Ackerman and H. F. Percival.) US Department of Interior, National Biological Service Technical Report No. 1, pp. 56–62.

Marsh, H., and Saalfield, W. K. (1989). Aerial surveys of sea turtles in the northern Great Barrier Reef Marine Park. *Australian Wildlife Research* **16**, 239–249.

Marsh, H., Prince, R. I. T., Saalfield, W. K., and Shepherd, R. (1994). The distribution and abundance of the dugong in Shark Bay, Western Australia. *Wildlife Research* **21**, 149–161.

Peterken, C. (1994). The dugong fishing industry of south-east Queensland – its rise, demise and consequences. Unpublished Report to Zoology Department, University of Queensland.

Petrie, C. C. (1975). 'Tom Petrie's Reminiscences of early Queensland.' (Lloyd O'Neil: Hawthorn.)

Preda, M., Cox, M. E., and King, R. (2000). Surface water quality in response to rainfall, Pumicestone Passage and tributaries. PASSCON 2000: Pumicestone Passage and Deception Bay Catchment Conference, 22–23 November 2000.

Preen, A. R. (1993). Interactions between dugongs and seagrasses in a subtropical environment. Ph.D. Thesis, James Cook University, Townsville.

QDEN (1993). Pumicestone Passage, its catchment and Bribie Island. Draft Integrated Management Strategy – Main Report, November 1993. Queensland Department of Environment and Heritage, Brisbane.

Thomson, A. K. (1967). 'The collected works of Thomas Welsby. Vols I, II, III.' (Jacaranda Press: Brisbane.)

Walker, D. I., and McComb, A. J. (1992). Seagrass degradation in Australian coastal waters. *Marine Pollution Bulletin* **25**, 191–195. doi:10.1016/0025-326X(92)90224-T

Welsby, T. (1931). 'Sport and pastime in Moreton Bay.' (Simpson Halligan: Brisbane.)

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