The Spatial Ecology of Dugongs: Applications to Conservation Management

Thesis submitted by
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"No seaman ever sailed his black ship past this place without listening to the sweet voice that flow from our lips, and none that listened has not been delighted and gone on a wiser man" [The SIRENS to Odysseus. Homer, Odyssey 12.184]

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ABSTRACT

Dugongs are large primary consumers of seagrass communities, and thereby shape the diversity, structure, and dynamics of these extensive ecosystems. The dugong is listed as vulnerable to extinction at a global scale. Because dugongs are seagrass specialists, understanding the interaction between dugongs and their seagrass habitats is crucial to their conservation. Habitat use by dugongs is beginning to receive greater attention by managers and ecologists, but a spatially-explicit model capable of predicting usage by dugongs based on attributes of those habitats is lacking. Studying the interaction between dugongs and their seagrass food requires knowledge of the movements and diving behaviour of dugongs at scales relevant to both dugongs and managers. Information is needed on dugong spatial patterns, including movement behaviours and habitat use, across domains of scale. Multi-scale approaches to dugong research have not been possible in the past because of the difficulties in observing dugongs directly and the low resolution of telemetric equipment.

My project capitalised on recent technology incorporating accurate GPS technology into tracking equipment to monitor the habitat use of wild animals at very high resolution (<10 m). Advances in geographic information systems (GIS) and spatial modelling enabled habitat selection by satellite-tracked dugongs to be analysed in a high-resolution, spatially explicit manner. I used hierarchical scales of spatial analyses to assess the relative importance of different seagrass meadows and parts of meadows to dugongs at scales that are suitable for informing policy concerning the management of human activities. My central research hypotheses were that: (1) dugongs forage like terrestrial mammalian grazers in that they prefer habitats where their foraging efficiency is greatest and (2) patterns of dugong movements and habitat use across spatial scales are intimately linked to the availability and distribution of quality seagrass forage.

I investigated the mechanisms that produce the large-scale distribution and movement patterns of dugongs by reanalysing the results of historical aerial surveys and satellite tracking conducted by earlier researchers in combination with new data from my GPS telemetry of 20 dugongs in sub-tropical and tropical waters of Queensland and the Northern Territory, Australia. The mean patch size supporting high relative density (> 0.1 dugongs/km^2) of dugongs over 20 years along the urban coast of Queensland was 77 km^2 (± 4 s.e.). Hence, at regional and landscape scales (> 100 km^2) dugongs select habitat at the level of individual bays along the coast. The tracked dugongs were followed for periods ranging from 15 to 551 days and exhibited a large range of individualistic movement behaviours; 26 individuals were relatively sedentary (moving < 15 km) while 44 made large-scale movements (> 15 km) of up to 560 km from their capture sites. Male and female animals, including cows with calves, undertook large-scale movements (LSM; > 15 km).

At least some of these movements were return movements to the capture location, suggesting that such movements were ranging rather than dispersal movements. Large-scale movements included macro-scale regional movements (> 100 km) and meso-scale inter-patch local movements (15 ≤ 100 km) and were qualitatively different from tidally-driven micro-scale commuting movements between and within seagrass beds (< 15 km). Large-scale movements were rapid and apparently directed. Tracked dugongs rarely travelled far from the coast (mean max distance = 12.8 ± s.e. 1.3 km). Dive profiles from the time-depth recorders suggest that dugongs make repeated deep dives while travelling rather than remaining at the surface. Some animals caught in the high latitude limits of the dugongs' range on the Australian east coast in winter apparently undertook long distance movements in response to low water temperatures, similar to the seasonal movements of Florida manatees.

A 24 km^2 seagrass meadow in Hervey Bay, Queensland, Australia was confirmed as important dugong habitat on the basis of the tracking data. Marine videography, Near-infrared Spectroscopy (NIRS) and Geographic Information Systems (GIS) were used to survey, analyse and map seagrass species composition, nutrient profile and patch structure of the meadow at high resolution (200 m). Five species of seagrass covered 91 % of the total habitat area. The total above and below-ground seagrass biomass was estimated to be 222.7 ± s.e. 19.6 t dry-weight. *Halodule uninervis* dominated the pasture (81.8 %, 162.2 t), followed by *Halophila ovalis* (35.3 %, 16.5 t), *Zostera capricorni* (15.9 %, 22.2 t), *Halophila spinulosa* (14.5 %, 21.9 t), and traces of *Halodule pinifolia*. Because the distributions of the various seagrass species overlapped, their combined percentage totalled > 100 % of the survey area. The seagrass formed a continuous meadow of varying density.

For all seagrass species, the above-ground component (shoots and leaves) possessed greater total nitrogen than the below-ground component (roots and rhizomes), which possessed greater total starch. Because of the relatively low intraspecific variation in nutrient composition, nutrients were concentrated according to seagrass biomass density. *H. uninervis* was the most nutritious seagrass species because of its higher whole-plant nitrogen (1.28 ± s.e. 0.05 % DW) and starch (6.42 ± s.e. 0.50 DW %) content. *H. uninervis* formed large, clustered patches of dense biomass across the pasture and thus nitrogen and starch were concentrated where *H. uninervis* was prevalent. These survey and analytical techniques enabled me to rapidly, economically and accurately quantify and characterise seagrass habitat at scales relevant to a large forager.

I used GIS and spatial statistics to identify the role of physical environmental characteristics in determining the activity patterns and fine-scale space-use of dugongs tracked in coastal and deepwater seagrass habitats using GPS telemetry. A seagrass meadow was defined as a core dugong habitat if more than 10 days of satellite location fixes were obtained from an individual animal occupying an area <100 km^2. Habitats were categorised as inshore/intertidal or offshore/subtidal depending on their distance to the shore and the water depth. Inshore/intertidal habitats had a shallow component that was exposed at low-tide. Offshore/subtidal habitats were at least 5 km from the nearest mainland and were at least 3 m deep at mean low water spring tide (MLWS). Location fixes acquired from dugongs tracked in coastal habitats exhibited significant circadian rhythms, with fewer locations during the morning than during late afternoon/night. GPS location fixes could only be acquired when the transmitter was at the surface. Such periods are typically brief, as when the animal surfaces to breathe. More GPS locations were acquired from inshore/intertidal dugongs that were foraging in the intertidal zone than from animals in the subtidal zone. This telemetric artefact provided an indication of when the animals were moving across shallow intertidal waters. More locations were received at night when the animals were generally closest to the shore and in shallow water and fewer locations were received during the day when animals were further subtidal in deeper waters. Hence, the average depth of water experienced by dugongs and their distances from the shore may have been significantly underestimated, especially when fix success was low, since animals that were in shallower water were more likely to be sampled. Consequently, my estimates of the diel patterns of dugong space use were more conservative than the actual situation and probably underestimated the strength of the tidal patterns.

Dugongs were in deeper water more often during the morning than during late afternoon/night. There was no effect of tide height on the actual depths in which dugongs occurred. Dugongs in coastal habitats were furthest from the shore between 6:00am and 12:00pm and closest between 3:00pm and 12:00am. Dugongs were closer to the shore during high tide than during low tide. Physical environment variables had little or no effect on the spatial patterns of dugongs tracked in deep water. The movement speeds of the coastal and deepwater dugongs increased marginally between 9:00am and 3:00pm, from an average of 200 to 300 m/hr.

Seven dugongs were GPS tracked at a fine spatial scale (< 10m) within the Burrum seagrass habitat in winter. Resource selection within the habitat was modelled by comparing the dugongs' use of space with the distribution of their seagrass food resources within an area defined using the combined space-use of the tracked animals. The association of dugongs with seagrass quantity (biomass) and quality (nutrients) was analysed within six time/tide combinations to examine the influences of tidal periodicity and the diel cycle on resource selection. I used resource utilisation functions (RUFs) to relate a probabilistic measure of each individual dugong's space-use in each time/tide combination in a utilisation distribution (UD) (dependent variable) to the spatial landscapes of the resource variables (independent variables) using multiple regression.

The RUF models indicated that dugong space-use was consistently centred over seagrass patches with high nitrogen concentrations, except during the day at low tides when their space-use was centred over high seagrass biomass and away from seagrass with high starch concentration. Dugong association with seagrass high in starch was positive during both day and night high tides when dugongs could access intertidal areas where the seagrass biomass was generally low. Patterns of association with seagrass species were less definite. Estimates of the intensity of dugong space-use in relation to available seagrass resources may be confounded by the differentiation of fix probability by depth and speed. Because my estimates of dugong space-use in relation to subtidal seagrass may have been more conservative than the data suggested, the positive association of dugongs with patches of high biomass seagrass and avoidance of patches containing *H. spinulosa* and *Z. capricorni* in the subtidal zone may have been over-estimated by this sampling bias.

I posit that dugong habitat selection and resource use occur hierarchically, across (at least) three different domains of scale: (1)at a regional-scale (> 10 000 km^2) dugongs select habitat at the level of individual bays along the Queensland coast; (2) at a landscape-scale (< 10 000 km^2), dugongs select seagrass pastures within bays along the Queensland coast comprised of nutritious plant species; (3) at a local-scale (< 10 km^2) within seagrass pastures that are within bays along the Queensland coast, dugongs select seagrass patches on the basis of their nutrient concentrations. I recommend that the appropriate scales at which to manage dugong populations and their seagrass habitats be co-ordinated within and across the hierarchical scales of habitat use indicated by my analysis.

My finding that dugongs frequently undertake large-scale moves has implications for management at a range of scales, and strengthens the aerial survey and genetic evidence for management and monitoring at ecological scales that cross jurisdictions. The capacity of large-scale monitoring programs to detect trends in dugong numbers at scales of even thousands of km^2 is confounded by the dugongs' tendency to undertake large-scale moves. With movement between bays a common occurrence, estimates of population size and trends can only be meaningfully made at regional scales.

The tendency for dugongs to track the bottom on large-scale movements may increase their vulnerability to incidental capture in bottom set gill nets. In addition, if dugongs transfer their spatial knowledge of the location of quality food resource patches to their offspring, then local depletions will lead to loss of this knowledge. Areas of high quality seagrass may thus become unknown to dugongs. In the absence of grazing pressure such areas may become less valuable as dugong habitat if the early seral stage species of seagrass preferred by dugongs convert to more fibrous species.

My research suggests that dugongs actively select seagrass habitats comprised primarily of *H. ovalis* and *H. uninervis*, based on the high starch and nitrogen content of these species. Bays containing these quality food resources comprise an interlinked network of core habitats between which dugongs frequently move. Accordingly, bays along the Queensland coast with seagrass meadows dominated by *H. ovalis* and *H. uninervis* should be afforded a high level of protection as potential quality dugong habitat. Bays with extensive intertidal meadows of *H. uninervis* should also receive enhanced protection, even if the seagrass biomass is low. Even though they have low seagrass biomass, thermoregulatory habitats play an important role in maintaining dugong populations and should be included in dugong habitat protection strategies.

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