1. INTRODUCTION AND OVERVIEW

INTRODUCTION

Study Brief

The waters of northern Australia, including the Great Barrier Reef World Heritage Area, have a significant proportion of the world's dugong (*Dugong dugon*) population and are likely to support the only remaining large populations. Aerial surveys of dugong populations have been commissioned by the Great Barrier Reef Marine Park Authority and carried out by James Cook University since 1984. An estimated 15% of the Australian population of around 85,000 animals is in the World Heritage Area (Marsh et al. 1999).

Declines in dugong numbers in the Great Barrier Reef Marine Park south of Cooktown are known to have occurred since 1987 (Marsh et al. 1996). Dugong are listed as vulnerable to extinction both internationally and under Queensland legislation (*Queensland Nature Conservation Regulations 1994, IUCN 2000*). Dugong are also a listed species under the *Environmental Protection and Biodiversity Conservation Act 1999,* and afforded protection under this Act.

In November 1996 the Great Barrier Reef Ministerial Council agreed that emergency action was required to conserve dugong numbers in the Great Barrier Reef World Heritage Area. As a consequence, 16 areas have been declared Dugong Protected Areas (DPAs). These areas were chosen because they were known to include large areas of seagrass and significant dugong populations. The Ministerial Council also acknowledged that one of the reasons for the decline in dugong numbers may be seagrass habitat loss.

Seagrasses are essential food for dugong. There is however, insufficient long-term information on the abundance, productivity and seasonal change of the preferred seagrass (food) species of dugong within the Great Barrier Reef World Heritage Area to make any firm connection between habitat status and dugong numbers. Seagrass information that is available for many of the DPAs, and on which the boundaries of the DPAs were determined, is broad-scale and over 10 years old.

For better management and to better understand the seagrass resources within DPAs the Great Barrier Reef Marine Park Authority commissioned detailed seagrass surveys of the DPAs in Upstart Bay, Newry region, Sand Bay, Ince Bay and Llewellyn Bay (Map 1.1). The Authority also commissioned a helicopter flyover and some limited ground truthing of the Clairview region DPA .

The objectives were:

1. To map the distribution of coastal inshore and island seagrass meadows within the DPAs of Upstart Bay, Newry region / Sand Bay and Ince / Llewellyn Bays in Autumn and Spring and to provide some management and planning advice for the Clairview region DPA;

2. To produce a detailed Geographic Information Systems on seagrass habitats within each of the DPAs for use by managers;

3. To identify areas of seagrass with a distribution, species composition, and density particularly suitable for dugong feeding within each of the DPAs;

4. To compare the survey results with previous seagrass survey results available for the DPAs;

5. To provide information needed to further improve understanding of the relationship between dugong feeding behaviour and the location and species characteristics of seagrasses and;

5. To identify juvenile prawns, other invertebrates and fish species present in representative seagrass meadows within each of the DPAs of Upstart Bay, Newry / Sand Bays and Ince / Llewellyn Bays in autumn and spring.

Dugong

Dugong are marine mammals of the order Sirenia. They look similar to a rotund dolphin or seal, although they are less streamlined. Despite their appearance, dugong and their relative (manatees) are more closely related to elephants than to other marine mammals. Dugong have a life span of about 70 years and an adult can grow to lengths greater than 3 m and weigh in excess of 400 kg (Marsh et al. 1999). Females have their first calf between 10 and 17 years. Calves are born singly between September and November, with an interval of 3 to 7 years between each calf being born. Calving is thought to occur in specialised areas, often shallow waters removed from seagrass meadows. The gestation period is 13 months, and calves suckle for 18 months. During this time there is a strong bond between the cow and calf (Marsh et al. 1999).

Dugong are the only marine mammal that is strictly a herbivore, feeding almost exclusively on seagrasses. Dugong prefer seagrasses that are lower seral or “pioneer” species (Preen 1995a, 1995b), especially species of the genera *Halophila* and *Halodule*. These species are lower in fibre and higher in available nitrogen (*Halodule*) and digestibility (*Halophila*) (Lanyon 1991).

Dugong have a wide geographical distribution in shallow tropical and subtropical waters of the Indo-Pacific region. Their range includes waters of 43 different countries, extending from eastern Africa to Vanuatu and between 27 degrees north and south of the equator (Marsh et al. 1999). Many dugong populations however, are relict or extinct. In Australia, their range is from Shark Bay in Western Australia, across the north to Moreton Bay, south eastern Queensland (Marsh et al. 1999).

To address declines in the dugong population south of Cooktown a two-tiered system of 16 DPAs came into effect in January 1998 in the GBR region. In these areas fishing practices which used gill- and mesh- netting were restricted, banned or modified, because incidental catch in commercial nets was considered to be a major threat to dugong populations. A reduction or cessation of indigenous fishing, a review of shark meshing activity and restrictions on boat speeds were also part of the DPA approach.

Present day dugong populations face numerous impacts that contribute to a decline in numbers either through direct impacts on dugong or indirect impacts via the seagrass food resource. Factors identified as presently posing a real or potential risk to populations include boat traffic, dredging, coastal development, traditional hunting, commercial gill netting, illegal fishing, defence activities, land clearing, agricultural activities and sediment run-off (Great Barrier Reef Marine Park Authority, Dugong

Information Kit, February 1998). Natural impacts including tropical cyclones, floods, storms and predators may also effect dugong numbers. For dugong populations to exist in a healthy state, these impacts must be effectively managed or the effects understood and where possible, prevented altogether. Underpinning all these factors is the requirement for dugong to have available a healthy and abundant food source in the form of seagrass meadows.

Dugong strandings and mortality in the present study DPAs have been minimal in 1999 and 2000, compared with all other DPAs (Table 1.1).

Table 1.1. Dugong strandings and mortality in Dugong Protection and adjacent areas 1999 and 2000 *(Source: Queensland Parks and Wildlife Service)*

Dugong Protected Area	No. of dugong strandings and mortality 1999	Adjacent sites in 1999	No. of dugong strandings and mortality 2000	Adjacent sites in 2000
Upstart Bay DPA ”A”	0	0	2	0
Newry region DPA “A”	0	1	0	0
Sand Bay DPA “B”	0	0	2	0
Llewellyn Bay DPA “B”	0	0	0	0
Ince Bay DPA ”A”	0	0	0	0
Clairview region DPA “B”	0	1	0	0
All other DPAs*	37	5	36	1
TOTAL	37	7	40	1

* *All other DPAs include Hinchinbrook region, Taylors Beach, Cleveland Bay, Bowling Green Bay, Edgcumbe Bay, Repulse Bay, Shoalwater Bay, Rodds Bay and Hervey Bay/ Great Sandy region.*

Seagrasses of Queensland

Seagrasses are flowering plants that can live entirely immersed in seawater. Tropical species are usually found in less than 10 metres below mean sea-level but may be found at depths to 50 metres or more (den Hartog 1977; Coles et al. 2000). They are found on substrates ranging from the nutrient rich soft muds adjacent to mangrove fringes to carbonate sands around cays on the outer Great Barrier Reef. Several species have also colonised the coral reef platforms, exposed reef slopes and to depths of 60m in the Great Barrier Reef lagoon.

Although totally submerged, seagrasses have all the general structures of their terrestrial plant relatives - a root system, a vascular system, and vegetative and sexual reproduction with flowers fertilised by water borne pollen. Adaptation to the marine

environment has imposed major constraints on morphology, and structure and the restriction to seawater has influenced their geographic distribution and speciation.

Seagrasses are one of the globes most common coastal ecosystem types forming vast meadows that are highly dynamic and important contributors to primary production (Costanza et al. 1997). Entire commercial fisheries may depend on seagrass nursery areas in Queenslands tropical coastal areas (Watson et al. 1993).

Instances of widespread seagrass losses have been reported from most parts of the world. Some from natural causes such as the wasting disease (Rasmussen 1977) of *Zostera marina* and from storms (Patriquin 1975). More commonly losses have resulted from the consequences of human activities such as land reclamation and changes in land use (Kemp et al. 1983) or eutrophication and light reduction (Shepherd et al. 1989).

It is important to document seagrass diversity and distribution before further changes occur. A scan of the scientific literature quickly identifies the paucity of published seagrass research, apart from taxonomic studies, available for tropical regions.

There are 15 or 16 species (there is presently some taxonomic uncertainty for species of the genus *Halophila*; (J. Kuo, University of Western Australia, pers. comm.)) of seagrass in Queensland east coast waters occupying a variety of habitats. Most species are widely distributed along the coast (Lee Long et al. 1993). The most commonly found species are in the genera *Halodule* and *Halophila.* Almost all can be found in shallow coastal waters. Only species of the genus *Halophila* are commonly found 15m or more below MSL (Coles et al. 2000).

In the mid 1980's, Coles et al. (1987) described from broad scale coastal surveys, three general depth zones of seagrass species composition for tropical waters: a shallow zone less than six metres deep with a high species diversity and likely to include all species found in the region; a zone between 6 and 11 metres where the most commonly found species were the pioneering *Halodule* and *Halophila* species, and a zone deeper than 11 metres where only species of the genus *Halophila* were common. The ability of *Halophila* species to grow in low light intensities may give this genus advantage over others in deep or turbid water (Coles et al. 1987).

The range of depth of seagrass is most likely to be controlled at its deepest edge by the availability of light of suitable spectral qualities for photosynthesis. Exposure at low tide, wave action and associated turbidity and low salinity from fresh water influences determine seagrass species survival at the nearshore edge. Seagrasses will survive in the intertidal zone especially in sites sheltered from wave action or where there is entrapment of water at low tide, (such as on a reef platform) protecting the seagrasses from exposure to drying at low tide.

Natural seasonal variation in seagrass biomass has been documented (McKenzie 1994) and more recent detailed surveys have indicated some large long-term changes in seagrass area at regional scales (Lee Long et al. 1998). The causes and scale of long-term changes, and the ecological consequences for faunal populations of fisheries and conservation value are not well understood for tropical species.

The Importance of Seagrasses in the Coastal Ecosystem

Seagrasses form complex ecosystems in coastal waters providing physical and biological functions such as:

(1) Larger seagrass species buffer wave action, stabilise and hold bottom sediments, and reduce sediment resuspension and erosion during storms;

(2) Meadows serve as a shelter for resident and transient adult and juvenile animals many of which are of commercial and recreational importance or important to traditional fishing communities;

(3) Seagrasses and their epiphytes are a major marine source of carbon and provide a food source to complex food webs through direct grazing or through detrital pathways; and

(4) Seagrass plants trap detritus, sediment and nutrients (derived from land runoff) within the seagrass ecosystem.

Seagrasses are also important in interactions with the other major coastal communities of mangroves and coral reefs. Each of these communities may exert a stabilising effect on the environment, which results in important physical and biological effects on the other communities (Amesbury and Francis 1988). Barrier reefs protect coastlines and in the Great Barrier Reef, the lagoon is protected from ocean swells allowing mangroves and seagrass communities to develop. The sediment trapping function of seagrasses benefits nearby corals by reducing sediment loads in the water. Mangroves also trap sediment from the land, reducing the chance of seagrasses and corals being inundated. Sediment banks accumulated by seagrasses may eventually form substrate that can be colonised by mangroves. All three communities trap and hold nutrients from being dispersed into the surrounding nutrient-poor oceanic waters.

Seagrass primary productivity ranks amongst the highest for submerged aquatic communities reaching rates of 550g C $m^{-2}yr^{-1}$ for above-ground productivity (Hillman et al. 1989). The major factors affecting seagrass productivity are irradiance, temperature, nutrient availability, and water movement. Light and temperature are probably the main factors governing seasonal and depth changes in productivity at any site (Hillman et al. 1989). Moriarty et al. (1985) suggested nutrient limitation, in particular nitrogen, may also limit growth in tropical seagrasses. However, in tropical coral reef waters where carbonate sediments predominate, N:P ratios in plant tissues suggest availability of phosphorous is also a limiting factor (Short 1987).

Standing crop biomass measurements for the tropics generally have relatively low values. Brouns (1987) recorded *Cymodocea serrulata* at 148 g DW m^{-2} above-ground biomass. Herbert (1986) recorded 104 g DW m^{-2} for *Halophila hawaiiana*. Similar or lower values were recorded for northern Australia (Lee Long et al. 1993) and in the present study. There is little information on how this biomass value changes seasonally. In Papua New Guinea variation in standing crop for five species was slight (Brouns 1987). Mellors et al. (1993) reported only a two-fold seasonal change in all species at Green Island, northern Australia, associated primarily with temperature and light availability. However some tropical *Halophila* species are annuals and almost completely absent (Kuo et al. 1993) at times of the year, leading to very large seasonal changes in biomass.

Seagrasses in tropical reef regions represent an accumulation of nutrients in what is otherwise a nutrient-poor environment. They are capable of absorbing nutrients from run-off and interstitial waters. They influence nutrient cycling and nitrogen fixation and may increase nutrient flux to local waters. Their influence may also extend to nearby regions through the export of live and dead seagrass material.

The abundant fauna in seagrass meadows is due to the richness of these systems as a source of food and shelter and their use as nursery areas by many fish and crustacean species (Coles et al. 1993; Bell and Pollard 1989). Recent fisheries research has shown that it is the shallow, high-diversity zone that is most productive, at least for commercially important penaeid shrimp fisheries (Derbyshire et al. 1995).

Dugong and some turtle are direct grazers of seagrasses and the importance of these animals has helped to raise conservation concerns for seagrasses in northeastern Australia. However many other species are also direct grazers. McRoy and Helfferich (1980) recorded 154 species, including invertebrates and fish which consume living seagrass.

Previous samples from tropical seagrasses in northern Australia identified 134 fish taxa at a density of nearly 9000 fish per hectare of seagrass (Coles et al. 1993). Twenty species of penaeid shrimp were also identified, of which nine species were of commercial importance to the fishing industry. Simulation modelling using just the three penaeid species that form the largest component of the fishery rate this tropical seagrass bed of 876 ha worth an estimated mean value of 1.2 million dollars Australian per year for 1987 to 1989, a figure that was verified from commercial fishing log book records (Watson et al. 1993).

Most information on seagrass fauna has come from studies of taxa of direct fisheries importance. Where there are not major commercial fisheries to fund research, or where fauna has no direct fisheries values, knowledge remains patchy. Howard et al. (1989) describe four types of fauna in seagrasses: *infauna* (animals living in the sediment amongst the seagrass rhizomes); *motile epifauna* (smaller, mobile animals on the sediment surface or on seagrass stems or leaves); *sessile epifauna* (permanently attached animals living on seagrass stems or leaves); and *epibenthic fauna* (the larger mobile animals which are loosely associated with seagrass meadows). All these groups should be considered when estimating the contribution of seagrass meadows to local productivity.

While carnivorous fish are the most important trophic group of fish communities, seagrass-associated crustaceans dominate the diet of fish communities (Klumpp et al. 1989). Crustaceans are the main source of food for fishes in seagrass beds and are thought to be a major link between primary producers and higher consumers (Klumpp et al. 1989).

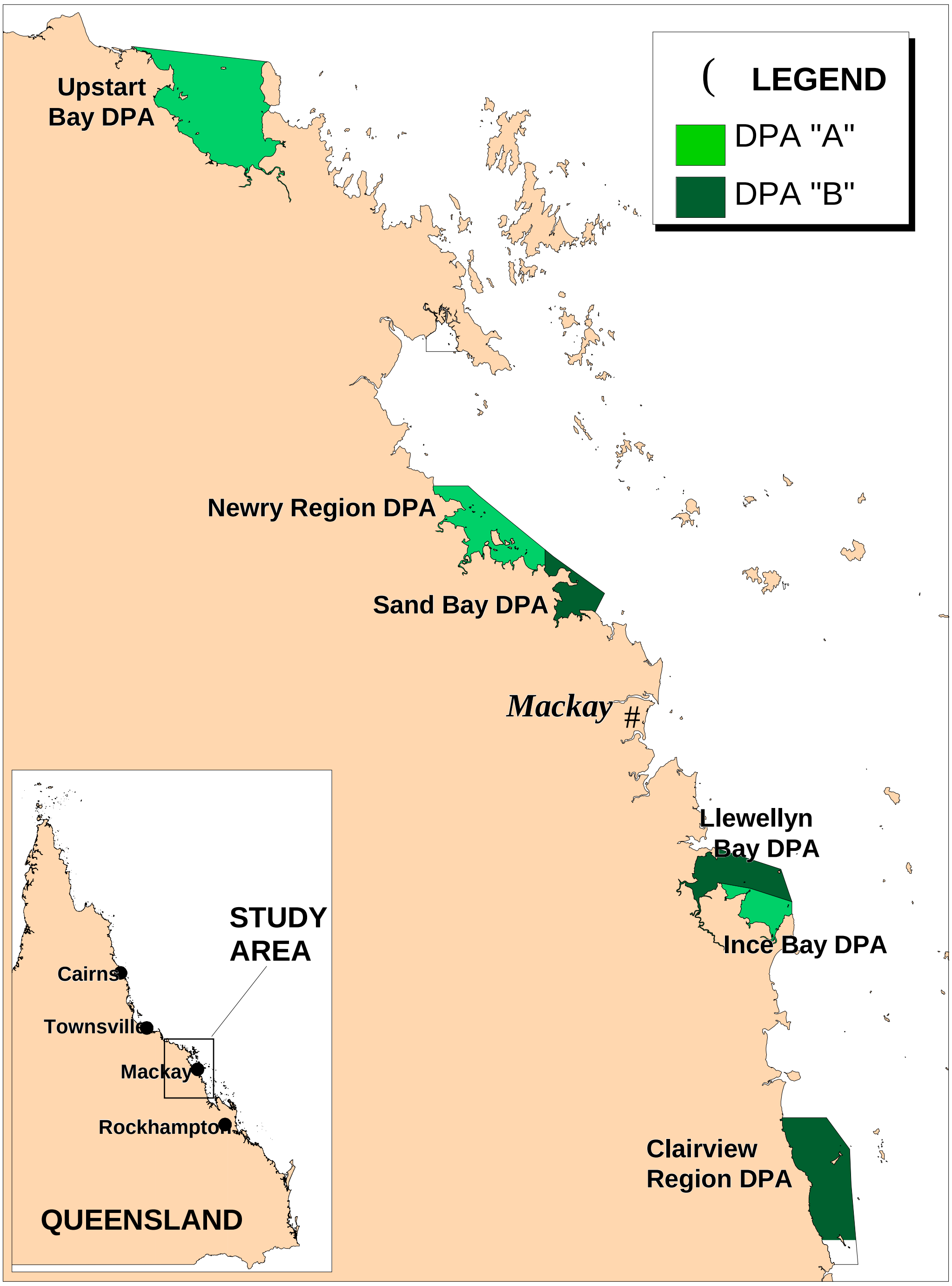
Although seagrass meadows by definition are dominated by the biomass of the seagrasses themselves, a diverse assemblage of other benthic flora are found within a seagrass meadow. Seagrass leaf surfaces typically carry a complex layer of diatoms, micro and macroalgae, bacteria, encrusting algae, fungi and other accumulated debris. Little information exists on algae production rates in the tropics as leaf turnover can be very rapid, but in temperate seagrasses epiphyte production can be 10% - 40% of seagrass leaf production (Klumpp et al. 1989).

Seagrasses play a vital role in supporting coastal marine communities and in maintaining diverse flora and fauna. They support coastal fisheries productivity and play a role in maintaining coastal water quality and clarity. It is important that coastal zone and catchment management decisions take into account these values and that seagrass areas are protected from loss.

METHODS

Description of Study Region

The study region includes the Upstart Bay, Newry region, Sand Bay, Llewellyn Bay, Ince Bay and Clairview region DPAs and is within the northern and central belts of Queensland (19°42'S to 21°36'S) (Map 1.1).



Map 1.1. The study region encompassing the Upstart Bay, Newry region, Sand Bay, Ince, Llewellyn Bay and Clairview region Dugong Protection Areas.

Agriculture (sugar and dry land grazing) is the main industry and urban development is low throughout the regions catchments. Mackay is the largest city situated on the coast between the Sand Bay and Llewellyn Bay Dugong Protection Areas, with a population of just over 124,000.

Monsoonal summer rains provide the bulk of precipitation for the region; intermittent showers occur through the remainder of the year. South-easterly trade winds dominate the drier winter and spring period (June to November). These trade winds create a general northerly, longshore current inshore, while a light southerly flow exists on the mid and outer shelf under the influence of the East Australian Current (Wolanski 1994).

Numerous creeks and rivers drain the Great Dividing Range and narrow coastal plain. The largest catchment in the region is the Burdekin River system, which drains into the northern part of Upstart Bay.

Tidal ranges in the study region vary from approximately 3.6 m in Upstart Bay to approximately 8.5m in the Clairview region (Queensland Department of Transport 1999).

Seagrass Survey Approach

Three sampling techniques were used to survey the DPAs in the present study. These were tailored to each of the DPAs according to the physical characteristics of the bays and to prior knowledge of seagrass distribution (Coles et al. 1987). The three techniques were:

1. Helicopter reconnaissance surveys - used to map shallow tidal flats inaccessible to small boats, scope the extent of the seagrass resources and to focus diver-based survey effort
2. Dive-based surveys (using small vessels and free divers) - used to sample shallow subtidal areas and intertidal areas accessible by small vessels
3. Deepwater surveys - remote, real-time video sampling used in subtidal areas too deep for free diving.

The majority of Upstart Bay is subtidal (Map 2.1). Shallow intertidal banks are confined to Nobbies Inlet in the southern part of the bay and a narrow fringe adjacent to the western shoreline. Helicopter surveys were not necessary to survey this DPA as the area of intertidal banks was small. Dive-based surveys and deepwater video were used to survey the bay.

Extensive intertidal sandbanks and shallow subtidal waters dominate the Newry region and Sand Bay DPAs (Map 3.1). Aerial photographs (1:25,000) taken at low tide (courtesy of Beach Protection Authority) were interpreted for presence or absence of seagrasses on intertidal banks and the helicopter was used to ground truth exposed upper intertidal areas of the mainland and adjacent islands. A dive-based survey was undertaken in the sheltered intertidal and subtidal areas between St Helens Bay and Seaforth in the Newry region DPA. A less intensive effort was spent on the Sand Bay DPA, where the helicopter reconnaissance found no seagrass, and large intertidal banks prevented access by boats. Deepwater video was used along the offshore margin of these DPAs.

Extensive intertidal sandbanks dominate Ince Bay, with the entire bay <5 m in depth (the majority <2m below MSL) (Map 4.1). Shallow subtidal and intertidal areas (<5m in depth) dominate Llewellyn Bay. A helicopter was used to survey the large exposed banks of Ince Bay, and along the western and southern shorelines of Llewellyn Bay. Divers were used to survey the accessible intertidal areas and subtidal areas of both DPAs. Deepwater video was used in the deeper waters of the DPAs.

Seagrasses were surveyed during autumn (April/May) and spring (October) to estimate the range of areal extent and biomass abundance of the meadows. Seagrass has been recorded at greatest/least areal distribution (McKenzie et al. 1998) and greatest/least abundance (McKenzie 1994; Mellors et al. 1993) during these seasons. The Clairview region DPA was only surveyed from a helicopter and only in April (autumn) with few ground truth sites.

Helicopter Surveys

Helicopter aerial surveys of intertidal seagrasses were conducted during the low spring tides on 27th and 28th April 1999. During flights, observers interpreted the distribution of seagrass onto survey charts and a Hi8 video camera was used to store a visual record for future reference and to aid interpretation when mapping on a GIS. Sites in seagrass meadows were also selected for ground truthing. At each site, a standard quadrat (0.25m^2) was haphazardly placed within a 5 m radius (3 quadrats per site), to visually estimate seagrass abundance (Mellors 1991) and seagrass species composition.

Dive Surveys

Shallow sub-tidal (2-10m below MSL) areas were surveyed by diver observations (free-diving) 16th-25th May (autumn) and 12th-20th October (spring) 1999. Dive sites were distributed haphazardly along transects according to changes in depth and habitat type (50m to 500 m apart). Survey transects extended from the upper intertidal reaches to approximately the 10 m (below MSL) depth contour (up to 7km offshore).

Seagrass habitat characteristics including above-ground seagrass biomass, species composition, % algae cover, sediment type, water depth and GPS coordinates were recorded at each site.

Above-ground seagrass biomass was determined by a visual estimates of biomass technique modified from Mellors (1991). This method avoids extensive destructive sampling. At each intertidal and shallow sub-tidal site, observers recorded an estimated rank of seagrass biomass and species composition in three replicates of a 0.25 m^2 quadrat per site. On completion of the survey, each observer ranked five quadrats that were harvested from a “low biomass” site and another five quadrats from a “high biomass” site and the above-ground biomass (g DW m^{-2}) measured. The regression curves representing the “high” and “low” biomass calibration of each observer’s ranks was used to calculate above-ground biomass from their estimated ranks during the survey. All observers had significant linear regressions ($r^2 > 0.80$) when calibrating above-ground biomass estimates against the sets of harvested quadrats (Appendix 1). Photographic examples of above-ground biomass (g DW m^{-2}) were used as a guide and to achieve consistency between divers and through time (Appendix 2).

Deepwater Surveys

Deep-water sites (>10m) were surveyed using a real-time towed underwater video camera and a sled-net. Five minutes of towed (at drift speed) video footage was recorded for each site and images were archived on VHS and DVCAM videotapes.

Deepwater sites were checked for seagrass presence by replaying and examining the videotapes. Seagrass biomass estimates were based on 10 random time frames, at a one-second accuracy, allocated within the 5 minutes of footage for each site (within-site variance was reduced by at least 50% with 10 replicates). Above-ground seagrass biomass was again determined by a visual estimates of biomass technique in this case modified from Mellors (1991) for use with video recording. Seagrass species composition was also recorded where this was possible. The video was paused at each of the 10 random time frames selected then advanced to the nearest point on the tape where the bottom was visible and sled was stable on the bottom. From this frame an observer recorded an estimated rank of seagrass biomass and species composition. To standardise biomass estimates a 0.25 m^2 quadrat, scaled to the video camera lens used in the field, was superimposed on the screen. On completion of the videotape analysis, the video observer ranked five to ten additional quadrats that had been previously videoed for calibration. These quadrats were videoed in front of a stationary camera, and then harvested, dried and weighed. A regression curve was calculated for the relationship between the observer ranks and the actual harvested value. This curve was used to calculate above-ground biomass for all estimated ranks made from the survey sites. All observers had significant linear regressions (r^2 =0.98) when calibrating above-ground biomass estimates against the harvested quadrats.

A second set of video images of quadrats that had been harvested, dried and weighed were used by the observer as a quick reference to minimise any drift in estimation over time during a series of video estimations. Sites that were used for biomass estimation were selected at random from the entire data set to limit the potential for bias through time.

Taxonomic specimens were collected from the towed dredge samples and by divers where ground truthing was undertaken. Seagrass species were identified according to taxonomic keys of Kuo and McCombe (1989) and Lanyon (1986). Seagrass voucher specimens for taxonomic use were lodged with the QDPI Northern Fisheries Centre Herbarium. Seagrass identifications were made from video tape alone only where species were clearly identifiable. Where identification was difficult on screen and no confirmation of the species was obtained from dredge or diver samples the genus was recorded.

Algae species were identified according to Cribb (1996) and percent cover of algae was estimated for each site.

A Van Veen grab was used to sample sediment type and a Secchi disc was used to measure water clarity at each site. Field descriptions of sediment type from hand samples were also recorded for each site as shell grit, rock, gravel, coarse sand, sand, fine sand and mud. Sediment and secchi information is presented in the site layer associated with the Geographic Information System.

Water depths of survey sites were recorded with an echo sounder (to the nearest decimetre) and converted to depths in metres below mean sea level (correct to tidal plane datums) (Queensland Department of Transport 1999).

Geographic location of sampling sites (±5 m) was determined by a differential Global Positioning System (dGPS).

Dugong observations

Dugong feeding trails were recorded as present at sites when observed by divers and observed from the helicopter flights. Dugongs were recorded when observed opportunistically from the vessels. This fauna information was coupled with position fixes and exported to MapInfo™ and displayed on maps.

Invertebrate and Fish Communities

Qualitative sampling using beam trawls was conducted in representative seagrass communities within the DPAs. Two trawling sites were chosen in the Upstart Bay and Newry Bay DPAs. One site was chosen in the Ince Bay DPA. Sites were trawled in May and October 1999. Sampling was conducted at the time of high water at night. A beam trawl (1.5 m wide, 0.5 m high with a 2.0 mm mesh) was towed along each 100 m transect at approximately 0.5 m s^{-1} (Coles et al. 1993). Four replicate trawls were conducted at each site as previous studies in north Queensland have shown that that is sufficient to adequately sample the representative fauna (Coles et al. 1993).

All Penaeidae (prawns) were identified to species according to Dall (1957) and Grey et al. (1983). Carapace length (posterio-dorsal margin of the carapace to the orbit of the eye) was measured to the nearest 0.1mm. All fish were identified as far as possible and standard length (tip of snout to last vertebra) measured to the nearest 0.1mm for the largest and smallest individuals from each taxa in May 1999 and October 1999.

Numbers of Brachyura (crabs), squid, sepiolids (cuttlefish) and miscellaneous crustaceans (shrimps, isopods, amphipods, and stomatopods) were pooled respectively and recorded for each trawl. Biomass (g dry weight) of fish, penaeids (all species pooled), crustaceans and miscellaneous from each trawl was determined by drying (60°C, 48 hrs) and weighing samples. Biomass of fish in May was for all taxa pooled and in October was separated by Family. Molluscs, polychaetes and other phyla were not measured for biomass.

Geographic Information System

All survey data was entered into Microsoft Access® then exported to MapInfo™ to construct a Geographic Information System (GIS) for mapping and presentation.

Recent colour aerial photographs (Beach Protection Authority, June 1998, 1:25,000) were rectified for use in the GIS to assist in mapping boundaries of intertidal seagrass meadows in Upstart Bay, Newry region, Sand Bays, Llewellyn Bay and Ince Bay.

Seagrass meadows with an average above-ground seagrass biomass over 20 g DW m^{-2} were considered “high biomass” and those with an average of less than 20 g DW m^{-2} were considered “low biomass” for analysis and presentation purposes

Boundaries of seagrass meadows were determined based on the GPS fix at each survey site and ground-truthed aerial photographs. Meadow boundaries drawn on GIS maps are estimates based on above-ground seagrass presence/absence information and location of sample sites. Each seagrass meadow in the DPAs was assigned a Mapping Quality rank (decreasing Mapping Quality from rank 1 to 6) (Table 1.2) based on the data sources and accuracy of each technique used for mapping the meadow. Other errors associated with mapping, include those associated with digitising and rectifying aerial photographs onto a base map. Differences between the GPS, and the diver's sampling position, were assumed to be embedded within this range. Estimates of error (in hectares) were calculated using the polygon buffer function in MapInfo®. Seagrass information for the 1999 helicopter survey in the Clairview region DPA was from field observations and qualitative information from landing sites.

Information specific to each site surveyed and each meadow drawn in each of the DPAs is found within the GIS.

Table 1.2. Map quality for seagrass meadows in Upstart Bay, Newry region, Sand Bay, Llewellyn Bay and Ince Bay.

Mapping Quality	Data sets	Comments
1	*Helicopter reconnaissance, aerial photos and dive survey*	*Detailed checking of meadow boundary during dive survey. Aerial photos taken June 1998, 1:25,000 scale, colour, high definition. Error = 15-20m*
2	*Helicopter reconnaissance, aerial photos and dive survey*	*Some meadow boundaries checked with several transects during dive survey. Aerial photos taken June 1998, 1:25,000 scale, colour, very high definition. Error = 20-30m*
3	*Helicopter reconnaissance aerial photos and dive survey*	*Occasional meadow boundaries checked during dive survey. Aerial photos June 1998, 1:25,000 scale, high definition. Error = 15-40 m*
4	*Helicopter and aerial photos*	*Photos of suitable resolution. Meadow boundaries checked during ground truth survey. No dive survey. Error = 25-50m*
5	*Aerial photos and dive survey*	*Meadow boundaries checked during dive survey. Aerial photos taken June 1998 or May 1991, 1:25,000 scale, colour and black & white images, low to high definition. Error = 30-50m*
6	*Dive survey only*	*Subtidal meadows not visible in aerial photos, Data densities generally low and reliant solely on dive survey. Error = 30- 70 m*

* *No seagrass was mapped from deepwater video sampling, it is not included in this table. Seagrass area was mapped for seagrass meadows in the Clairview region DPA, but coarse reliability than shown in this table.*

Analysis

Seagrass abundance data is presented graphically with standard errors calculated. A visual representation is best where signals are large and seasonal comparisons fit poorly with the assumptions of ANOVA.

Direct statistical comparisons between 1987 and 1999 seagrass data were not performed as methodology and site location accuracy has changed and improved. Comparisons rely on maps and graphical representation.

OVERVIEW AND SUMMARY OF RESULTS

Seagrass Species

In the five DPAs surveyed in May and October 1999, ten species of seagrasses (from three families) were identified (Table 1.3). Two species were also found in the Clairview region DPA but this list is likely to be incomplete as Clairview was not surveyed subtidally or at a fine scale.

Table 1.3. Seagrass species present in the Upstart Bay, Newry region, Sand Bay, Llewellyn Bay and Ince Bay Dugong Protection Areas

Seagrass Family	Seagrass species	UPSTART BAY		NEWRY REGION		SAND BAY		LLEWELLYN BAY		INCE BAY		CLAIRVIEW REGION	
		May 1999	Oct 1999	May 1999	Oct 1999	May 1999	Oct 1999	May 1999	Oct 1999	May 1999	Oct 1999	Mch 1987	April 1999
ZOSTERACEAE Drummortier	***Zostera capricorni***	V	V	V	V	-	-	V	V	V	V	V	-
CYMODOCEACEAE Taylor	***Cymodocea rotundata***	-	-	V	-	-	-	-	-	-	-	-	-
	Cymodocea serrulata	V	V	V	V	-	-	-	-	-	-	-	-
	Halodule uninervis	V	V	V	V	-	-	V	V	V	V	V	V
	Syringodium isoetifolium	-	-	V	V	-	-	-	-	-	-	-	-
HYDROCHARITACEAE Jussieu	***Halophila decipiens***	V	V	V	V	-	-	-	V	-	V	-	-
	Halophila minor	-	-	V	-	-	-	-	-	-	-	-	-
	Halophila ovalis	V	V	V	V	-	-	V	-	V	V	V	V
	Halophila spinulosa	V	V	V	V	-	-	-	V	V	V	-	-
	Halophila tricostata	-	V	-	-	-	-	-	-	-	-	-	-

General Seagrass Distribution

787 sites were sampled in May 1999 and 892 in October 1999 in the Upstart Bay, Newry region, Sand Bay, Ince Bay and Llewellyn Bay DPAs. 48 sites were surveyed from helicopter in the Newry/Sand, Llewellyn/Ince and Clairview DPAs, 27-28th April 1999. 12 sites were ground truthed in the Clairview region DPA to confirm seagrass presence, abundance and species.

The total area of seagrass habitat mapped in the 5 DPAs surveyed in May 1999 was 6015 ± 982ha and 7128 ± 1232ha in October. Of the 10 species, *Halodule uninervis* was the most common species in the study area in May 1999 (all sites pooled) and was present at approximately 55% of sites that had seagrass. Depth ranges are very narrow with almost all records between 0 and 6 m below MSL.

Species number decreased with increasing latitude in agreement with previous observations (Lee Long et al. 1993). Some species may be limited in the present case by the high tidal range and exposure at low tide in the regions south of Mackay.

It is difficult to interpret the present results when compared with those collected 12 years ago by Coles et al. (1987). In 1987 only one day was allocated to each region and there was no seasonal comparison undertaken. Particularly at Llewellyn Bay and Seaforth this led to little or no sampling in the upper intertidal regions due to tide height and time constraints on the day. Position fixing at the time was by RADAR fix and position errors could be up to 100 times the error in the present study. Biomass was estimated by percent area cover and so is not easily comparable with present techniques.

Despite this, some patterns in distribution have remained remarkably similar. Upstart Bay seagrasses in both surveys were predominantly on the extensive intertidal and shallow subtidal banks that fringe the bay. Seagrasses remain absent from the deeper waters in the middle of the bay. Almost 1000ha more seagrass area was mapped in 1999 compared with 1987 but a large part of this may be due to improved survey techniques. There is no evidence of long-term decline in seagrass area in this or any of the DPAs surveyed. The suite of seagrasses species is similar with only *Syringodium isoetifolium* and *Cymodocea rotundata* missing in the present survey. *Syringodium isoetifolium* population size can change rapidly (Rasheed 2000) and *Cymodocea rotundata* is uncommon on the east coast and may have been an isolated patch in 1987 or simply missed in the latest survey. Upstart Bay seagrasses remain important to penaeid prawn and fish production and diversity.

In the Newry region and Sand Bay DPAs, Port Newry was rich in seagrass species (up to six at a site) in 1987 and again in 1999, and seagrass was found in the same general locations. Sand Bay remains consistently without seagrass despite records of dugong in the area. Sand Bay is exposed to wave action and is unlikely to support large meadows of seagrass although it is possible that seagrass survives there on occasions.

The area of seagrass mapped in Ince Bay in October 1999 is unchanged from the area mapped in 1987. Llewellyn Bay has now seagrass meadows that were not recorded at all in 1987 but this is likely due to improved techniques (including use of helicopter) allowing access to intertidal sandbanks in an area with tide ranges of 5 metres or more.

The flyover of the Clairview region DPA indicates intertidal seagrass in similar locations to that in 1987.

In the present surveys and in 1987 the suite of seagrass species is predominantly species that are preferred dugong food. Those species can occur at depths ranges from around 20 cm above MSL to 13 metres below MSL and be potentially available to dugong as food in all but the most extreme tidal or weather conditions. However, because large tidal ranges and tidal currents generate high coastal turbidity in these DPAs, most of the seagrass resources are confined to intertidal and very shallow sub-tidal depths, leaving a very limited area of seagrass (feeding habitat) available to dugong during low tide periods.

Mean biomass for the above-ground plant material of any seagrass species in the DPAs ranged from a high of just over 20 grams dry weight (g DW m^2) in each square metre of sea bed in Upstart Bay; to less than 20 in the Newry region; less than 15 in Ince Bay; and only a mean of 5 g DW m^2 in Llewellyn Bay.

The maximum above-ground biomass for a single species was 100 g DW m^2 in a square metre of *Zostera capricorni* in Upstart Bay. This upper range represents dense seagrass beds by tropical standards with plants standing 20 to 30cm tall. Most seagrass area was

relatively low biomass, particularly early in the year (Figure 1.1). Dugong feeding trails were usually common only in areas with an above-ground biomass of less than 15 g DW m^{-2}.

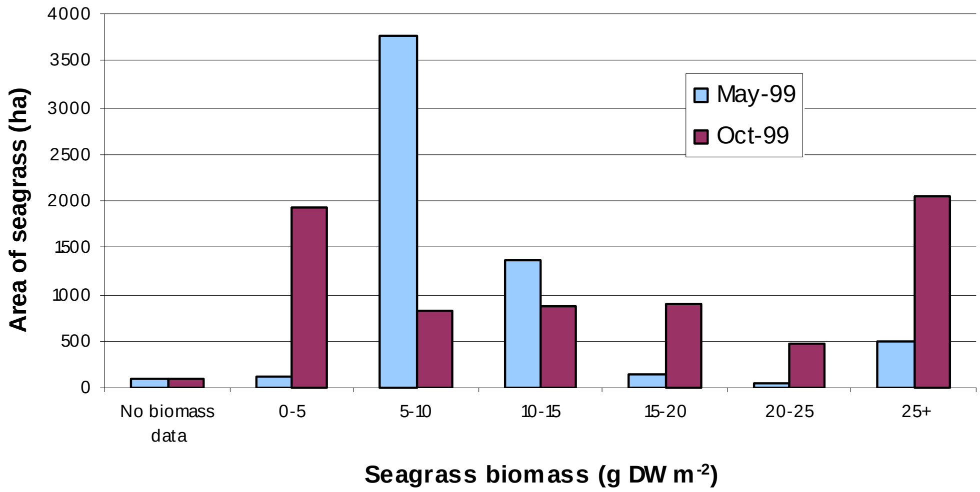


Figure 1.1. Total meadow area of above-ground seagrass biomass (all species and DPAs pooled), May and October 1999**.**

DISCUSSION

Habitat Area and Distribution

The area of seagrass within the DPAs is substantial and represents an important food resource for dugong. The majority of the meadows are low biomass and are dominated by *Halophila* and *Halodule*, species that are the preferred food species for dugong (Preen 1995b). All seagrass meadows surveyed were contained wholly within the DPA boundaries. Most of these habitats were at intertidal depths and not accessible to dugong during low-tide periods. The scarcity of seagrass habitat in sub-tidal areas is likely a result of large tidal ranges and tidal currents and corresponding high coastal water turbidity. Influence of tide-generated currents on coastal turbidity, on the sub-tidal extension of seagrass habitat and on availability of food to dugong, increases from regions of small tidal range (eg., Hinchinbrook region - Lee Long et al. 1998) to medium tidal range (eg., Upstart Bay), large tidal range (Newry region and Llewellyn/Ince Bays) and very large tidal range (eg., Shoalwater Bay region – Lee Long et al. 1997).

Bays with the greatest seagrass abundance were all “DPA A”, offering the higher level of protection (Upstart Bay, Newry region and Ince Bay). Two bays assigned “DPA B”

had little (Llewellyn Bay) or no (Sand Bay) seagrass. Anecdotal evidence is that dugong may move through these areas which would then act as a buffer to the "A" areas. Clairview region although assigned as a B area appeared to support similar dugong populations to the nearby A area in Ince Bay.

Except for Nobbies Inlet in Upstart Bay, almost no seagrass was found in creeks and rivers entering into the DPAs. Under present management arrangements for net fishing in DPAs only, limited netting (limited to 3 nets in "A" and "B" zones and fishers must be within 800m of nets) is allowed in the creeks and rivers. Because there is no seagrass in these creeks and rivers, the net fishery is unlikely to lead to conflict with feeding dugong (R. Garret, QDPI, pers. comm. 2001). In the Upstart and Newry DPAs, some important dugong feeding habitats are also areas of high recreational vessel traffic, where threats to dugong through boat strike and disturbance to feeding, are increasing.

Temporal Changes

Recent research and monitoring programs are showing that many of the seagrass species in tropical waters may vary greatly in abundance seasonally and inter-annually. The range of change may extend to entire species being absent at times of the year (eg. *Halophila tricostate,* Kuo et al. 1993) and meadows changing and moving significantly (Lee Long et al. 1997; McKenzie et al. 1998). Little quantitative long-term information is available for the DPAs and the best interpretation from the present study is that there is no evidence of seagrass being less now than in 1987. However, regular seasonal and annual surveys are necessary to build a more detailed picture of the range of changes that dugong face in finding food throughout the year and between years.

Little seagrass was found in the deepwater (10m to 20m) video camera surveys although some areas appeared to be suitable habitat for seagrass colonisation. Typical deepwater seagrass species such as *Halophila decipiens* and *Halophila tricostata* are known to be highly seasonal in abundance and tend to germinate in early spring and disappear by late summer (Kuo et al. 1993), times in between the sampling times in the present study. Little is known about the importance of *Halophila tricostata* and *Halophila decipiens* to dugong diets.

Implications for Dugong Management and Fisheries

Coles et al. (1997) described seven classes of information on seagrasses needed to assess the value of a seagrass habitat for dugong. These were:

1. Estimates of seagrass area and biomass available;
2. Above-ground and below-ground biomass measures;
3. Mix of seagrass species present;
4. Range of depths and availability to dugong;
5. The area, biomass, availability, productivity of seagrass required to support a dugong in breeding condition;
6. Long term trends in area, biomass, species composition, and productivity; and
7. Seasonal changes in seagrass parameters.

For the DPAs in this study there is now a set of information to answer points 1, 3, and 4. We have little information on below ground biomass although roots and rhizomes make up a significant proportion of the food dugong eat. Key pieces of information missing are rates of seagrass productivity through a year and long term trends in seasonality and what area of seagrass is required to support a dugong.

It is essential that research is undertaken to answer these questions, however empirical estimates can be made based on numbers in Hervey Bay to the south. These suggest that a maximum population of around 2000 animals was supported by nearly 2000 square kilometres of seagrass. Historically, numbers of dugong per area of seagrass may have been much higher. Unlike the DPAs in the present study some of the Hervey Bay seagrass resources include large areas of subtidal habitat that is always available although some is in a 20 to 30 metre depth range and may not be ideal for feeding. A best estimate with this in mind would be that on average an area of available seagrass of between 50 and 100 hectares is required to provide long-term food support for a dugong. A sustainable dugong population for the Upstart Bay to Ince Bay DPAs based on these estimates would be 55 to 110 animals.

The dense *Zostera capricorni* meadows in Upstart Bay and the Newry region support commercial prawn and fish species. Similar meadows in other north Queensland locations are also important nursery habitats for juvenile prawns (McKenzie et al. 1996; Coles et al. 1993). The survey results in the present study support the protection of seagrasses under the *Queensland Fisheries Act 1994* as these habitats are confirmed as components of the ecosystem supporting sustainability of the east coast prawn and fin fish fisheries.

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