Plant-Herbivore Interactions between Seagrasses and Dugongs in a Tropical Small Island Ecosystem

een wetenschappelijke proeve op het gebied van de Natuurwetenschappen

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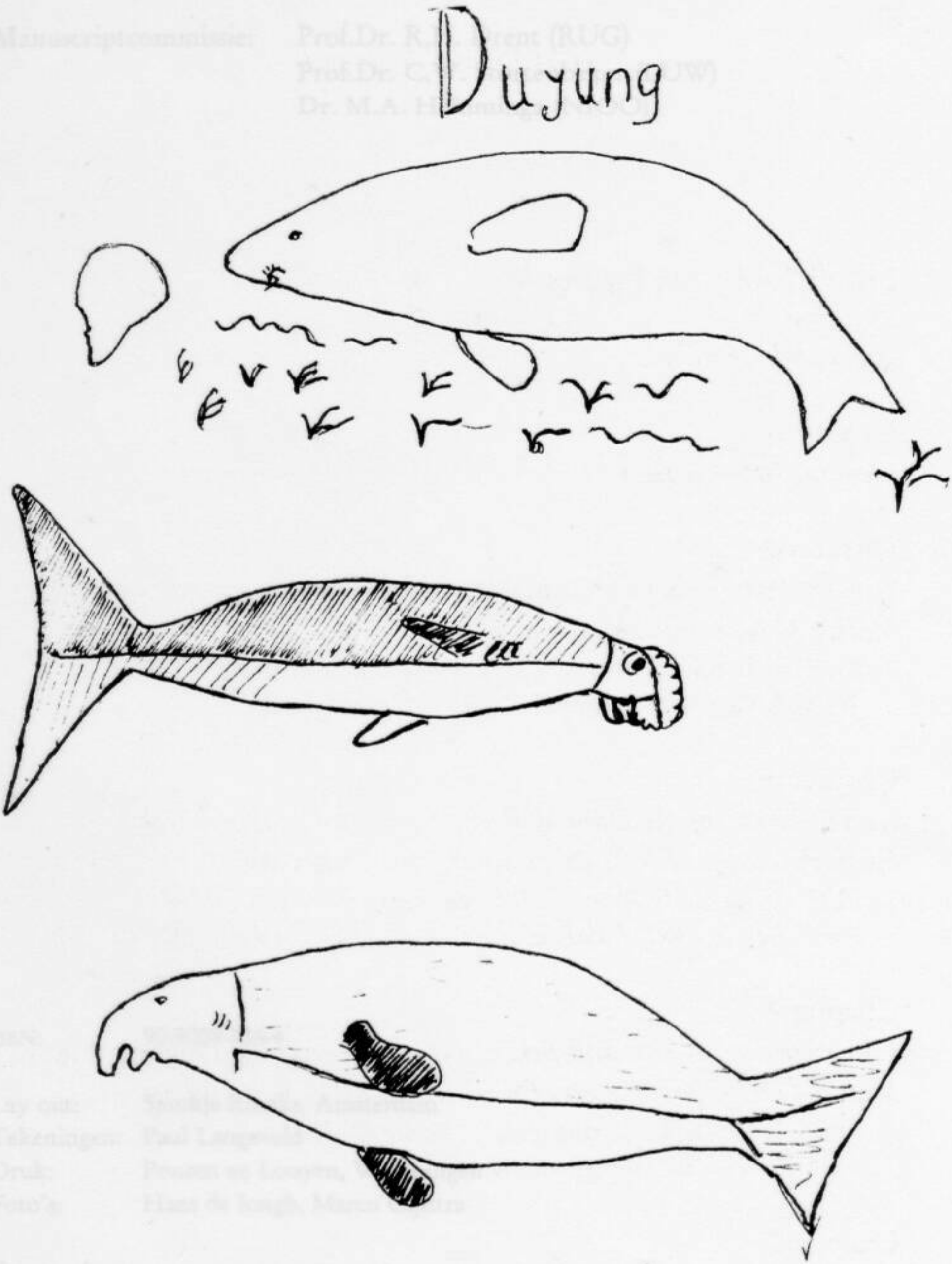

Dugong drawings of Moluccan pupils from the elementary school of Koijabi, East Aru (courtesy Gerard Persoon)

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Chapter 1

General Introduction

Samuel Fallours' painting of the 'Sirenne', which he kept in a bath tub at Ambon for four days and seven hours in 1712. It died presumably of hunger, since it refused to eat (Pietsch, 1991)

General Introduction

The present thesis covers the results of a research programme on the feeding ecology of the dugong (*Dugong dugon* Müller, 1776) in a tropical island ecosystem. The dugong was chosen as a study subject because its supposed important role in the seagrass ecosystem (Thayer *et al.*, 1984) and because most of its feeding ecology in tropical island ecosystems is still a mystery.

Ambon and the Lease islands in the Moluccas Province of East Indonesia were selected as a study area, because they represent all the characteristics of a typical tropical small island ecosystem and are well accessible to the researchers and harboured a dugong population (Figs 1.1 and 1.2).

The present thesis is based on the supposition that the survival value of the social organization adopted by a given species can only be fully appreciated if its relationship with food exploitation has been studied (Clutton-Brock & Harvey, 1978; Prins, 1987, 1989).

The Dugong

The dugong (*Dugong dugon* Müller, 1776) is the only true marine herbivorous mammal. Together with the three species of the riverine and euryhaline manatees they form the order of the Sirenians, the sea cows (Marsh *et al.*, 1984).

A fifth species, the Steller's sea cow, which was found in the Bering Sea, was exterminated by passing sailors in the 17th century. The scientific classification of the Sirenians is as follows:

Order:	Sirenia	
Family:	*Dugongidae*	*Trichechidae*
Subfamily:	*Dugongidae*	*Trichidae*
Genus:	*Dugong*	*Trichechus*
Species:	*Dugong dugon*	*Trichechus manatus*; *T. senegalensis*; *T. inugius*

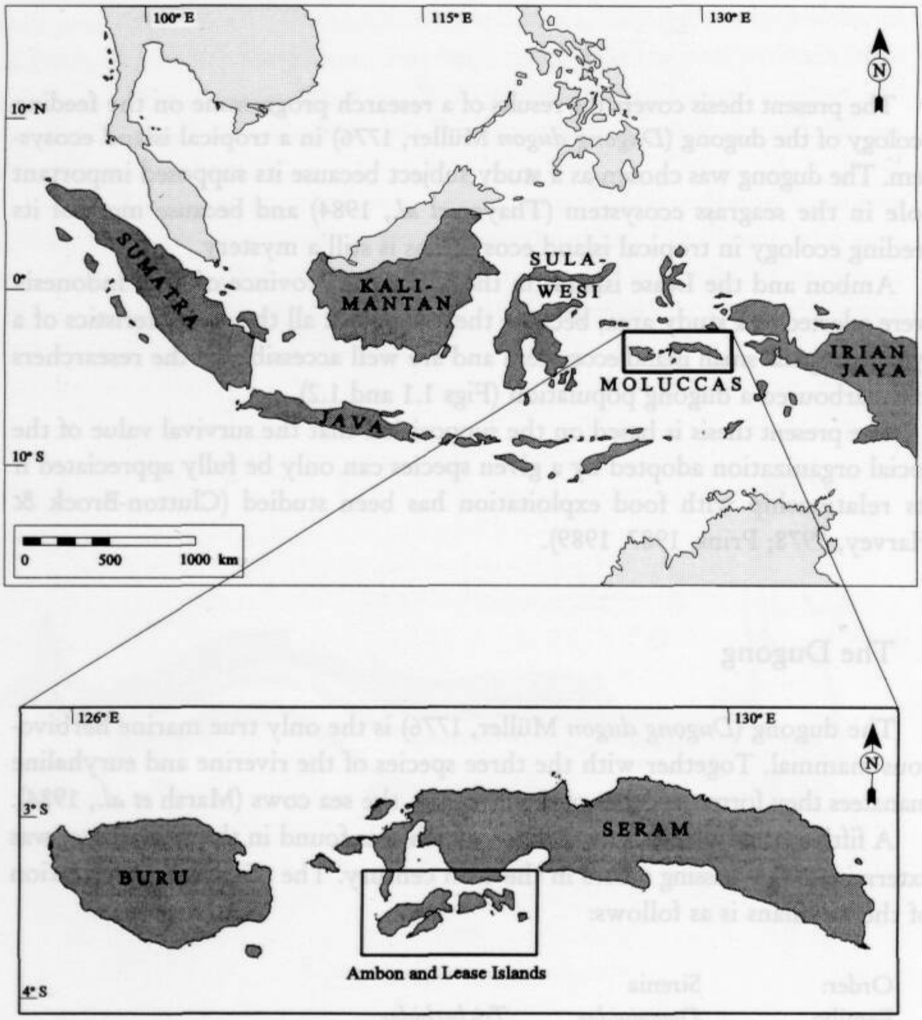

Figure 1.1

Maps representing the location of the study area in the Indonesian archipelago (above) and a more detailed map of Ambon, the Lease islands, Seram and Buru (below)

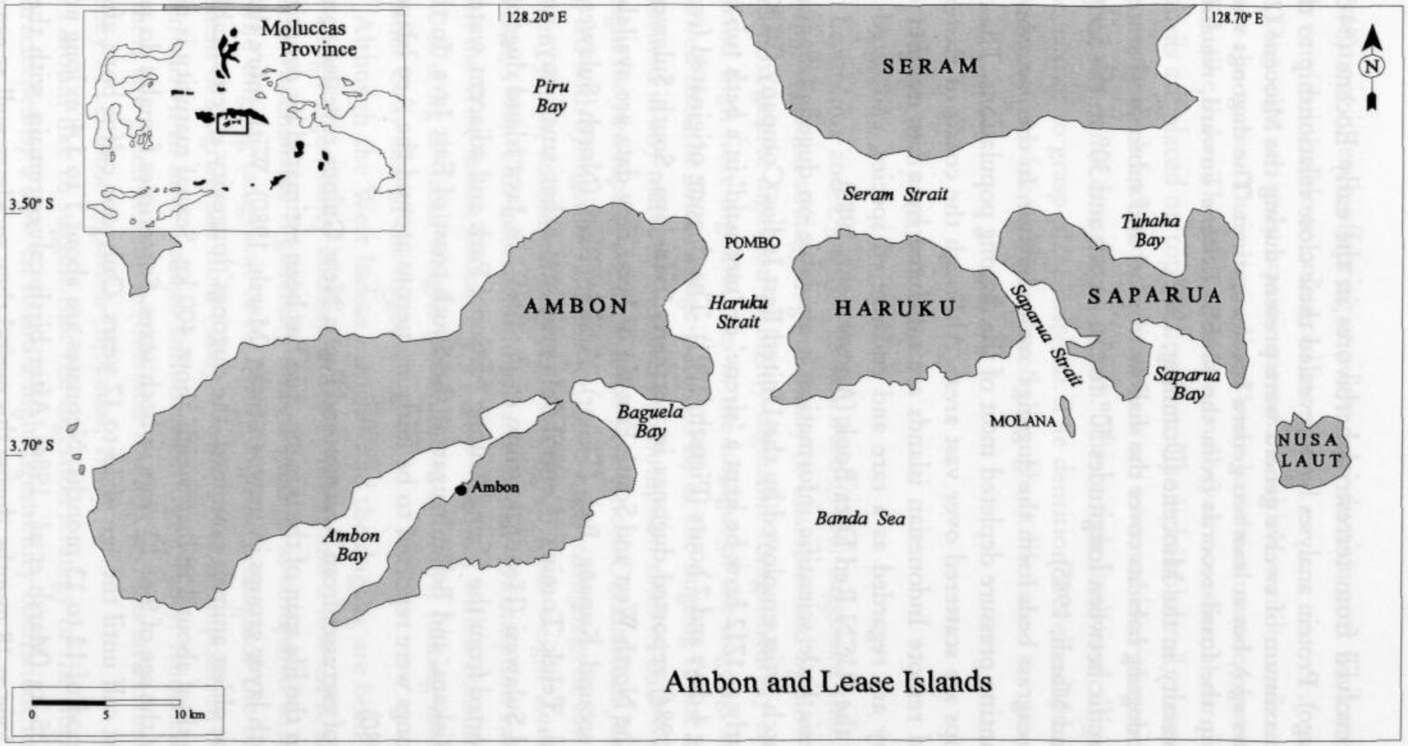

Figure 1.2

Map representing the study area of Ambon and the Lease islands

Sirenians evolved from terrestrial herbivores in the early Eocene (54-38 million years ago). Protein analyses have revealed their close relationship to the elephants. A maximum of twelve genera were present during the Miocene (26-27 million years ago), but at least ten genera became extinct. The dugongs were conspicuous in the fossil records from the Middle Eocene onward, reaching their peak diversity in the Miocene (Domning, 1982).

At present dugong habitats cover the shallow tropical and subtropical waters of the Indo-Pacific between longitudes 30° to the North and 30° to the South (Nishiwaki and Marsh, 1985).

Extensive seagrass beds form the dugongs' major habitat. In the past centuries severe hunting pressure depleted most of the dugong populations. The remaining groups are scattered over vast areas. Although the coasts of Eastern Australia and remote Indonesian islands are inhabited by a fair number of dugongs, they are regarded as a rare and endangered species, and listed as vulnerable in the IUCN Red Data Book (Anonymous, 1988).

In Indonesia little scientific information is available on dugongs. Samuel Fallours, a Dutch artist employed by the United East Indies Company (VOC) described as early as 1712 how he kept a 'sirene' or 'mermaid' in a bath tub on Ambon during 4 days and 7 hours (Pietsch, 1991). The dugong originated from Buru. Salm (1984) reported dugongs in northern Irian Jaya, South Sulawesi, Sumatra and the North-West and South-East tip of Java. Few data are available on dugongs around Kupang Bay (Timor), Arakan Reef (North Sulawesi), Togian island, Teluk Toming (Central Sulawesi) and other small bays and straits around Sulawesi (Hendrokusumo *et al.*, 1981). In Java island dugongs have been reported from the Ujung Kulong National Park and adjacent waters like Teluk Miskam, and Belambangan at the South coast of East Java. In the Moluccas dugongs were reported to be fairly numerous around the Aru islands (Compost, 1980).

The study of carcasses from Australia and Papua New Guinea revealed some information on the life span of the dugong. Age has been estimated by counting dentinal growth layer groups in unworn tusks (Marsh, 1980). With more than 70 years for the oldest animals examined, the dugongs' longevity is remarkable. At a body length of about 3 m they weigh about 400 kg. Sexual maturity is not reached before the age of 9 or 10 years in both sexes. Sometimes females do not have their first calf until the age of 15 to 17 years. Only one calf is born after a gestation period of 12 to 13 months. Neonates are about 1 to 1.4 m long and weigh 20 to 35 kg (Marsh *et al.*, 1984). After birth calves remain with their mother for as long as 18 months, during this period they suckle as well as graze. The calving interval ranges from 3 to 7 years. The dugong is a species with high investment in each offspring at a low reproduction rate. This means that they are very vulnerable to enhanced mortality.

Dugongs are truly aquatic mammals, which - unlike seals - never have to leave the water. Their streamlined body has short rounded fore-flippers and a whale-like fluke. The large head has small eyes, no external ear pinnae and the nostrils are placed on top of the snout. The light coloured, almost bare skin is extremely thick and smooth. Sinus hair are scattered over the entire body, and especially dense around the mouth. The muzzle itself is a complex structure, specialized to grasp plant material. The dentition is well adapted to grind the food, a series of teeth are replaced throughout lifetime.

Digestive System

Lomolino and Ewel (1984) and Burn (1986) suggested that the sirenians feeding/digestion strategy in general may be characterized by slow passage rates and post-gastric digestion of highly digestible forage. Murray *et al.* (1977) reported high fibre digestibilities in the hindgut of the dugong. Lanyon (1991) showed that the Gut Passage Rate (GPR) of the dugong is one of the slowest measured in any mammal and found consumption rates of 26.0-47.5 kg d^{-1} fresh weight for two captive dugongs in the Jaya Ancol Oceanarium Jakarta, Indonesia, fed with *Syringodium isoetifolium*. Two captive dugongs in the Toba Oceanarium, Japan, consumed between 15-30 kg d^{-1} fresh weight *Zostera capricorni* (Wakai, 1995). This information indicates similar consumption rates, compared with the West Indian Manatee *Trichechus manatus*, with a consumption rate of 43.0-57.3 kg d^{-1} fresh weight (Lomolino *et al.*, 1984) (taking into account the smaller body size of the dugong).

Although the West Indian manatee and the dugong are both characterised by a high digestibility coefficient for cellulose and a low GPR the food available to the manatee is generally more digestible as compared to the main food of the dugong (seagrass). A relatively high percentage of the organic matter content of seagrasses is fibre (Thayer *et al.*, 1984). Composition of the diet has been shown to have a major influence on digestibility. Another seagrass consumer, the green sea turtle (*Chelonia mydas*), also has an extremely high efficiency of cellulose digestion (Bjorndal, 1980).

I would like to suggest that the digestion strategy of the dugong, which is characterised by a slow GPR and a high digestibility coefficient for cellulose, is an adaptation to its low quality forage (seagrass). As a consequence I expect that the dugong, as part of its 'optimal foraging strategy', selects seagrass with a low neutral detergent fibre (NDF), a high *in vitro* digestibility and a high carbohydrate content. I believe that the particular characteristics of the dugongs digestion strategy is probably a key factor explaining much of its feeding ecology and social organization, including population size and density, dispersion and herd size, movements and home range and spatial and temporal feeding pattern.

Population Density, Herd Size and Movements

Few scientific records are available on the population density, and movements of individual dugongs in small tropical island ecosystems. During aerial surveys Brownell *et al.* (1981) reported 5.4 dugongs per hour in the Palau archipelago (West Pacific), while Rathbun and Ralls (1988) mentioned 7.5 dugongs per hour in the same study area eight years later. Marsh *et al.* (1984) recorded 9.2 dugongs per hour in Torres Strait and during aerial surveys in the Philippines 1.9 dugongs per survey hour were reported (Trono, 1995). These numbers are low, when compared with the 150 dugongs per hour recorded by Marsh (1985) during aerial surveys in North Australia. The maximum herd size reported for tropical island ecosystems is 7 in Palau (Rathbun and Ralls, 1988) and 6 in Torres Strait (Marsh *et al.*, 1984), while a maximum of 20 is recorded in Queensland (Marsh and Saalfeld, 1987) and distinct herds of 100 or more have been recorded from Moreton Bay (North-East Australia), Shark Bay (West Australia), the Arabian Gulf and Cape York (North Australia), the first three locations representing sub-tropical areas (Preen, 1993). The available scientific literature suggests a smaller maximum herd size and a higher dispersion of dugongs in tropical island ecosystems compared to the Australian continental shelf and sub-tropical areas. Anderson (1985) mentioned that the extreme dispersion observed in Torres Strait and Palau compared with Shark Bay and North Queensland may be a result of disturbance and hunting pressure, but I believe that the pattern is too regular to be solely explained by disturbance factors.

Preen (1993) stated that dugong herds may be more than just feeding assemblages and may also have a social function. Anderson (1982) also assessed that dugongs are 'essentially' gregarious, though frequently solitary. I hypothesise that dugongs with reported herd size ranging from 1 to 674 (Preen 1993) can be classified as 'mildly social' and 'facultative herders' and represent rather feeding assemblages with loose social interaction than fixed herds with a strong social bond.

No scientific records are available on movements of dugongs in tropical small island ecosystems, and few in tropical waters. Most scientific information on movements refers to studies in Australia. Marsh and Rathbun (1990) developed a technique for satellite tracking individual dugongs and tracked six dugongs caught off the north Queensland coast. Preen (1993) tracked 13 dugongs in subtropical Moreton Bay including four males (two adults, two sub-adults) and nine females (five adults, four sub-adults). Six dugongs were tracked through winter, four through spring and summer.

Preen (1995a) recently reported on the preliminary results of telemetry studies in the (tropical) Gulf of Carpentaria (North Australia) during 1994, where he satellite-tracked five adult dugongs. The results of the studies of Marsh *et al.* (1990) and Preen (1993; 1995a) provided information on the movements of individual dugongs in coastal areas of tropical (only males) and sub-tropical (both males and females) Australia. The available studies do not cover movements of females in tropical island ecosystems outside Australian coastal waters and indicate a pattern of high individual mobility and regular visits to 2-3 core areas.

Dietary Preference

The dugong (*Dugong dugon* Müller 1776) feeds predominantly on seagrasses (Gohar, 1957; Heinsohn *et al.*, 1977; Anderson and Birtles, 1978; Marsh *et al.*, 1982). Several authors suggested dietary preference of dugongs for 'soft' and 'sparse' pioneer species such as *Halodule uninervis* (Forsk.) Aschers. and *Halophila ovalis* (R. Br.) Hook. f. (Gohar, 1957; Heinsohn and Birch, 1972; Lipkin, 1975; Johnstone and Hudson, 1981). Heinsohn and Spain (1974) reported the consumption of brown algae by dugongs in tropical North Queensland after extensive damage to seagrass beds caused by a cyclone. Based on the analyses of 95 North Queensland dugongs Marsh *et al.* (1982) concluded that the generic composition of stomach contents probably reflects that of the seagrass beds in the areas where the dugongs were captured and is not necessarily indicative of discrimination in selecting food. They also stated that even local differences in dietary intake indicated by her study [and by Gohar (1957), Heinsohn and Birch (1972), Lipkin (1975) and Johnstone and Hudson (1981)] may be, at least partly, an unavoidable artefact of the sampling. However Marsh *et al.* (1982) did not reject the possibility of preferential feeding of dugongs on specific seagrass species. It is an important observation that in their study *Halodule* and *Halophila*, representing pioneer genera, were the most dominant food items present in 95% and 89% of the stomachs respectively, while seagrass rhizomes were present in all stomachs.

Preen (1993) studied dugongs in subtropical Moreton Bay, South-East Australia, and found that they fed on very sparse seagrass beds of delicate species of *Halophila* and *Halodule* more frequently than on others. He found quantitative evidence suggesting that dugongs in Moreton Bay preferred seagrasses in the following decreasing order: *Halophila ovalis* > *Halodule uninervis* > *Halophila spinulosa* > *Syringodium isoetifolium* > *Cymodocea serrulata*. Herbivores select food items that maximise the rate of energy intake (Pyke *et al.*, 1977; Belovsky, 1978), and nitrogen intake (Owen-Smith and Novellie, 1982) and that maximise the digestion rate (Westoby, 1974; Van de Koppel *et al.*, 1995). Recent studies showed that dietary preference of dugongs for certain seagrass species may be influenced by nutritional requirements (Lanyon, 1991; Preen, 1993).

Lanyon (1991) stated that dietary preference of dugongs is based on high total nitrogen (N) and low neutral detergent fibre (NDF) in seagrass. Also terrestrial herbivores, such as the African buffalo *Syncerus caffer* (Sparrman) are reported to select their diet on high total N (Prins, 1989). Preen (1993, 1995c) showed that dugongs in sub-tropical Moreton Bay may have significant quantities (in 69% of samples and 29% of wet weight) of ascidians (a source of animal protein) in their stomach. Also Anderson (1986) reported dugongs deliberately foraging on invertebrates in sub-tropical Shark Bay (West Australia). These observations are confirmed for dugongs in tropical regions (Hirakasa, 1932; Harry, 1956; Jones, 1959), and suggest dugongs to be facultative omnivores, contrary to large terrestrial grazers such as the African buffalo. As a consequence total N may be a less important nutritional factor for dugongs as stated by Lanyon (1991).

Preen (1993) suggested soluble carbohydrates as a possible important factor for diet selection by dugongs. The study of Lanyon (1991) did not cover a possible preference of dugongs for carbohydrates in the below-ground biomass of seagrass. The importance of seagrass rhizomes and roots as a food source for dugongs has been stressed by Anderson (1991) and Erftemeijer *et al.* (1993).

Taking into account the observed (facultative) omnivory of the dugong and the suggestion that the dugongs low quality forage (seagrass) may be a key factor to explain its feeding/digestion strategy, I support the hypothesis, contrary to Lanyon (1991), that the maximisation of energy and digestion rate, rather than total nitrogen would be major factors determining its pattern of dietary preference for seagrass.

Dietary preference of dugongs for soft and small pioneer seagrass species, in my view, is therefore part of its feeding strategy as a permanent response to low quality forage.

Cultivation Grazing

Several studies proved that both seagrass quantity and quality are important factors regulating dugong population size, density and dispersion. Heinsohn and Spain (1974) reported increased movements of dugongs off Townsville (Queensland) in search of food following severe damage to seagrass beds caused by a cyclone in December 1971. Jones (1969) reported a great reduction in the number of dugongs along the South Indian coast during 10 years following a cyclone in December, 1954. Preen *et al.* (1995) reported a significant depletion of a dugong population in Hervey Bay from 2,206 (±se 420) to 600 (±se 126) individuals 21 months after a cyclone destroyed approximately 1,000 km^2 of seagrass bed during February/March 1992. Preen (1993) proved that dugongs in Moreton Bay suffer seasonal stress and show a loss of condition and fat reserves in winter, when seagrass biomass and nutritional quality shows a minimum. During a detailed study of the grazing impact of the West Indian Manatee (*Trichechus manatus*) on seagrasses in South-East Florida Lefebvre and Powell (1990) defined two hypothesis; one that 'manatees, like turtles, may be maintaining a source of forage of higher nutritional value by returning to previously grazed sites' and a second hypothesis that 'grazing alters the texture of the substrate, so that roots and rhizomes become easier to remove'. Similar observations were made by De Boer and Prins (1990) for terrestrial grazers with respect to the African Buffalo (*Syncerus caffer*), which appeared to manipulate the vegetation at the level of a patch and showed a foraging strategy which is characterized by a periodic cyclical return to these mono-specific patches. By choosing the appropriate return time the buffalo could optimize the quality of the vegetation in relation to their food requirements.

Preen (1993, 1995b) demonstrated that intensive grazing by a large herd of dugongs (referred to as cultivation grazing) can have significant effects on seagrass meadows. Cultivation grazing can alter the species composition, the age structure and the nutrient status of seagrass meadows. As a result, relatively high biomass, climax communities can be converted to ones of low biomass and pioneer stage. In his study *H. ovalis* gains advantage by these changes, at the expense of *Z. capricorni* (broad leaved form). According to Preen (1993) this change of species results in a meadow-wide increase in nitrogen levels and decrease in fibre levels.

Preen (1993) argued that it is the combination of a sub-optimal diet and the seasonal stresses imposed by the cold water (resulting in a loss of condition) in Moreton Bay and that the dugongs attempt to counter these stresses by maximising the quality of their diet through cultivation grazing. Also according to Preen (1993, 1995b) the nutritional benefits of cultivation grazing can only be achieved if dugongs feed in large herds, and effect these changes over large areas. By feeding in large herds dugongs achieve a sufficient density of feeding trails, over a large enough area to effect an advantageous change in species composition. Preen (1993) also stated that in tropical areas the benefits of cultivation grazing may not be necessary, or relevant, in which case there may be no pressure to feed in large herds.

I suggest that the digestion strategy of the dugong, which is characterised by a slow GPR and a high digestibility coefficient for cellulose, is a permanent adaptation to its low quality forage (seagrass), and I hypothesise that thus the particular feeding strategy of the dugong aims at a maximisation of energy and digestion rate. Thus cultivation grazing, in my view, is a permanent response to cope with a low quality forage rather than a response related to seasonal nutritional stress factors and cold water temperatures during winter as postulated by Preen (1993) and dugongs in tropical areas may perform cultivation grazing, even in smaller herds.

Hypothesis

To assess the interaction between dugongs and seagrass beds in a tropical island ecosystem both the foraging strategies of dugongs and the seasonal dynamics of the preferred seagrass species have to be known. So knowledge has to be acquired on the nutrient and energy requirements of dugongs and the related feeding preference and temporal and spatial feeding patterns on preferential seagrass meadows. Herbivores select food items that maximise the rate of energy intake (Pyke *et al.*, 1977; Belovsky, 1978), of nitrogen (Owen-Smith and Novellie, 1982), or that maximise digestion rate (Westoby, 1974; Sorensen, 1984) if digestion is slower than ingestion.

This study was based on the hypothesis that both the dugongs digestion and feeding strategy can be characterised as a permanent response to its low quality forage (seagrass). These conditions may explain most of its social organization and feeding ecology, including population size and density, dispersion and herd size, movements and home-range, dietary preference and temporal and spatial feeding patterns.

With respect to the dugongs *social organisation*, I regard dugong herds as facultative feeding assemblages with a loose social interaction rather than fixed herds with a strong social bond (Chapters 3 and 6).

With respect to the dugongs feeding ecology, I would like to postulate that the *feeding ecology* of dugongs is predominantly characterised by permanent adaptations, and not by seasonal stress oriented adaptations such as suggested by Preen (1993). In my view these permanent adaptations include: a) a pattern of dietary preference, b) spatial feeding patterns, and c) temporal feeding patterns.

With respect to *the pattern of dietary preference* I hypothesise, contrary to Marsh *et al.* (1982) but in support of Preen (1993), a preference for soft and small pioneer species *Halodule* and *Halophila* in my study area (Chapters 2, 5 and 7). In my view this dietary pattern is principally aiming at energy maximisation and maximisation of digestion rate rather than total nitrogen (Chapter 2). I have classified dugongs, unlike terrestrial grazers such as the African buffalo, as facultative omnivores and thus I support the hypothesis that dietary preference which is principally aiming at maximisation of total nitrogen as postulated by Lanyon (1991) and Preen (1993) is less likely (Chapters 2 and 8).

With respect to *spatial feeding patterns*, contrary to Preen (1993), I support the hypothesis that cultivation grazing of smaller herds of dugongs in my study area is possible as part of a permanent response to a low quality forage. The following arguments give further support to my hypothesis: a high dispersion of dugongs over small feeding assemblages and a high individual mobility through regular visits to 'core areas' in my study area will spread the feeding pressure over the different 'core areas' and thus prevent over-exploitation of one particular 'core area' (Chapter 3 and 6). In addition cultivation grazing by a small feeding assemblage on restricted 'core areas' will maintain a pioneer meadow with a low standing crop and will optimize energy and digestion rate (Chapters 4, 5, 7 and 8).

With respect to *temporal feeding patterns*, the temporal feeding of dugongs on intertidal *Halodule uninervis* meadows with a high level of total organic C in the below-ground biomass will support the aim of energy-maximisation (Chapter 5).

The main questions of this research programme are:

1. Is it possible to identify a pattern of dietary preference as part of dugongs feeding strategy and what are the major explanatory factors? (Chapters 2, 5 and 7)
2. What is the density and distribution of dugong populations in the study area and to what extent do body size and behaviour differ from Australian dugong populations? (Chapters 3, 4, 6 and 7)
3. What is the distribution and seasonal dynamics of seagrass meadows in the project area and what is the related maximum sustained population size of dugongs? (Chapters 5 and 7)
4. What is the effect of dugong grazing on the quantity, quality and species composition of seagrass meadows in the study area? (Chapters 4, 5 and 8)
5. What are the grazing patterns of dugongs in space an time and what are the explaining factors? (Chapters 4, 5, 6, 7 and 8)
6. What patterns of movement and home-range size can be identified and to what extent are these related to food exploitation? (Chapter 6)

Outline of the Thesis

The present thesis describes the results of research on the interactions between dugongs and their habitat in Ambon and the Lease islands, East Indonesia. Chapter 2 describes the results of a 'cafeteria' experiment with a captive adult female dugong, kept in Surabaya Zoo, executed during 1992 and 1993, and gives information on the dietary preference for different seagrass species. Chapter 3 covers the results of aerial surveys implemented during 1990 and 1992 in the Lease islands and provides a minimum population estimate. Chapter 4 describes observations on size and behaviour of captured (live and dead) and captive (live) dugongs in the Lease islands, in Surabaya Zoo and in the Ancol Oceanarium in Jakarta, made during 1990-1992. Chapter 5 gives an analyses of the interactions between dugongs and an intertidal seagrass meadow during 1991-1992 and provides information on the seasonal dynamics of this seagrass bed. The movements and home-ranges of four individual dugongs through the use of conventional and satellite telemetry during 1994 are described in Chapter 6. Chapter 7 covers an analyses of seagrass quantity and (accidental) mortality as major factors regulating dugong population size and the practice of concentrated recropping of grazing swards by dugongs as a major factor regulating herd size and dispersion, through fieldwork during 1992-1993. It also covers the application of a computer model to simulate dugong grazing and to estimate maximum sustained feeding pressure. In Chapter 8 the phenomenon of cultivation grazing in the Lease islands is described based on fieldwork during 1992 and 1993. Chapter 9, finally, provides a review of the nutritional ecology of the dugong in tropical small island ecosystems and recommendations for conservation and management of dugong populations in the study area. This chapter refers to a qualitative model describing the plant-herbivore interactions between seagrasses and dugongs.

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Chapter 2

*Dietary Preference of a Captive Held Dugong (*Dugong dugon *Müller 1776) in Surabaya Zoo, Indonesia*

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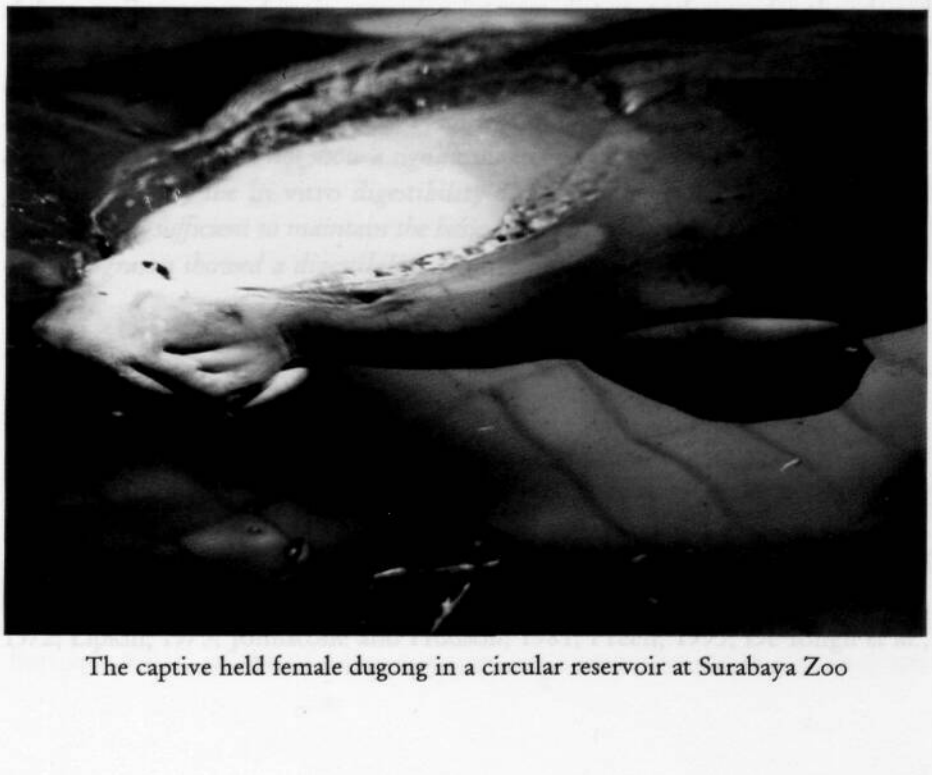
Submitted to *Wildlife Research*



The captive held female dugong in a circular reservoir at Surabaya Zoo

Dietary Preference of a Captive Held Dugong (Dugong dugon *Müller 1776*) *in Surabaya Zoo, Indonesia*

Abstract

A cafeteria experiment with a captive held female dugong in Surabaya Zoo implemented during 1992 and 1993 showed dietary preference for seagrass taxa offered. In spite of the fact that the animal had been exclusively fed with leaves of Syringodium isoetifolium *during the past 19 years, the experiment resulted in a sequence of decreasing preference:* Halodule uninervis *(Forsk.) Aschers.* > Halophila ovalis *(R. Br.) Hook. f.*/Cymodocea rotundata *Ehrenb. et Hempr. ex Aschers.* > Syringodium isoetifolium *(Aschers.) Dandy*/Thalassia hemprichii *(Ehrenb.) Achers. in Petermann. Linear regression between dietary preference for the selected species and different parameters was significant for* In Vitro *Digestibility (positive) and total Ca content (negative). In contrast Neutral Detergent Fibre (NDF), total Ash content, total N content, total P content, total Mg content, total Na content and total K content did not show a significant correlation with the observed dietary preference. Only the* in vitro *digestibility of* H. uninervis *(63%) and* H. ovalis *(50%) seemed sufficient to maintain the basic metabolism of the dugong, whereas all other seagrasses showed a digestibility below basic metabolic requirement.*

Introduction

Dugongs feed predominantly on seagrasses (Gohar, 1957; Heinsohn and Birch, 1972; Lipkin, 1975; Marsh *et al.*, 1982), incidentally on marine algae (Heinsohn *et al.*, 1974) and ascidians (Preen, 1993). Several authors suggested dietary preference of dugongs for 'soft' and 'sparse' pioneer species such as *Halodule uninervis* and *Halophila ovalis* (Gohar, 1957; Heinsohn and Birch, 1972; Lipkin, 1975; Johnstone and Hudson, 1981; Preen, 1993; De Iongh *et al.*, 1995). Based on the analyses of 95 north Queensland dugongs Marsh *et al.* (1982) concluded that the generic composition of stomach contents probably reflects that of the seagrass beds in the areas where the dugongs were captured and is not necessarily indicative of discrimination in selecting food. It is an important observation, however, that in the study of Marsh *et al.* (1982) the genera of *Halodule* and *Halophila*, representing pioneer species, were by far the most dominant food item and present in 95% and 89% respectively of the stomachs, while seagrass rhizomes were present in all stomachs. Erftemeijer (1993a) determined the fractions of food items in the stomach of a single dugong in South Sulawesi (Indonesia) and concluded that 60% of the stomach content on dry weight basis consisted of rhizome and root material. In subtropical Moreton Bay, Preen (1993) found quantitative evidence suggesting that dugongs prefer seagrasses in the following order of decreasing preference: *Halophila ovalis* > *Halodule uninervis* > *Halophila spinulosa* - (R. Br.) Aschers. > *Syringodium isoetifolium* > *Cymodocea serrulata* - (R. Br.) Aschers. et Magnus > *Zostera capricorni* Aschers. De Iongh *et al.* (1995) and De Iongh and Hein (1996a) found a similar preference for *Halophila* and *Halodule* during a field study in tropical waters of the Lease islands in East Indonesia. Although there seems consistency in the pattern of dietary preference of dugongs at different study sites, we still know little of the mechanisms behind this pattern. Several authors have confirmed the dugongs digestion strategy is characterised by a slow Gut Passage Rate (GPR) and a high digestibility coefficient for cellulose (Murray *et al.*, 1977; Murray, 1981; Lomolino and Ewel, 1984; Burn, 1986; Lanyon, 1991).

We suggest that the digestion/feeding strategy of the dugong is a permanent adaptation to the low quality forage (seagrass) provided by its marine habitat and may explain its pattern of dietary preference. As a consequence the dugongs feeding strategy could be based on the maximisation of nutrients (a.o. total nitrogen), digestibility rate and energy as major factors.

Some authors have stressed the importance of total nitrogen (N) in the dietary preference of dugongs. Lanyon (1991) stated that dietary preference of dugongs is based on high total N-content and low neutral detergent fibre (NDF). Her study did not cover a possible preference of dugongs for below-ground biomass of seagrass. Preen (1993) suggested, besides high total N, soluble carbohydrates in seagrass rhizomes as a possible important factor for diet selection by dugongs.

However, Preen (1993, 1995) also showed that dugongs in sub-tropical Moreton Bay may have significant quantities (in 69% of the samples) of ascidians (a source of animal protein) in their stomach. Anderson (1989) reported dugongs deliberately foraging on the thin shelled burrowing mussel (*Botula vagina*) and on seapens (*Virgularia* sp.) in sub-tropical Shark Bay (West Australia). Preen (1993) postulated that this omnivory by the dugongs in Moreton Bay is a response to seasonal nutritional stress combined with the physiological and energetic stresses caused by cold water temperatures at the edge of the species range. Anderson (1989) also observed that dugongs feeding on burrowing mussels and seapens created circular craters with a mean diameter of 54.9 cm (SE = 3.21 cm) and a mean depth of 8.7 cm (SE=1.96 cm). However, omnivory is confirmed for dugongs in tropical regions (Hirakasa, 1932; Harry, 1956; Jones, 1959), and these observations suggest that total N in seagrass may be a less important nutritional factor than stated by Lanyon (1991). We conclude that the dugong can be characterised as a facultative omnivore.

With reference to the above cited literature, we think that the observed pattern of the dugongs dietary preference for certain seagrass species may be explained by a maximisation of energy and digestibility rate rather than optimisation of total N.

It is remarkable that in the study of De Iongh *et al.* (1995) dugongs feeding on *Halodule* dominated intertidal meadows seemed to respond to subtle changes in total organic carbon content in the below-ground biomass during consecutive years. A threshold of 80% total organic carbon (as a % of total DW) seemed to trigger dugong feeding. These changes indicate an extremely high sense of dugongs for food quality.

The aim of the present study was to test the possible high sense of dugongs for seagrass quality and to test the hypothesis of maximising energy and digestibility rate as a possible mechanism explaining dietary preference during a cafeteria experiment with a captive held dugong in Surabaya Zoo. Since the animal had been exclusively fed with *Syringodium isoetifolium* leaves since its capture in 1975, it seemed unlikely that the dugong had developed a preference for different seagrass species due to variations in food supply during its captivity. Factors considered to classify seagrass quality were *in vitro* digestibility, neutral detergent fibre (NDF), total ash content, total nitrogen (N), total phosphorus (P) and minerals (Na, K, Mg and Ca).

Materials and Methods

Cafeteria test

A cafeteria test was performed twice on 18 September 1992 and 16 January 1993 with a captive held dugong in Surabaya Zoo. The dugong, a female with a length of 2.70 m, had been caught in 1975 in Gragagan Bay, South East Java and had been kept since in good health in a reservoir of 60 m^3 (circular 30 m^2, depth 2 m). The reservoir was refreshed weekly with a truckload of seawater obtained from the Street of Madura, some 30 km from the Zoo. The dugong had been fed daily in the morning at 8.00 a.m. with approximately 51 kg fresh weight of leaves *Syringodium isoetifolium*, which was transported over 300 km weekly by truck from Muncar (South East Java) and kept in a cool storage. Fresh weight of seagrass fed daily to the dugong was weighted to the nearest 0.1 kg during 7 days before each experiment. The main reason for feeding *Syringodium* leaves was the fact that those leaves float after being cut and are thus easily collected. (During a field trip to Muncar the authors observed 5 fishermen who collected 250 kg *Syringodium* leaves in less than two hours.)

Since the research team was based at the National Research Centre for Oceanology in Jakarta, it was decided to collect seagrasses in Banten Bay, approximately 150 km East of Jakarta. During September 1992 and February 1993 the following seagrass species were collected (5 kg fresh weight per sample of): *Halodule uninervis, Halophila ovalis, Cymodocea rotundata* (below-ground and above-ground biomass). *Thalassia hemprichii* was included only in the experiment of February 1993. *Syringodium isoetifolium* (only above-ground) was used from the stock in the cool storage of Surabaya Zoo. Seagrasses were identified according to Den Hartog (1970). The samples, obtained from Banten Bay, were stored in a coolbox on ice and directly after collection transported to Surabaya Zoo by car. The research team arrived in Surabaya the following day and made preparations for the cafeteria test at the Zoo. The seagrass samples were divided in patches of 0.5 kg fresh weight each and tied to a bamboo pole, with ropes of approximately 1.50 m long. During the two experiments the seagrass was offered in a different sequence, to avoid a bias of sequence. One day before the start of the cafeteria test, the dugong had to fast and the following morning at 8.00 a.m. (normal feeding time) the seagrass patches were offered simultaneously. An observer noted the number of bites per seagrass species during the experiment. In addition the time in minutes and seconds when the dugong had finished a certain seagrass species, after the start of the experiment, was registered using a stopwatch. Each experiment lasted 30 minutes. The seagrass species which were finished during the experiment, were considered most preferred. For those seagrass species which were not finished, the number of bites was used as an indicator, more bites representing a higher preference. After the experiments faeces in the reservoir were collected. Of each seagrass species approximately 150 gr (total biomass) was taken apart and dried in a stove at 70 °C to constant weight. Of the faeces 20 g were dried at 70°C to constant weight.

Seagrass and faeces were analyzed for Ash and NDF (Neutral Detergent Fiber) according to Goering and Van Soest (1970). N, P and minerals (Na, K, Mg and Ca) were measured after destruction with a mixture of H_2SO_4, Se and salicyclic acid. Nigrogen (N) and phosphorus (P) were measured with a Skalar San-plus autoanalyzer, minerals were measured with a flame photometer. The *in vitro* digestibility of feed offered, feed residues and faeces were analyzed according to Tilley and Terry (1963).

C:N:P sampling

During May-July 1991, as part of the preparations for the cafeteria experiment, seagrass samples from Haruku Strait, East Indonesia, had been analyzed for total carbon (%), total nitrogen (%) and total phosphorus (%). Five replicates were taken per species for atomic C:N:P analyses, with a PVC corer (Ø = 12.5 cm). Of the seagrass species used in the experiment, only *Syringodium isoetifolium* was not included, since it was not present at the study site. The samples were sieved (1 mm mesh size) and cleaned from sediment. The above-ground fraction and below-ground fraction were separated and DW and AFDW were analyzed according to Ott (1990). The samples were dried for 24 h in an oven at 70°C.

Seagrass tissue C, N and P content of dried, powdered plant tissue was measured on a Carbo-Eba NA 1500 C-/N-Analyzer (for C and N) or by a strong oxidizing acid digestion (hydrochloric acid + nitric acid + perchloric acid) followed by a standard colorimetric phosphate determination of the digest solution (for P) (Allen, 1974). Data are presented as the average of samples (±SD).

Statistics

The sequences of preference ranked according to the number of bites per seagrass species between the two cafeteria experiments were compared with a two-sample T-test. Significance of differences in the values of preference between species was tested with a one way ANOVA, followed by a Duncan test

(Pollard, 1977). The mean values (±SD) of IVD, NDF, Ash, N, P, Na, K, Mg and Ca per species of seagrass were calculated. A correlation analysis between dietary preference and selected seagrass parameters was executed, to confirm the significance of correlation (Zar, 1984). For comparison of the level of significance of the mean values of C%, N% and P% between seagrass species a Wilcoxon two-sample test was used ($P < 0.05$).

Results

Preference

The daily fresh weight measurements of *Syringodium* fed to the dugong 7 days prior to the experiment resulted in a mean of 5.1 kg DW d^{-1} (s.d.=0.7). The results of the cafeteria test are summarized in Table 2.1. They show that in September 1992 both *Halodule uninervis* and *Halophila ovalis* were finished during the experiment in respectively 12 and 11 bites respectively. During the experiment of February 1993 *Halodule uninervis* and *Halophila ovalis* were nearly finished in 15 and 8 bites respectively. The results of the two experiments are samples of the same distribution (t_{35}=-0.81; $P < 0.001$), they could therefore be grouped to make one sequence of preference. Preference varied significantly between species ($F_{4,32}$=102.3; $P < 0.001$), indicating that dugongs are able to distinguish preference as follows (differences between each are significant, Duncan test with 95% confidence level): *Halodule uninervis* > *Halophila ovalis* > *Cymodocea rotundata* > *Syringodium isoetifolium* > *Thalassia hemprichii.*

Seagrass and dung composition

The mean values (±SD) of IVD, NDF, Ash, N, P, Na, K, Mg and Ca per species of seagrass are presented in Table 2.1. A correlation analyses of both tests showed a significant positive correlation with IVD and a significant negative correlation with Ca (Table 2.2). Preference showed no significant correlation with any of the other separate parameters. This indicates that the dugong in our study may prefers food with high IVD values and low Ca content, like *Halodule uninervis* and *Halophila ovalis.*

Table 2.1

Preferences related to the nutritives properties of different seagrass species (mean ± SD)

Species	Sept. 1992 preference P (bites)	Jan. 1993 preference P (bites)	IVD %	NDF % fibre	Ash % Ash	N content % N	P content % P	Na content % Na	K content % K	Mg content % Mg	Ca content % Ca
Halodule uninervis	12 (F)	15	61.0 ± 8.4 (n = 9)	61.4 ± 7.6 (n = 8)	27.5 ± 7.1 (n = 9)	1.47 ± 0.63 (n = 9)	0.26 ± 0.17 (n = 9)	3.01 ± 1.2 (n = 9)	1.99 ± 0.2 (n = 4)	1.02 ± 0.21 (n = 9)	1.86 ± 1.43 (n = 9)
Halophila ovalis	11 (F)	8	50.5 ± 11 (n = 2)	69.6 ± 8.8 (n = 2)	26.9 ± 11 (n = 2)	2.13 ± 0.37 (n = 2)	0.26 ± 0.021 (n = 2)	2.64 ± 0.83 (n = 2)	0.795 ± 0.87 (n = 2)	0.98 ± 0.23 (n = 2)	2.79 ± 0.72 (n = 2)
Cymodocea rotundata	4	6	46.3 ± 16 (n = 5)	54.5 ± 13 (n = 4)	28.6 ± 7.2 (n = 5)	1.7 ± 0.62 (n = 5)	0.16 ± 0.078 (n = 5)	3.39 ± 1.4 (n = 5)	1.81 ± 0.12 (n = 2)	0.87 ± 0.097 (n = 5)	3.45 ± 1.29 (n = 5)
Syringodium isoetifolium	2	3	43.7 ± 10 (n = 2)	59.5 ± 3.3 (n = 2)	44.7 ± 8.8 (n = 2)	1.62 ± 0.15 (n = 2)	0.18 ± 0.035 (n = 2)	5.9 ± 0.83 (n = 2)	2.11 ± 0.085 (n = 2)	1.48 ± 0.16 (n = 2)	2.99 ± 1.33 (n = 2)
Thalassia hemprichii	no sample	0	17.8 (n = 1)	59.3 (n = 1)	36.5 (n = 1)	1.52 (n = 1)	0.19 (n = 1)	3.32 (n = 1)	1.62 (n = 1)	1.22 (n = 1)	4.96 (n = 1)
Dung			29.3 ± 12 (n = 2)	48.9 ± 11 (n = 2)	17.2 ± 1.6 (n = 2)	3.94 ± 0.59 (n = 2)	0.71 ± 0.25 (n = 2)	1.92 ± 0.71 (n = 2)	0.62 ± 0.12 (n = 2)	1.22 ± 0.87 (n = 2)	3.64 ± 0.52 (n = 2)

P = Preference; IVD = In Vitro Digestibility (%DW); NDF = Neutral Detergent Fiber (%DW); Ash = Total Ash content (%DW); N content = Total Nitrogen content (%DW); P content = Total Phosphorus content (%DW); Na content = Total Natrium content (%DW); Mg content = Total Magnesium content (%DW); Ca content = Total Calcium content (%DW); (F) = sample entirely consumed after experiment

Table 2.2

Correlation analyses between the results of the preference tests (pref1 and pref2) and seagrass variables, representing correlation coëfficient R and significance between brackets (sample size n = 5)

	pref1	pref2	ivd	NDF	Ash	N	P	Na	K	Mg	Ca
pref1	1.00	0.91	0.83	0.62	-0.73	0.38	-0.51	-0.55	0.26	-0.54	-0.82
	(0.00)	(0.02)	(0.07)	(0.25)	(0.15)	(0.52)	(0.37)	(0.33)	(0.66)	(0.34)	(0.08)
pref2	0.91	1.00	0.89	0.28	-0.67	0.02	-0.56	-0.42	0.50	-0.52	-0.88
	(0.02)	(0.00)	(0.04)	(0.64)	(0.21)	(0.97)	(0.32)	(0.47)	(0.38)	(0.36)	(0.04)
ivd	0.83	0.89	1.00	0.26	-0.48	0.21	-0.87	-0.12	0.74	-0.38	-0.97
	(0.07)	(0.04)	(0.00)	(0.66)	(0.40)	(0.72)	(0.05)	(0.84)	(0.14)	(0.52)	(0.00)
NDF	0.62	0.28	0.28	1.00	-0.29	0.69	-0.06	-0.35	-0.31	-0.05	-0.33
	(0.25)	(0.64)	(0.64)	(0.00)	(0.63)	(0.19)	(0.91)	(0.55)	(0.60)	(0.93)	(0.58)
Ash	-0.73	-0.67	-0.48	-0.29	1.00	0.36	0.21	0.90	0.07	0.95	0.35
	(0.15)	(0.21)	(0.40)	(0.63)	(0.00)	(0.54)	(0.73)	(0.03)	(0.90)	(0.01)	(0.55)
N	0.38	0.02	0.21	0.69	-0.36	1.00	-0.32	-0.30	-0.21	-0.32	-0.14
	(0.52)	(0.97)	(0.72)	(0.19)	(0.54)	(0.00)	(0.59)	(0.62)	(0.73)	(0.59)	(0.82)
P	-0.51	-0.56	-0.87	-0.06	0.21	-0.32	1.00	-0.20	-0.84	0.21	0.81
	((0.37)	(0.32)	(0.05)	(0.91)	(0.73)	(0.59)	(0.00)	(0.73)	(0.06)	(0.72)	(0.09)
Na	-0.55	-0.42	-0.12	-0.35	0.90	-0.30	-0.20	1.00	0.46	0.84	0.02
	(0.33)	(0.47)	(0.84)	(0.55)	(0.03)	(0.62)	(0.73)	(0.00)	(0.43)	(0.07)	(0.96)
K	0.26	0.50	0.74	-0.31	0.07	-0.21	-0.84	0.46	1.00	0.03	-0.73
	(0.66)	(0.38)	(0.14)	(0.60)	(0.90)	(0.73)	(0.06)	(0.43)	(0.00)	(0.95)	(0.15)
Mg	-0.54	-0.52	-0.38	-0.05	0.95	-0.32	0.21	0.84	0.03	1.00	0.20
	(0.34)	(0.36)	(0.52)	(0.93)	(0.01)	(0.59)	(0.72)	(0.07)	(0.95)	(0.00)	(0.73)
Ca	-0.82	-0.88	-0.97	-0.33	0.35	-0.14	0.81	0.02	-0.73	0.20	1.00
	(0.08)	(0.04)	(0.00)	(0.58)	(0.55)	(0.82)	(0.09)	(0.96)	(0.15)	(0.73)	(0.00)

IVD = In Vitro Digestibility (%DW); NDF = Neutral Detergent Fibre; Ash = Total Ash content (%DW); N = total Nitrogen (%DW); P = total Phosphorus (%DW); Na = total Natrium (%DW); K = total Kalium (%DW); Mg = total Magnesium (%DW); Ca = total Calcium (%DW)

Table 2.3

Total C, N and P content of seagrasses. Total atomic C, N and P content as % of the dry weight, with standard deviation (SD), for *Halodule uninervis* (Hd), *Cymodocea rotundata* (Cy), *Halophila ovalis* (Hp) and *Thalassia hemprichii* (Th) for the above-ground (a) and below-ground (b). F indicates a significant difference between a and b fraction of the same species. Behind each value are also given the species (same fraction) with significantly different values (n = 5, P < 0.05)

		C% (±SD)			N% (±SD)			P% (±SD)			C/N	C :	N :	P
Hd	a	38.2	(0.5) F	Hp Th	2.99	(0.15) F	Cy Ha Th	0.35	(0.02) F	Cy Hp Th	13	107	8	1
Hd	b	32.9	(1.9) F	Cy Hp Th	1.19	(0.15) F	Cy Hp Th	0.22	(0.03) F	Cy	30	153	5	1
Hp	a	33.0	(1.6) F	Hd Cy	2.83	(0.46) F	Cy Th	0.56	(0.05) F	Hd Cy Th	12	59	5	1
Hp	b	26.0	(2.7) F	Hd Cy Th	0.81	(0.17) F	Hd Ha Th	0.22	(0.03) F	Cy	30	120	4	1
Cy	a	37.1	(2.0)	Hp Th	1.77	(0.28) F	Hd Hp	0.22	(0.02) F	Hd Hp	21	171	8	1
Cy	b	40.4	(2.6)	Hd Hp	0.57	(0.16) F	Hd	0.14	(0.01) F	Hd Hp	72	287	4	1
Th	a	32.1	(2.8) F	Hd Cy	1.90	(0.41) F	Hd Hp	0.24	(0.06)	Hd Hp	17	137	8	1
Th	b	39.4	(1.8) F	Hd Hp	0.69	(0.24) F	Hd Hp	0.16	(0.07)	Ha	67	270	4	1

C:N:P analysis

The results of the atomic C:N:P analysis are summarized in Table 2.3. Average total C (%) content varied between 32.1 and 38.2% for the above-ground fractions (AG), and between 26.0 and 40.4% for the below-ground fractions (BG). Total C (%) was significantly higher in the above-ground fraction compared with the below-ground fraction for *Halodule uninervis* and *Halophila ovalis*, but significantly lower in the above-ground fraction for *Thalassia Hemprichii* ($P < 0.05$). Total N (%) content was between 1.77 and 2.99% (AG) and between 0.57 and 1.19% (BG) and total P (%) content was between 0.22 and 0.56% (AG), and between 0.14 and 0.22% (BG).

Total N (%) was significantly higher in the above-ground fractions of all species and total P (%) was significantly higher in the above-ground fractions of all species except for *Thalassia hemprichii* ($P < 0.05$).

Total C (%) was significantly higher in the above-ground fraction of *Halodule uninervis*, compared with the same fractions of *Halophila ovalis* and *Thalassia hemprichii*, but the below-ground fraction of *Halodule uninervis* showed only significantly higher values compared with the same fraction of *Halophila ovalis* and lower values compared with the same fractions of *Cymodocea rotundata* and *Thalassia hemprichii* ($P < 0.05$).

Total N (%) values were significantly higher in the above-ground fractions of *Halodule uninervis* and *Halophila ovalis* compared with the same fractions of *Cymodocea rotundata* and *Thalassia hemprichii*, and the same was observed for the below-ground fractions, except for *Halophila ovalis* compared with *Cymodocea rotundata.*

Discussion

The present study confirms the dugongs preference for the small and soft pioneer species *Halodule uninervis* and *Halophila ovalis* as reported by different authors (Gohar, 1957; Heinsohn and Birch, 1972; Lipkin, 1975; Johnstone and Hudson, 1981, Marsh *et al.*, 1982; Lanyon, 1991; Preen, 1993; De Iongh *et al.*, 1995; De Iongh and Hein, 1996a; De Iongh and Langeveld, 1996b).

Since the cafeteria experiment was only implemented twice, the results should be interpreted with some caution. However, the results are still remarkable, since the dugong had been exclusively fed with leaves of *Syringodium isoetifolium* since its capture in 1975, and confirm findings on preferential sequence of Preen (1993) and of De Iongh *et al.* (1995), indicating a high sense of quality by dugongs for seagrass species. In the present study the dugongs preference correlated positively with IVD, but negatively with Ca-content. Other factors, like NDF, total N, total P, Ash-content and minerals (Na, K and Mg) did not explain the observed preference in the present study. Also the C:N:P ratio of the investigated species does not explain the observed sequence of preference.

High *In vitro* digestibility in combination with low Ca-content, seem to be major factors to explain the dugongs preference for *H. uninervis* and *Halophila ovalis* in this study. This supports the hypothesis that the dugongs feeding strategy with respect to seagrass is based on a maximisation of digestibility rate and energy, rather than total N. The efficiency of digestion of food depends on a combination of the passage rate of food through the digestive track (Gut Passage Rate; GPR) and the rate of nutrient extraction (Van Soest, 1982). The relationship between these two factors may be an important determinant of how well an animal uses a particular food source and has even been found to influence food choice in several groups of herbivores. Generally, the longer the food remains in the gut, the greater the degree of chemical digestion of the food (Van Soest, 1982). Beekman and Prins (1989) postulated that hindgut fermenters have a selective advantage when food quality is a limiting factor, whereas ruminants perform better when the quantity of food is limited. The dugong, like the manatee, combines slow consumption and passage rates and postgastric digestion of highly digestible forage (Lomolino and Ewel, 1984; Burn, 1986; Lanyon, 1992). In the present study only *H. uninervis* (IVD = 63%) and *H. ovalis* (IVD = 57%) seem sufficient to maintain the basic metabolism of the dugong. These were the most dominant species in the stomachs of 95 north Queensland dugongs reported by Marsh *et al.* (1982). All seagrass samples in our test showed values of total N above the critical level of 1.1% for cattle (Van Soest, 1982) except for the below-ground fractions of *Halophila ovalis*, *Cymodocea rotundata* and *Thalassia hemprichii*.

As a hind-gut fermenter, the dugong may attempt to maximize cell content intake if this fraction is the major contributor to the energy budget. De Iongh *et al.* (1995) proved that dugongs may adapt their frequency of feeding to periods when those seagrass species contain high levels of cell solutes, including energy-rich soluble carbohydrates in the below-ground parts. In this perspective dugongs seem to have at least two adaptations to their low quality diet. First, they have developed a high capacity of cellulose digestion by combining physiological adaptations in their intestinal track with a slow Gut Passage Rate. Secondly, they select more digestible forage by dietary preference for highly digestible pioneer species like *Halodule uninervis* and *Halophila ovalis*.

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Chapter 3

Aerial Survey of the Dugong (Dugong dugon *Müller 1776) in the Coastal Waters of the Lease Islands, East Indonesia*

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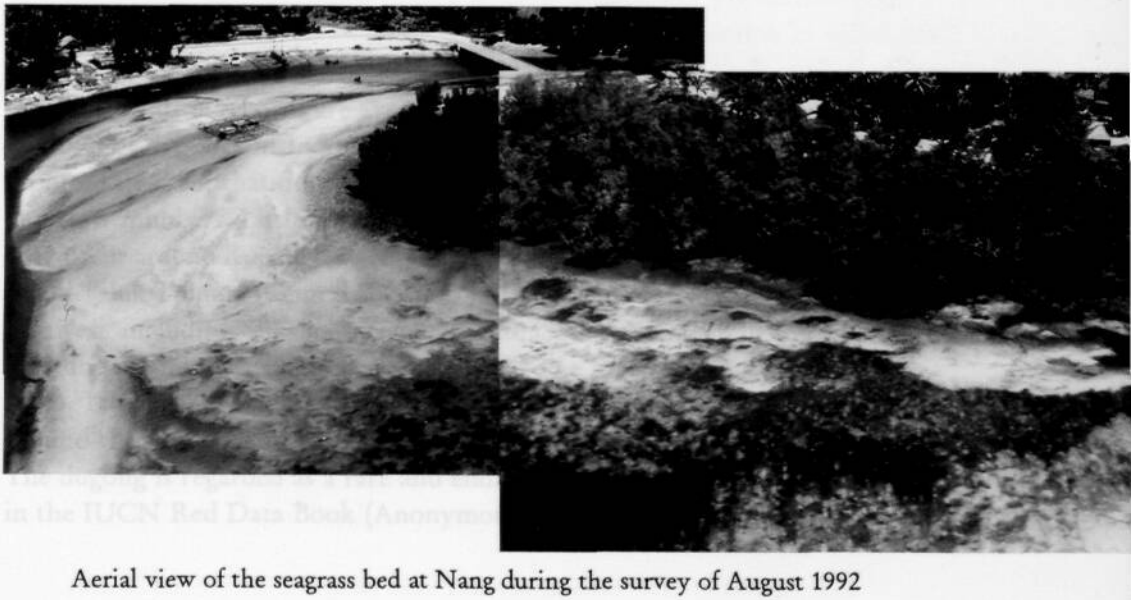

Aerial view of the seagrass bed at Nang during the survey of August 1992

*Aerial Survey of the Dugong (*Dugong dugon* Müller 1776) in the Coastal Waters of the Lease Islands, East Indonesia*

Abstract

During December 1990 and August 1992 aerial surveys of dugongs were made following the coastline of the Lease islands in East Indonesia. The aerial surveys followed a strip transect covering the coastal shelf and totalling 3.5 hours of observation. During the first survey a total of 17 dugongs was observed one of which was a neonate calf, during the second survey 10 dugongs were seen but no neonate calf. The minimum population of dugongs was estimated to be between 22-37 animals. The population is probably in interaction with a larger unidentified reservoir of animals in coastal waters of nearby Seram and Buru island.

Introduction

Few scientific records are available on the abundance, distribution and behaviour of dugongs in Indonesia. R.V. Salm (in Nishiwaki and Marsh, 1985) reported in 1984, that dugongs are scattered throughout Indonesia, usually in very low numbers. Little is known of the smaller populations other than that they occur around Kupang Bay (Timor), Arakan Reef (North Sulawesi), Togian Island-Teluk Tominy (Central Sulawesi) and other small bays and straits around Sulawesi including the Spermonde Island, South Kalimantan and Bangka-Belitung Islands (Karimata Strait) (Allen *et al.*, 1976; Nishiwaki and Marsh, 1985). Towards the end of 1979 dugongs were apparently still fairly numerous around the Aru Islands, their last known area of abundance (Compost, 1980). The dugong is regarded as a rare and endangered species, listed as 'vulnerable' in the IUCN Red Data Book (Anonymous, 1988).

Dugongs are known to feed on intertidal and subtidal meadows of the seagrasses *Halodule uninervis, Halophila ovalis* and *Halophila ovata*. These species are often found in low density stands (Heinsohn *et al.*, 1972; Marsh *et al.*, 1982; Lanyon, 1991). When dugongs feed on morphologically small-leafed seagrasses such as *Halodule* and *Halophila*, they uproot and consume the entire plant, including rhizomes and roots (Anderson and Birtles, 1978). This method of feeding produces characteristic feeding trails (Heinsohn *et al.*, 1977). No scientific reports are available on the presence of dugongs in the Moluccas Province, apart from the Aru Islands. The present study covers an aerial survey of dugongs in coastal waters of the Lease Islands (Ambon, Haruku, Saparua, Nusa Laut). The study was part of the Dugong Management and Conservation Project, funded by the European Development Fund, a project jointly implemented by the Environmental Study Centre of the Pattimura University in Ambon and the Foundation AID Environment in Amsterdam.

Study Site

The study area covers Ambon and the Lease Islands (Haruku, Saparua and Nusa Laut), located in the centre of the Moluccas Province on the east side of Indonesia (3°30'S, 128°E). The islands border the Banda Sea in the south and the Seram Sea in the north (Fig. 3.1).

The islands are characterized by a mountainous landscape. The highest mountain of Ambon reaches 1,036 m, whereas Haruku's highest points is 587 m. A shallow shelf of up to 20 m deep and on average 400 m wide is present along most of the shore. At the East coast of Ambon the widest shelf is found between the villages Waai and Tulehu It is at maximum 500 m wide. Seagrass meadows are all found on the coastal shelf. A sharp drop-off borders the flat. The maximum depth of the Haruku Strait (between Ambon and Haruku) and Saparua Strait (between Haruku and Saparua) is approximately 120 m, while the maximum depth of Saparua Bay is approximately 40 m. In general the shelf areas are sandy, but in estuaries muddy-silty sediment is found which is under the continuous influence of rainfall, waves and tides. This sediment transport results in a very dynamic coastline. Ambon is in the monsoonal tropics. The rainy season occurs during the south-east monsoon, from May until September, the dry season during the north-west monsoon, from October until April.

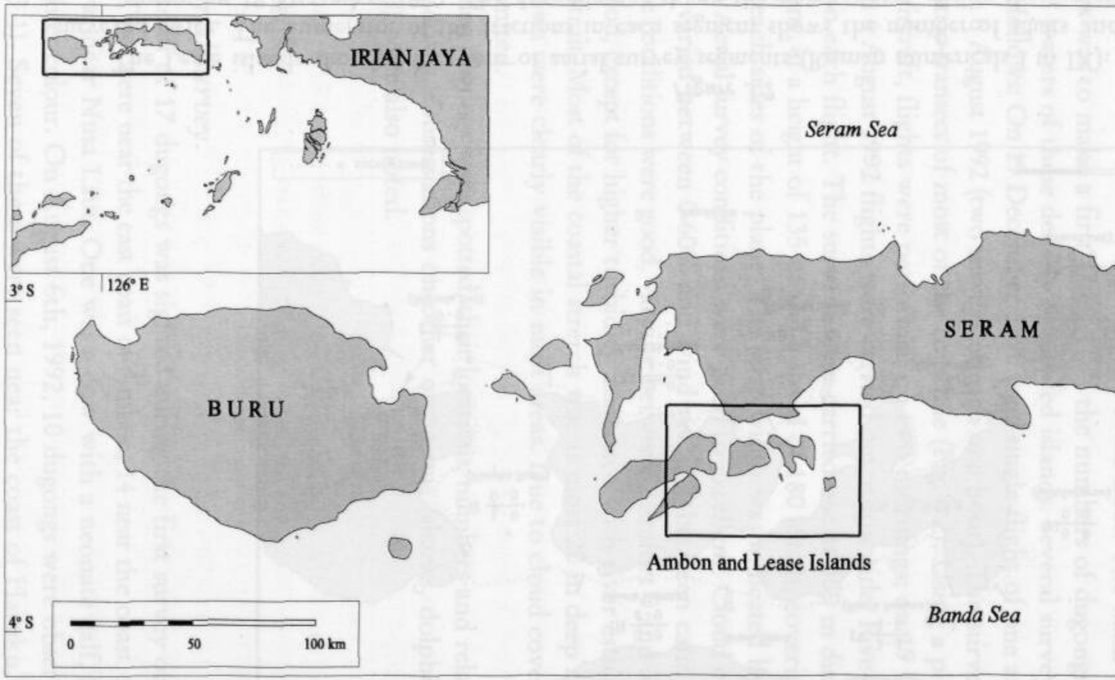

Figure 3.1

Map representing the location of the study area covered by the aerial survey in the Moluccas Province, East Indonesia

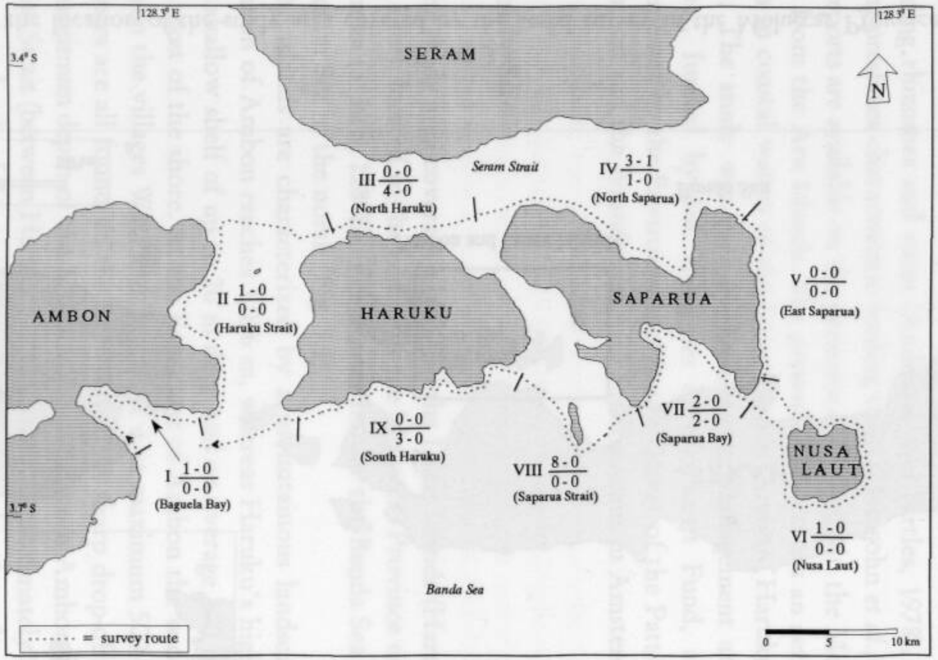

Figure 3.2

The Lease islands showing locations of aerial survey segments (Roman numericals I to IX). The study area was surveyed twice. The numerator of the fractions in each segment shows the number of adults and calves sighted during the survey on 19 December 1990. The denominator shows the number seen during the survey on 6 August 1992

Methods

Aerial survey

Within the framework of the Dugong Management and Conservation Project in the Maluku Province of eastern Indonesia, aerial surveys were carried out during 1990 and 1992, covering coastal waters of East Ambon and the nearby islands of Haruku, Saparua and Nusa Laut. The main objective of the surveys was to make a first estimate of the numbers of dugongs present in the coastal waters of these densely populated islands. Several surveys were carried out as follows: On 19 December 1990 (one single flight of one and a half hour) and on 6 August 1992 (two surveys of each one hour). The surveys covered the same strip-transect of most of the coastline (Fig. 3.2). Using a piper Aztec low-wing aircraft, flights were performed on two mornings; on 19 December 1990 and on 6 August 1992 flights were carried out at low tide. Five observers were used on each flight. The surveys were carried out at 400 m distance from the shoreline, at a height of 135 m and a speed of 180 km/h, covering strips of 200 m on each sides of the plane. The strip width was indicated by marks on the wings. Aerial survey conditions were good to excellent. Cloud cover above the plane varied between 0-60% and wind velocity between calm and 10 km/h. Surface conditions were good, varying between Beaufort 0 and 3. Water clarity was good, except for higher turbidity associated with river estuaries in the Haruku Strait. Most of the coastal stretch was at most 20 m deep and the seagrass meadows were clearly visible in most areas. Due to cloud cover, surface glare was limited.

When dugongs were spotted, their locations, numbers and relative sizes were noted down. Observations on other organisms (sharks, dolphins, turtles and whales) were also noted.

Results

Aerial survey

A total of 17 dugongs was sighted during the first survey on 19 December 1990. Two were near the east coast of Ambon, 14 near the coast of Saparua, and one was near Nusa Laut. One was a cow with a neonate calf, as indicated by the lighter colour. On August 6th, 1992, 10 dugongs were observed (no calves) (Fig. 3.1). Seven of these were seen near the coast of Haruku, three near the coast of Saparua. All dugongs were within 400 m of the shoreline, none was observed outside the coastal shelf.

During the survey flight of December 1990 11 dugongs were sighted per survey hour. The corresponding rate for the August survey was 5 dugongs per survey hour. These figures are comparable to the 5.4 dugongs per hour, reported by Brownell *et al.* (1981) and the 7.5 dugongs per hour reported by Rathbun and Ralls (1988) for Palau. Marsh (1985) however recorded over 150 dugongs per hour during aerial surveys in northern Australia, indicating that dugong numbers around Palau and the Lease Islands are much lower than in parts of Australia. Mean group size was 3.0 and 2.5 for respectively December 1990 and August 1992.

The number of dugongs observed is very encouraging, considering the limited scope of the survey and the fact that Ambon and surrounding islands belong to the most densely inhabited part of the province. The project will continue to implement aerial surveys in order to compile more specific data on dugong population size and distribution.

At least 22-37 dugongs are estimated to occur in the study area (assuming that the aerial survey covered 45% of the total coastal area in the Lease islands). However when considering population size, in a genetic sense interactions with dugong populations at Seram and Buru should be taken into account (Fig. 3.1). Suitable habitat for dugongs was also observed in Kayeli Bay (East Buru) and Piru Bay, Southwest Seram. Although the coastal area of North and East Seram was not surveyed, interviews with fishermen indicated the presence of dugongs.

Table 3.1
Total dugong sightings from aerial surveys in the Lease Islands.
First number represents adults, second number represents calves

Survey date	Time survey started (total hours)	Northern Half (III, IV)	Southern Half (I, VI, VII, IX)	Straits/ East Saparua (II, V, VIII)
December 19 (1990)	9.11 a.m. (1.5 h)	3 + 1	4 + 0	9 + 0
August 6 (1992)	8.46/10-11 a.m. (2x1.0 h)	5 + 0	5 + 0	0 + 0

Research on dugongs movements by Marsh and Rathbun (1991) suggests that dugongs undertake local daily (10-20 km) and regional (up to 140 km in one week) movements. Recent telemetry studies with satellite transmitters on four dugongs have confirmed the movement of a juvenile male dugong from Haruku to S. Seram, journeying 65 km in as little as 2 days (unpublished information).

This information suggests that dugongs in Ambon and adjacent islands interact with animals from Seram and may interact with animals of Buru island. In the Lease islands accidentally dugongs are caught in nets. No harpooning of dugongs is reported from the area, while the impact of sharkfishing is limited as shark gillnetting is mainly concentrated in the waters adjacent to East Seram, targeting surface sharks. The impact of deliberate hunting on dugongs around Ambon seems much lower, than in the Aru Islands, where shark netting has boomed during recent years, but accidental capture by fishing nets may be a factor of importance.

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Chapter 4

Observations on Size, Behaviour and Feeding Ecology of Dugongs (Dugong dugon *Müller 1776) at the Lease Islands, Eastern Indonesia*

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Submitted to *Contributions to Zoology*

Accidental catch of a juvenile dugong by local fishermen of Desa Hutumuri on 8 January 1992

Observations on size and behaviour of the Dugong (Dugong dugon *Müller 1776) from the waters of Lease Islands, East Indonesia*

Abstract

A small population of dugongs was discovered in coastal waters of the Lease islands in East Indonesia. The present study covers the first records on size measurements, behaviour and feeding ecology of this population. Observations are reported on the size range of animals obtained from (accidental) catches and of captive animals from Indonesian Zoos. Studies on behaviour and feeding ecology revealed information on the interaction with seagrass meadows, modes of surfacing and submergence times and behaviour in the presence of scuba-divers. Regular concentrated feeding was observed in a grazing sward at a subtidal mono-specific Halophila ovalis *meadow, confirming earlier observations of regular recropping by dugongs of grazing swards, covered by mono-specific* Halodule uninervis, *inside an intertidal multi-species meadow.*

Introduction

Few scientific records are available on the abundance, distribution and behaviour of dugongs in Indonesia. Salm (in Nishiwaki and Marsh, 1985) reported in 1984, that dugongs are scattered throughout Indonesia, usually in low numbers. Little is known of the populations other than that they occur around Kupang Bay (Timor), Arakan Reef (North Sulawesi), Togian Island-Teluk Tominy (Central Sulawesi) and other small bays and straits around Sulawesi including the Spermonde Islands, South Kalimantan and the Bangka-Belitung Islands (Karimata Strait) (Allen *et al.*, 1976; Hendrokusomo *et al.*, 1981). Towards the end of 1979 dugongs were apparently still fairly numerous around the Aru Islands, their last known area of abundance in Indonesia (Compost, 1980). De Iongh *et al.* (1995a) reported on a population of 22-37 dugongs in the Lease islands, identified during aerial surveys and studied the feeding ecology of dugongs on an intertidal *Halodule* dominated meadow (De Iongh *et al.*, 1995b). The present study aims to elaborate on the results of the studies of De Iongh *et al.* (1995a, 1995b) and covers size distribution, behaviour and feeding ecology of the dugong population at the Lease islands, and size distribution of captive live animals..

With respect to the dugongs feeding ecology, most of the tropical areas supporting the highest dugong densities have extensive inshore seagrass meadows of *Halodule uninervis, Halophila ovalis* and *Halophila ovata*, species which are often found in low density stands (Lanyon, 1991). These and other species of seagrass eaten by dugongs generally occur in the intertidal and upper subtidal to a depth of 10 m below the low-water mark (Heinsohn and Birch, 1972). When dugongs feed on morphologically small-leafed seagrasses such as *Halodule* and *Halophila*, they uproot and consume the entire plant, including rhizomes and roots (Anderson and Birtles, 1978). This method of feeding produces characteristic feeding tracks (Heinsohn *et al.*, 1977).

Preen (1993) postulated that seasonal nutritional stress in sub-tropical areas and a response to this stress by the phenomenon of 'cultivation grazing', would be a major factor for the observed difference in herd size between sub-tropical and tropical areas. According to Preen (1993, 1995) 'cultivation' grazing occurs when herds of dugongs forage intensively in an area, effecting a high level of seagrass removal over a large area. 'Cultivation' grazing allows dugongs to improve the quality of their diet by one or more of the following: 1) maintaining the meadow at a younger, actively growing stage, so the seagrasses contain less fibre, 2) converting the meadow to a pioneer stage composed of preferred and nutritionally superior seagrasses, and 3) concentrating the regrowth vegetation into areas that can be efficiently cropped. He also stated that in tropical areas, the benefits of cultivation grazing may not be necessary or relevant, in which case there may be no pressure to feed in large herds.

De Iongh *et al.* (1995b) found quantitative evidence of a practice of regular recropping of grazing swards by small herds of dugongs in a tropical intertidal meadow. Regular recropping of fixed grazing swards was associated with 'islands' of mono-specific *Halodule uninervis* with a high density of feeding tracks, surrounded by an undisturbed mixed meadow of *Cymodocea rotundata* and *Thalassia hemprichii*.

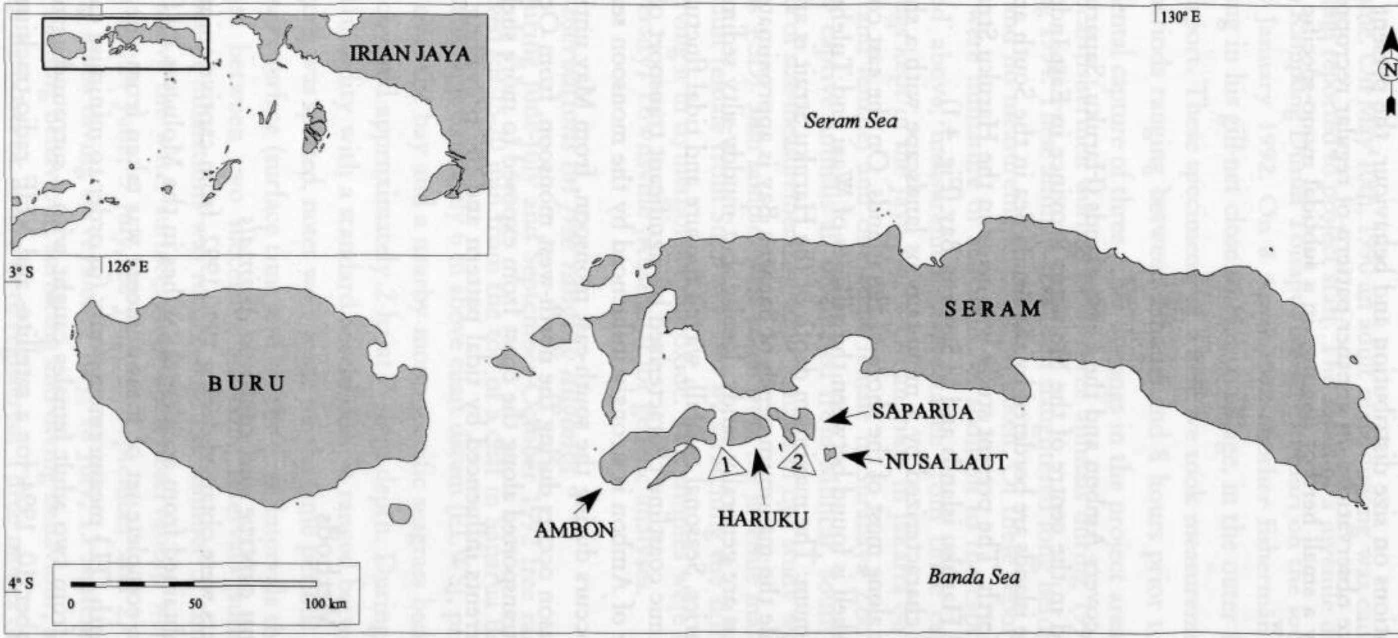

Figure 4.1
Map of the Central Moluccas, with the location of Haruku Strait (1) and Saparua Bay (2)

Besides observations on size distribution and behaviour, the present study describes qualitative observations on another pattern of regular recropping of a grazing sward by a small herd of dugongs in a subtidal mono-specific *Halophila ovalis* meadow.

Study Site

The study area covers Ambon and the Lease islands (Haruku, Saparua and Nusa Laut), located in the centre of the Moluccas Province in East Indonesia (3°30'S, 128°E). The islands are bordered by the Banda Sea in the South and the Seram Sea in the North. The present study was made in the Haruku Strait between Ambon and Haruku islands and in Saparua Bay (Fig. 4.1).

The islands are characterized by a mountainous landscape with a shallow coastal shelf present along most of the shore of the islands. On the east coast of Ambon the widest shelf is found between the villages of Waai and Tulehu, 500 m wide at the maximum. The maximum depth of the Haruku Strait is approximately 120 m, while the maximum depth of Saparua Bay is approximately 40 m. These shelf areas are generally sandy, locally, but muddy-silty sediment is deposited near estuaries. Seasonal rainfall, wave-exposure and tidal fluctuations lead to a very dynamic coastline characterized by significant transport of sediments. The climate of Ambon is strongly influenced by the monsoon seasons. The rainy season occurs during the south-east monsoon, from May until September. The dry season occurs during the north-west monsoon, from October until April. Sand is transported along the coast from exposed to more sheltered locations by seacurrents influenced by tidal pattern and the prevailing wind direction.

Materials and Methods

Observations on captive and captured animals

Size measurements were obtained during 1990-1992, from captive animals in zoos and animals obtained from accidental catches in the Moluccas by fishermen. In addition, a complete set of measurements was taken from one adult female and total length (TL) measurements only (in order to minimise capture stress) were taken from two adult females caught with a surrounding net on April 15 and October 10, 1994 for a satellite- and VHF radio-tracking programme. On May 10th, 1990 an adult male dugong was caught in Balatan, East Aru and reported to project staff. The catch of a juvenile dugong was reported from Kampung Dusun Toisapu, Desa Hutumuri on the south coast of Ambon on 8 January 1992. On 8 April 1992 another fisherman caught a pregnant dugong in his gill-net close to Hative village, in the outer Bay of Ambon near the airport. These specimens, of which we took measurements, had been dead for periods ranging between 2 hours and 8 hours prior to examination. The accidental capture of three other dugongs in the project area was reported to us by local fishermen during 1992, three animals during 1993 and four animals during 1994. These animals had been slaughtered long before we arrived at the site, and no measurements could be taken. Of these reported animals at least four were immature or sub-adult. In addition to the captured dugongs mentioned above, measurements were taken from three captive animals, two dugongs kept in the Jaya Ancol Oceanarium in Jakarta on 14 July 1991 (adult male and female) and one adult female in Surabaya Zoo on 10 April 1992. These captive animals all originated from Muncar, south coast of Java. The results of size-measurements of adult females in our study were presented as the means ±SD). Skin samples were taken from the juvenile male from Ambon and the adult female from Surabaya Zoo by scratching the skin with a scalpel and preserving it in dymethol sulphuroxide. The samples were sent to James Cook University, Townsville (Australia) for genetic analyses.

Observations on free ranging dugongs

During June-July and September-October 1992 free ranging animals were observed for 15-20 min from the top of a cliff in Saparua Bay. This site, which is situated approximately 6 m above chart datum (ELWS), provided an excellent view over the bay and a nearby mono-specific seagrass bed of *Halophila ovalis* that covered approximately 2 ha at 7-10 m depth. During the study we measured turbidity with a standard Secchi disk; it ranged between 10-21 m. When a dugong was spotted, notes were made on the time periods the animal spent at the water surface (surface time and on the time intervals the animal spent submerged between two successive surfacing intervals (submerged time). The number of inhalations was recorded as the number of times its nostrils were seen above the water surface. Additional observations were made from small boats on 24 June, 5 July, 20 July, 14 September and 23 October 1992 and during scuba diving surveys on 5 July, 18 July, 13 September and 1 October 1992. Feeding behaviour, surfacing and diving behaviour, and responses to approach by boats or divers were registered. Three modes of surfacing were described: rolling, sinking forward and sinking back (Anderson and Birtles, 1978).

Table 4.1
Size measurements of captive and captured dugongs from Moluccas and Java

	Ancol 14 July 91	Ancol 14 July 91	Surabaya 10 Apr. 92	Balatan (E. Aru) 10 May 90	Ambon 8 Apr. 92	Ambon 8 June 92	Haruku 15 April 94 & 10 October 94	Spain (1975) (females)			Present study (females)		
Variable	male	female	female	male	female	juvenile	females	Mean	n	S.D.	Mean	S.D.	n
TL	192	198	290	246	287	115	290/256/273	218	29	47	265	32	6
SB	79	82	93	82	89	36	n.m./n.m./n.m.	72	26	16	88	4	3
B_1	35	41	n.m.	n.m.	n.m.	n.m.	n.m./n.m./n.m.	n.m.	-	n.m.	n.m.	n.m.	-
B_2	12	11	n.m.	n.m.	n.m.	n.m.	n.m./n.m./n.m.	n.m.	-	n.m.	n.m.	n.m.	-
LLF	37	35	46	40	43	20	n.m./31/n.m.	33	28	7	39	6	4
LRF	38	35	46	40	44	21	n.m./32/n.m.	33	28	7	39	6	4
BLF	18	16	19	20	22	9	n.m./17/n.m.	15	28	3	19	2	4
BRF	18	16	19	20	21	9	n.m./18/n.m.	15	28	3	19	2	4
0_1	47	46	67	55	48	11	n.m./50/n.m.	45	7	6	53	8	4
0_2	78	121,5	n.m.	124	200	65	n.m./134/n.m.	100	10	15	152	34	3
0_3	121	121,5	161	137	156	58	n.m./n.m./n.m.	131	18	33	146	17	3
0_3/TL	0.63	0.61	0.55	0.55	0.54	0.50	n.m./n.m./n.m.	0.60	-	n.m.	0.56	0.03	-

TL = total length, SB = fluke width, B_1 = axillary width, B_2 = basal fluke width, LLF = left flipper length, LRF = right flipper lenght, BLF = left flipper width, BRF = right flipper width, 0_1 = basal fluke girth, 0_2 = anal girth, 0_3 = axillary girth, n.m. = not measured (measurements according to Spain, 1975)

The response of dugongs to approaches by one or more swimmers, or observers on a boat were described as; a) no apparent response (continued routine activity), b) curiosity or c) avoidance.

During each observation period snorkling transects covering the seagrass bed (perpendicular to the coast and at 30 m intervals) were made, to identify feeding track density in the meadow. By visual observation a distinction was made between ungrazed and grazed patches.

Results

Observations on captive and captured dugongs

Table 4.1 summarizes the results of the measurements we obtained, compared to the data published by Spain (1975). The captive adult female dugongs in Ancol Oceanarium and Surabaya Zoo, the adult female dugong caught accidentally and killed off Ambon and the three adult female dugongs measured during the satellite radio tracking program are all in the larger size range with a mean TL of 265 cm (±32) (range 198-290 cm) compared with the mean of 218 cm as reported by Spain for Australian dugongs. The means of all size measurements of our female dugongs were larger, but due to lack of access to the database of Spain (1975) we could not analyse the significance of this difference. The female caught accidentally by a fishermen off Ambon was pregnant, which explains the extreme measurement of 200 cm for the anal girth.

Observations on free ranging dugongs

The results of the dugong observations in Saparua Bay are listed in Table 4.2. The results of the field observations are summarized below. Table 4.3 presents a summary of submergence times from the present study, compared with other authors.

Feeding behaviour

During the research period fourteen free-ranging dugongs were observed, all occurring in the outer part of Saparua Bay. Observations of dugongs were made between 9.20 am and 4.25 pm, not indicating regular feeding times. We observed that dugongs forage at depths down to 10 m in the Bay. During several observations dugongs foraged within 50 m of a ten meter high cliff (which was used as an observation site). Dugongs were spotted during both high and low tide. During a diving session we observed that three distinct feeding tracks were made by a dugong within a single dive. The dugong moved from one place to another in the seagrass meadow without surfacing. It grazed upon the vegetation, hovering above the substratum with only the rostrum bent down. During snorkling transects over the Paperu meadow periodical concentrated grazing in a mono-specific *Halophila ovalis* meadow was observed in a distinct sward of approximately 260 m^2 with a high density of feeding tracks, surrounded by an undisturbed seagrass bed at the southern part of the meadow (Fig. 4.2). During all consecutive observation periods individual dugongs revisited this feeding sward to forage. This regular pattern of revisiting was consistent during the study period.

Table 4.2

A summary of field observations on individual dugongs in Saparua Bay, during June-October 1992

No.	Date	Time	Site	Juvenile/ adult	Swimming direction	Remarks
1	24/6/92	10:30 am	cliff	adult	N	None
2	4/7/92	1:05 pm	cliff	adult	N	None
3	5/7/92	9:20 am	cliff	juvenile	NE	Swimming small circles
4	18/7/92	10:50 am	cliff	juvenile	N	None
5	20/7/92	9:40 am	diving	juvenile	E	Swimming circle around diver
6	13/9/92	4:25 pm	boat	adult	E	Loud noise while breathing (exhalation)
7	13/9/92	4:35 pm	boat	adult	E	None
8	14/9/92	1:05 pm	boat	juvenile	E	None
9	15/9/92	1:00 pm	boat	adult	N	2 Dugongs/vertical surfacing
10	16/9/92	10:00 am	diving	juvenile	NE	Approaching diver (2 times)
11	19/9/92	10:15 am	diving	juvenile	E	Swimming in high speed while being followed
12	1/10/92	9:45 am	diving	adult	NW	Approaching diver
13	1/10/92	1:20 am	boat	adult	W	None
14	23/10/92	11:00 am	diving	juvenile	S	Approaching diver (3 times)/ grazing behaviour

Abbreviations:
No: Observation number, Date: Date of observation, Time: Time of observation, Site: Observation took place from a cliff, from the boat or while diving; Swimming direction: The swimming direction of the dugong when leaving the feeding sward; Remarks: Remarks on observations.

Although local fishermen claimed that dugongs would forage deliberately on a Lingulid Brachiopod and *Sipunculus* sp. (indentification Dr. K. Den Hartog, State Museum Natural History, Leiden) this was nog confirmed by our own fieldobservations.

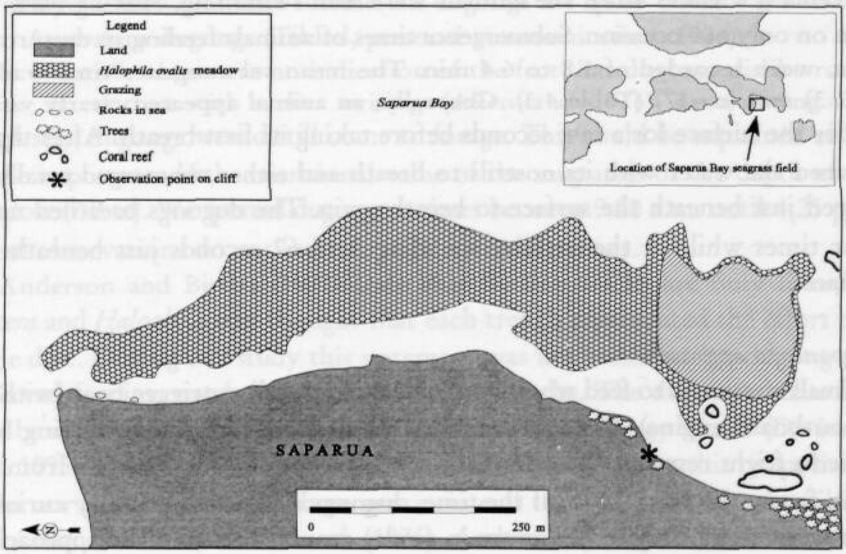

Figure 4.2
Detailed map of the mono-specific *Halophila ovalis* meadow in Saparua Bay and the location of the grazing sward

Table 4.3
Submergence times (minutes) of free ranging dugongs in Saparua Bay, compared with other authors

Number of observations	Submerged time (mean ± SD)	Location	Author
17	4.6 (± 1.3)	free ranging dugongs at the Bay of Saparua	present study
162	2.7 (± 0.07)	free ranging cow with calf in Shark Bay	Anderson, 1982
346	0.9 (± 0.04)	free ranging adults without calves in Shark Bay	Anderson, 1982
370	1.2 (± 0.04)	free ranging adults without calves in Shoalwater and Cleveland Bays	Anderson and Birtles, 1978
70	2.5 (± 0.05)	adults	Allen, 1976

Surfacing and diving behaviour

All three modes of surfacing have been observed. Rolling was the most frequently observed mode of submerging. Each time the back was clearly seen and sometimes even the tail cleared the water. The sinking forward mode was observed a few times when the animals were seen swimming. Sinking back was seen on only one occasion. Submergence times of animals feeding in deep rough seas, were recorded of 1.8 to 6.4 min. The mean submergence time was 4.6 (± 1.3) min (n=17) (Table 4.3). Generally, an animal appeared clearly visible under the surface for a few seconds before taking its first breath. After that it cleared the water with its nostrils to breath and either submerged totally or stayed just beneath the surface to breath again. The dugongs breathed up to four times while at the surface, spending 3 to 62 seconds just beneath the surface.

Response to approach
Animals continued to feed when approached in a small outrigger boat (without an outboard engine). On one occasion, the approach of a large rowing boat caused a fright response. The animal surfaced vertically a few meters from the boat, facing the boat. Most of the time, dugongs appeared to display curiosity towards divers. They either swam in circles around the divers or approached while swimming, at a distance of approximately three meters. Once a diver was able to approach an adult dugong at c. 1 m distance. On another occasion an adult dugong of approximately 3 m in length approached the diver, who was lying at the bottom, swimming in a zigzag fashion. It swung around its long axis, holding its flippers wide-open and passed the diver, turned and passed again in the same way. Suddenly the dugong swam upwards to the sea surface. The animal rested just beneath the surface, turned again and swam in a straight line towards the diver, changing its course only at close range (c. 2 m distance).

Discussion

Based on our own fieldobservations and anecdotal information obtained from fishermen we conclude the accidental capture in our study area of at least 5 dugongs during 1992, 3 dugongs during 1993 and 4 dugongs during 1994.

The analyses of size measurements of six adult female dugongs in our study indicates that these animals are larger in size, when compared to data reported by Spain (1975) for Australian dugongs, although we could not analyse the significance of this difference. Similar size ranges were, however, reported by Hudson (1986) for dugongs in Papua New Guinea. In addition, skin samples fixed in dymethol sulphuroxide of the juvenile male from Ambon and the adult female dugong from Surabaya Zoo, which were sent to James Cook University for analyses, indicated that Indonesian dugongs are quite distinct genetically from Australian dugongs (Tikkel, personal communication, 1994).

In our study there was no indication of the fact that dugongs dislike rough water, in contrast with earlier writings (Allen *et al.* 1976). Even during very rough seas, dugongs would still come to forage. This could be explained either by the importance of the nutritional value of the seagrasses or the depth of the meadow (7-9 m). We spotted dugongs at times between 9.20 a.m. until 4.25 p.m. These observations do not indicate regular feeding times.

Anderson and Birtles (1978) state that feeding tracks are only found in *Zostera* and *Halophila* and thought that each trench represented the effort of a single dive. During our study this statement was not confirmed; a dugong was observed feeding, producing multiple feeding tracks. The dugong's behaviour may be adjusted to minimize effort for a maximum of energy intake (De Iongh *et al.* 1995b). Multiple feeding tracks during one dive support this proposition.

In our study the mean submergence time of the dugong is 4.6 min. This is more than found by Allen *et al.* (1976), Anderson (1982) and Anderson and Birtles (1978) who observed mean submergence times of 2.5, 2.7 and 1.2 min respectively (Table 4.3). Those studies were done in waters up to 3 meters of depth. Our studies were carried out in seagrass beds up to 9 m depth. This suggests that the submergence time may correlate with the depth of the bed. This coincides with Anderson (1982) who concluded that the interval between appearances at the surface varies with locality (habitat), foraging mode and foraging species, activity and reproductive status. His data, obtained from waters of varying depths, suggest a trend for dugongs to remain submerged longer in deeper water. In the present study, the time spent at the surface was a minimum of 3 seconds for one breath, which agrees with Anderson and Birtles (1978).

With respect to the feeding ecology of the dugong some of our observations do not correspond with the findings of other authors. Anderson (1981) and Anderson and Birtles (1978), for example, report that dugongs forage at depths of 3 to 4 m in both sublittoral and intertidal areas. Most of the feeding tracks we observed at the seagrass bed in Saparua Bay were located at a greater depth (7-9 m). Marsh *et al.* (1994) and Marsh (1993) reported on the importance of deepwater seagrass meadows to dugongs and found evidence of dugong feeding up to 40 m depth. Favoured feeding areas appeared to be characterized by relatively sparse seagrass and ready access to deeper water. The regular recropping by dugongs of restricted grazing swards in a mono-specific *Halophila ovalis* meadow may indicate a pattern of cultivation grazing as described by Preen

(1993, 1995) for dugongs in Moreton Bay, but more research data are needed to confirm this.

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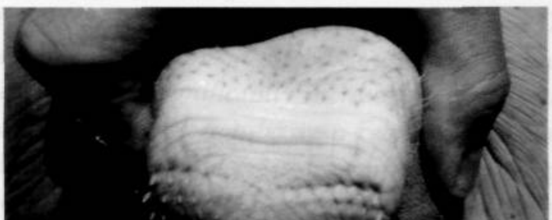
Chapter 5

Seagrass Distribution and Seasonal Biomass Changes in Relation to Dugong Grazing in the Moluccas, East Indonesia

H.H. de Iongh, B.J. Wenno, E. Meelis

Aquatic Botany 50: 1-19 (1995)



The muzzle of the dugong is a complex structure, specialized in bottom feeding; a feeding dugong produces characteristic 'feeding tracks'. This photograph (muzzle upside down) shows the characteristic bristle fields on the lower and upper lips

Seagrass Distribution and Seasonal Biomass Changes in Relation to Dugong Grazing in the Moluccas, East Indonesia

Abstract

Seagrass distribution and seasonal changes in biomass and total organic C were studied in relation to dugong grazing, in intertidal meadows dominated by Halodule uninervis *(Forsskål) Ascherson between December 1990 and December 1992 in Nang Bay on the East coast of Ambon. Both below-ground and above-ground biomass of Halodule uninervis significantly increased during the transition period from the dry season to the wet season between February and May. Above-ground biomass of* Halodule uninervis *decreased significantly during the wet season (between May and August), when low tide occurred in day time, and only slow recovery took place until November. Below-ground biomass remained high until November, resulting in a significant decrease of the ratio of above-ground to below-ground biomass during the period between May and August, and in a 'sparse' visible seagrass meadow, with a non-visible high below-ground biomass between August and November. Total organic carbon level in the below-ground plant parts gradually increased between May and August with a peak value in August. Dugong grazing was concentrated in distinct swards dominated by* Halodule uninervis *and regular recropping of these swards may indicate a pattern of cultivation grazing. Dugong grazing removed 93% of the shoots and 75% of the below-ground biomass of the upper 4 cm deep layer of sediment. Seagrass biomass in freshly grazed feeding tracks was restored to levels of the nearby seagrass bed after five months during the onset of the wet season. No significant restoration took place during the dry season. The frequency of dugong grazing showed a strong positive correlation with total organic C level in the below-ground plant parts, indicating that the dugongs preference for the* Halodule uninervis *seems to be based on a strategy of a high net rate of energy intake.*

Introduction

The dugong (*Dugong dugon* Müller 1776) feeds predominantly on seagrasses (Gohar, 1957; Heinsohn and Birch, 1972; Heinsohn *et al.*, 1977; Anderson and Birtles, 1978; Marsh *et al.*, 1982). Several authors suggested dietary preference of dugongs for 'soft' and 'sparse' pioneer species such as *Halodule uninervis* (Forsk.) Aschers. and *Halophila ovalis* (R. Br.) Hook. f. (Gohar, 1957; Heinsohn and Birch, 1972; Lipkin, 1975; Johnstone and Hudson, 1981). Heinsohn and Spain (1974) reported the consumption of brown algae by dugongs in tropical North Queensland after extensive damage to seagrass beds caused by a cyclone. Based on the analyses of 95 North Queensland dugongs Marsh *et al.* (1982) concluded that the generic composition of stomach contents probably reflects that of the seagrass beds in the areas where the dugongs were captured and is not necessarily indicative of discrimination in selecting food. They also stated that even local differences in dietary intake indicated by her study [and by Gohar (1957), Heinsohn and Birch (1972), Lipkin (1975) and Johnstone and Hudson (1981)] may be, at least partly, an unavoidable artefact of the sampling However Marsh *et al.* (1982) did not reject the possibility of preferential feeding of dugongs on specific seagrass species. It is an important observation that in their study *Halodule* and *Halophila*, representing pioneer genera, were the most dominant food items present in 95% and 89% of the stomachs respectively, while seagrass rhizomes were present in all stomachs.

Preen (1993) studied dugongs in subtropical Moreton Bay and found that they fed on amazingly sparse seagrass beds of delicate species of *Halophila* and *Halodule* more frequently than on others. He found quantitative evidence suggesting that dugongs in Moreton Bay preferred seagrasses in the following decreasing order: *Halophila ovalis* > *Halodule uninervis* > *Halophila spinulosa* (R. Br.) Aschers. > *Syringodium isoetifolium* (Aschers.) Dandy > *Cymodocea serrulata* (R. Br.) Aschers. et Magnus. Recent studies showed that dietary preference of dugongs for certain seagrass species is influenced by nutritional and energy requirements. Lanyon (1991) stated that dietary preference of dugongs is based on high total N and low neutral detergent fibre.

Preen (1993) suggested soluble carbohydrates as a possible important factor for diet selection by dugongs. The importance of seagrass rhizomes and roots as a food source for dugongs has been stressed by Anderson (1991) and Erftemeijer *et al.* (1993a). Selective feeding of dugongs on *Halodule uninervis* rhizomes seems part of a strategy of 'energy maximisation', rather than a strategy of 'optimisation of nutritional balance'. Foraging behaviour of dugongs, like other large herbivores, may aim at a high net rate of energy intake (Pyke *et al.*, 1977). The 'optimal foraging theory' applied for dugongs feeding on *Halodule uninervis* meadows, assumes that the fitness of a foraging animal is a function of the efficiency of foraging in terms of 'energy'.

The present study describes the interactions between dugongs and *Halodule* dominated intertidal seagrass meadows at Nang Bay, Ambon, Indonesia, in order to identify factors determining dietary preference, with regard to the 'optimal foraging theory'. For this purpose, the dynamics of biomass and total organic carbon in *Halodule uninervis* meadows, spatial and temporal feeding patterns of dugongs, the impact of feeding on the seagrass meadows and recovery of seagrass after feeding were studied. The study presented here covers the relation between dugong feeding tracks in time and space and seasonal dynamics of the seagrass meadow in grazed and in non-grazed plots.

The present study covers the first research effort on dugong-ecology in a tropical small island ecosystem of East Indonesia, after the review of Hendrokusumo *et al.* (1979) on the distribution of dugongs in Indonesian waters.

Materials and Method

Study area

The seagrass bed sampled is located on a sandy and muddy tidal flat of approximately 6 ha, in a mangrove bordered embayment at the East coast of Ambon, East Indonesia, near the village of Waai (3° 55' S, 128° 50' E). The embayment is sheltered from the North-West monsoon during the dry season (October through April) and from the South-East monsoon during the wet season (May through September) (Fig. 5.1). The study was carried out between December 1990 and December 1992, covering two dry and two wet seasons, most of the fieldwork being carried out during 1991. Variables like rainfall and air temperature were obtained from the Meteorological station at Ambon Airport, while tidal data were taken from the Tidal Table of Ambon (TNI-AL, 1991/1992). The edge of the tidal flat has a relatively steep slope, descending to 20-30 m depth at c. 300-400 m from the shore. The seagrass meadow is under influence of the Rutung river and is visited regularly by villagers from Waai, who gather shellfish at low tide and fish with castnets and gillnets at high tide.

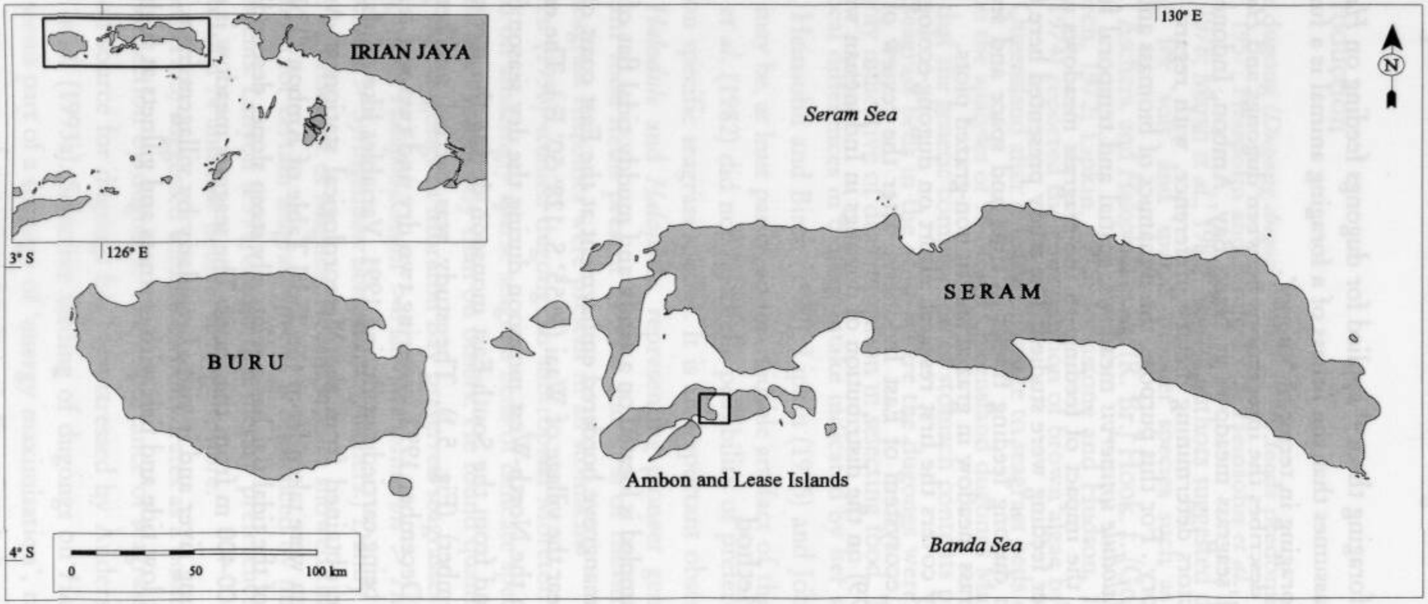


Figure 5.1

Location map of the study area (expanded: Central and East Moluccas, inclusion: Buru island, Seram and the Leas islands, indicating the location of the study area of Nang Bay, East Ambon

Mapping

The study area was subdivided into quadrats of approximately 20 x 20 m, by dividing the seagrass bed in the study area by North-South and East-West lines (Figs 5.2 and 5.3). Inside the seagrass bed the location of the quadrats was marked with wooden poles and paint marks on adjacent mangrove trees. Mapping of the seagrass bed was done between January and May 1991, determining seagrass species composition and cover, bathymetry and sediment composition, in a total of 153 quadrats.

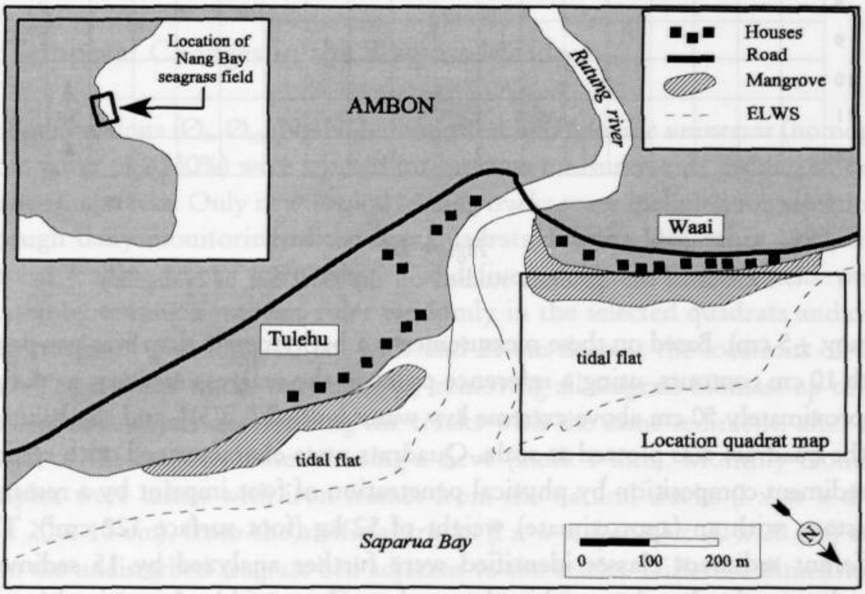


Figure 5.2
Map of Nang Bay, East Ambon, with the location of the area covered by quadrats

Seagrass species composition and coverage were assessed for each quadrat using methods described by Nienhuis *et al.* (1989). Cover was estimated per species per quadrat for *Halodule uninervis*, *Cymodocea rotundata* Ehrenb. and Hempr. ex Aschers. and *Thalassia hemprichii* (Ehrenb.) Aschers., with coverage classes: 0%, 'few individuals', 5%, 10%, 20%, 30%, 40%, 50% and >60%. Bathymetry was measured at high tide with marked measuring poles (3 m length) following the North-South lines of the quadrats at 10 m intervals (ac-

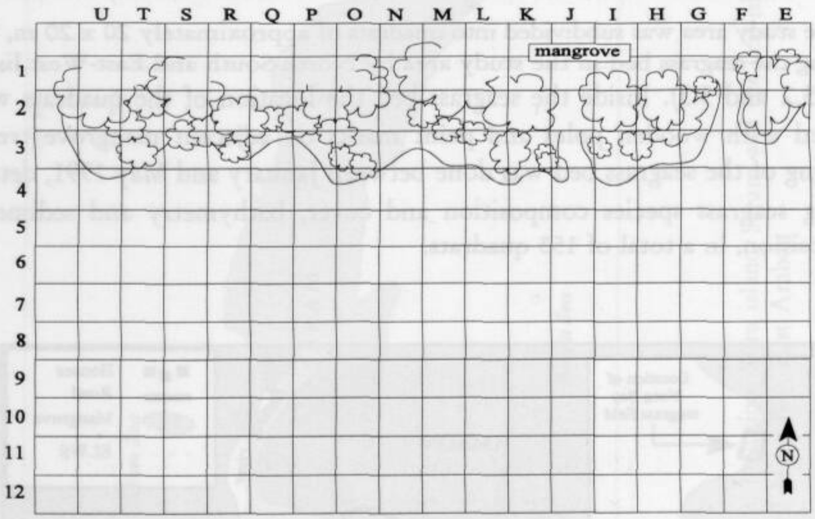


Figure 5.3
Layout of the quadrats studied on the tidal flat of Nang Bay

curacy ±5 cm). Based on these measurements a bathymetric map was pre-pared with 10 cm contours, using a reference point in the seagrass meadow as datum [approximately 50 cm above extreme low water level (ELWS)], and the location of the quadrats was plotted at scale. Quadrats were characterized with respect to sediment composition by physical penetration of foot imprint by a research assistant with an (approximate) weight of 52 kg (foot surface 122 cm^2). The different sediment classes identified were further analyzed by 15 sediment samples, randomly taken within the quadrats [5 in muddy, 5 in mixed (sandy mud) and 5 in sandy/sandy with stones sediment]. Sediment samples were obtained with a corer (diameter 8 cm) and analyzed for grain-size, calcium carbonate and organic matter content (POC) according to Nieuwenhuizen *et al.* (1990).

The following sediment types were distinguished:

- Muddy sediment (M): characterized by 15-30 cm imprint, a mean grain size of 53 μm (±9.34), mean calcium carbonate of 0.40% (±0.093) and mean POC of 1.7% (± 0.52);

- Sandy sediment (Z): characterized by < 5 cm imprint, mean grain size of 192 μm (s.d.=9.31), mean calcium carbonate 0.3% (±0.29) and mean POC of 0.38% (±0.15);
- Sandy sediments with stones (K): similar to sandy sediments, but with a significant fraction of coral debris and/or pebbles. A sub-division was made between coarse sand with pebbles and stones < one inch (2.54 cm) and very coarse sand with stones and pebbles > one inch.
- Mixed sediment (m): characterized by 5-15 cm imprint, a mean grain size of 167.16 μm (±79.70), mean calcium carbonate of 0.25% (±0.12) and mean POC of 0.62% (±0.20).

Temporal Changes in the Seagrass Meadow

Four quadrats ($Ø_9$, $Ø_{10}$, N_9, N_{10}), dominated by *Halodule uninervis* (homogeneous cover of 20-30%) were selected for biomass measurements inside and outside feeding tracks. Only new natural feeding tracks were included for selection, through daily monitoring of the four quadrats. During December 1990, five natural feeding tracks were selected and five random artificial tracks were located by tossing a wooden ruler randomly in the selected quadrats and digging tracks of 3 m long, 20 cm wide and 20 cm deep at the locations of the ruler. The artificial tracks were made by removing all seagrass biomass up to 20 cm sediment depth and refilling the tracks with the same sediment, after removal of the seagrass material using a sieve (mesh 1 mm). Monthly biomass samples were taken with iron frames from the natural tracks (l x w x d = 20 x 20 x 10 cm), from the artificial tracks (l x w x d = 20 x 20 x 20 cm) and from the undisturbed seagrass bed adjacent to the tracks. Different dimensions of the iron frames used for sampling natural and artificial feeding tracks are explained by the fact that all natural tracks selected were in the 10 cm width range, whereas the artificial tracks were standardised on 20 cm width. These natural and artificial tracks were sampled until June 1991. From June until December 1991 a new set of four artificial tracks and four adjacent controls in the undisturbed seagrass bed were included, which were dug on 7 June 1991. More natural tracks were not selected for sampling because the results of the first sets of tracks did not show significant differences with the artificial ones. Monthly samples of above-ground and below-ground biomass of the undisturbed seagrass bed were taken during 1991 and this sampling was continued throughout 1992, with the same iron frames used for the natural tracks. The samples were sieved inside a sieve (1 mm mesh size). The above-ground fraction and below-ground fraction of seagrass were separated and the above-ground fraction was soaked in a 5 % phosphoric acid solution, to remove calcareous epiphytes and dry weight (DW) and ash free dry weight (AFDW) were analyzed according to Ott (1990). The samples were dried for 24 hours in an oven at 90° C. The ratio AFDW to DW was used as a measure for the level of total organic carbon in the seagrass fractions, and based on the C:N:P ratio of 340:19:1 for Indonesian seagrass beds reported by Erftemeyer (1993b).

Following of changes regarding feeding tracks

To start an overview of the cumulative number of feeding tracks, a count was made of the numbers of feeding tracks per quadrat at the initial stage of the study during 28-30 January 1991. As from February 1991 onwards, new tracks were counted and measured on each quadrat at monthly intervals. Length and width of each feeding track were measured and a sketch was made of the location of feeding tracks in each quadrat. Sketch maps were prepared of the spatial distribution of feeding tracks over the tidal flat in January 1991, and between August and December 1991.

The monthly counts of new feeding tracks were related to seasonal climatic changes (rainfall, air temperature) and tidal movement, fluctuations in seagrass biomass (above-ground and below-ground) and related parameters, including the ratio between DW below-ground and DW above-ground and the ratio between AFDW and DW in below-ground and above-ground fractions.

Statistical analysis

Through multivariate analyses partial correlation coefficients between all factors were calculated for spatial distribution and for temporal distribution. The dependent variables were transformed, by taking the logarithm +1, in order to obtain approximate linear relationships and a normally distributed error term.

For comparison of the level of significance of differences between monthly dry weight biomass samples of below-ground and above-ground biomass a Wilcoxon two sample test was used ($P < 0.05$). A multiple regression was used to determine the relationship between the spatial grazing pattern (dependent variable) and various environmental variables (cover of *Halodule uninervis*, *Cymodocea rotundata* and *Thalassia hemprichii*, 'sediment composition' and 'bathymetry').

Stepwise variable selection was applied to determine the relevant factors, which explain most of the variation of the temporal grazing pattern (feeding frequency expressed as total number of new feeding tracks per month) as dependent variable. The variable inputs were: 'tidal fluctuations' (expressed as the % of nights per month when low tide is equal or lower than 50 cm in the Tidal Table for Ambon), and the monthly means of 'rainfall', 'air temperature', 'mean below-ground biomass of *Halodule uninervis*', 'mean above-ground biomass of *Halodule uninervis*', 'the ratio DW *Halodule uninervis* below-ground to above-ground fraction', 'the ratio AFDW to DW of the below-ground fraction' and 'the ratio AFDW to DW of the above-ground fraction'.

Results

Mapping

The following seagrasses were encountered in the study area of Nang Bay (nomenclature according to Den Hartog (1970); *Cymodocea rotundata*, *Halodule uninervis* (narrow leaved form) *Halodule uninervis* (broad leaved form), *Enhalus acoroides* (Linnaeus f.) Royle, *Thalassia hemprichii*, and *Halophila ovalis*. A species zonation from the shoreline to deeper waters was observed, with *T. hemprichii*, *C. rotundata*, being dominating species in the upper intertidal zone (above the datum line), with *C. rotundata*, *Halodule uninervis* and *Halophila ovalis* becoming more abundant in the lower neap tide zone (between the datum line, and the 110 cm depth line) and *E. acoroides* dominating the upper subtidal zone (below the 110 cm depth line). Seagrass cover maps of *Halodule uninervis*, *T. hemprichii* and *C. rotundata* are presented in the Figs 5.4A, 5.4B and 5.4C. *Halodule uninervis* was the dominant species in the meadow, in 33% of the quadrats it covered 20% of the area. *C. rotundata* was the second dominant species, covering 20% or more in 21% of the quadrats. *T. hemprichii* covered 20% or more in 17.6% of the quadrats. *C. rotundata* and *T. hemprichii* were significantly correlated ($r = 0.5940$; $p = 0.0007$), while all other partial correlation factors between seagrass species were smaller than 0.3.

The results of bathymetry and sediment sampling analyses are presented in Fig. 5.5. Above the datum line muddy (M) and mixed sediments (m) were dominant, while below the datum line sandy and sandy (z) sediments with stones (k) dominated.

Halodule uninervis was most commonly found on sandy sediments or sandy sediments with stones (71% of the quadrats with a cover of 20% or more), decreasing on more muddy sediments. *Cymodocea rotundata* and *Thalassia hemprichii* were rare on sandy sediment and sandy sediments with stones (resp. 40%

and 43% of the quadrats with a cover of 20% or more), but occurred more on the other categories of sediments.

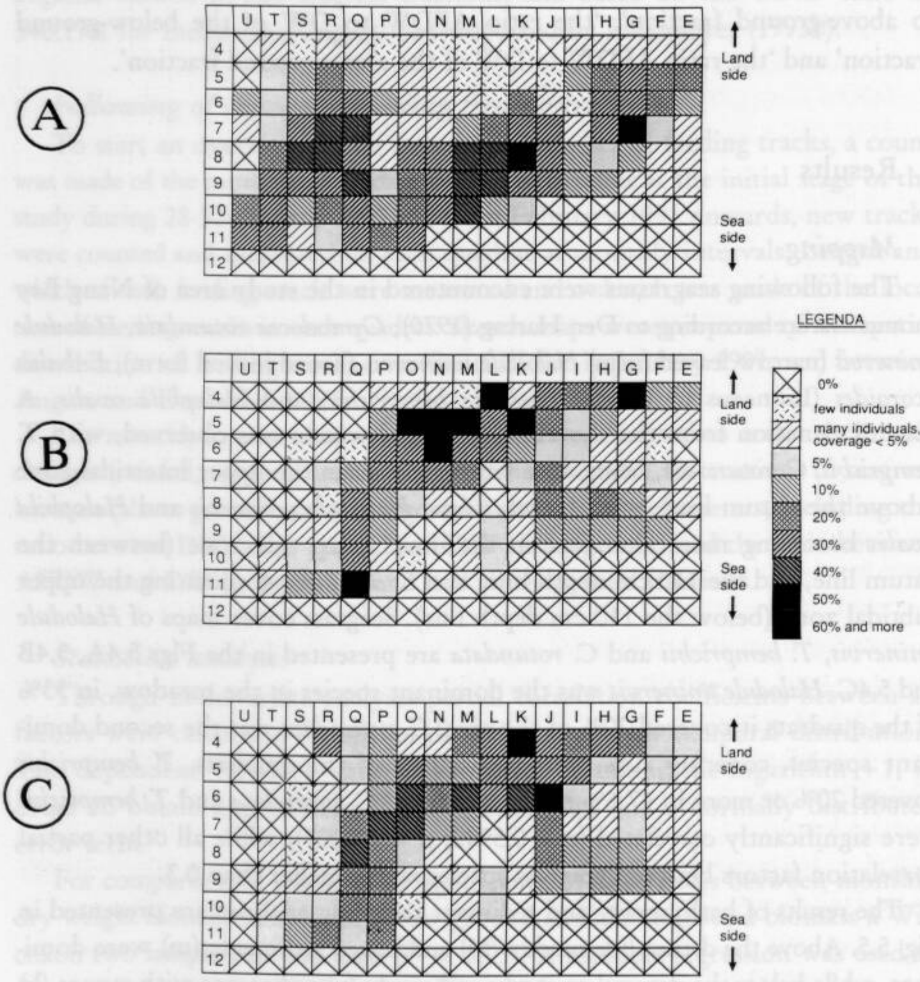


Figure 5.4
Distribution and coverage of *Halodule uninervis* (A), *Thalassia hemprichii* (B) and *Cymodocea rotundata* (C) on the tidal flat at Nang Bay

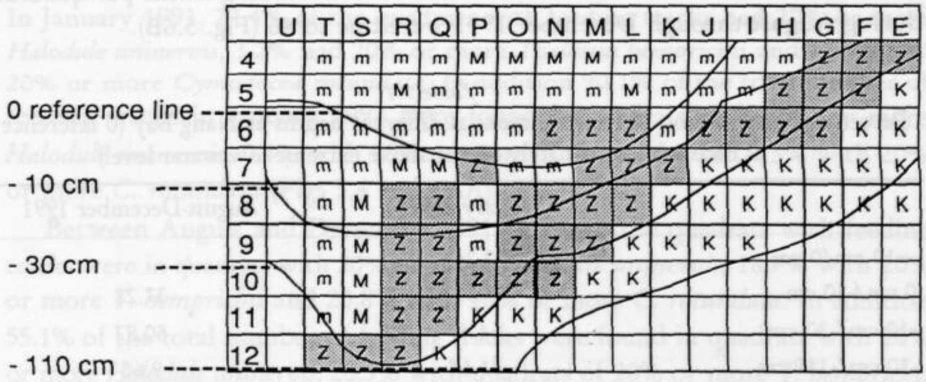


Figure 5.5
Dominant sediment types (Z = sandy sediment; K = sandy sediment with stones; m = mixed sediment; M = muddy sediment) on the tidal flat at Nang Bay (0 reference line used as datum, approximately 50 cm above extreme low water level)

Spatial variation of feeding tracks

Relation to sediment-type

Total number of old and new tracks counted in January 1991 and the cumulative number of tracks, counted between August-December 1991 were 752 and 800 respectively. In January 1991 73.2% of the total number of tracks were found in sandy sediments (Figs 5.5 and 5.6A). During August until December 1991, 64.2% of the total number of tracks were in sandy sediments (Figs 5.5 and 5.6B). For muddy and mixed sediments, these figures are 15.7% in January 1991 and 31.0% between August and December 1991. Although these data suggest some preference of dugong feeding for sandy sediments, the correlation factor between 'feeding tracks' and 'sandy sediment is not significant (January: $r = 0.2327$, $p = 0.2244$; August and December: $r = 0.1364$, $p = 0.4803$).

Relation to bathymetry

The pattern of feeding tracks shows a tendency to concentrate at the lower edge of the intertidal meadow in January 1991 and in the central zone of the meadows between August and December 1991. However, distribution over depth contours was not consistent throughout the year (Table 5.1).

Numbers of feeding tracks per quadrat during January 1991 ranged between one and 160 (Fig. 5.6A). Between January and July 1991 very few feeding tracks were encountered. The cumulative numbers of fresh feeding tracks per quadrat during August through December 1991 were one to 46 (Fig. 5.6B).

Table 5.1
Percentage distribution of feeding tracks at different depths at Nang Bay (0 reference line as datum approximately 50 cm above extreme low water level)

	January 1991	August-December 1991
+10 cm/0 cm	2.24	
0 cm/-10 cm	3.85	37.28
-10 cm/-30 cm	64.49	50.87
-30 cm/-110 cm	31.64	9.60

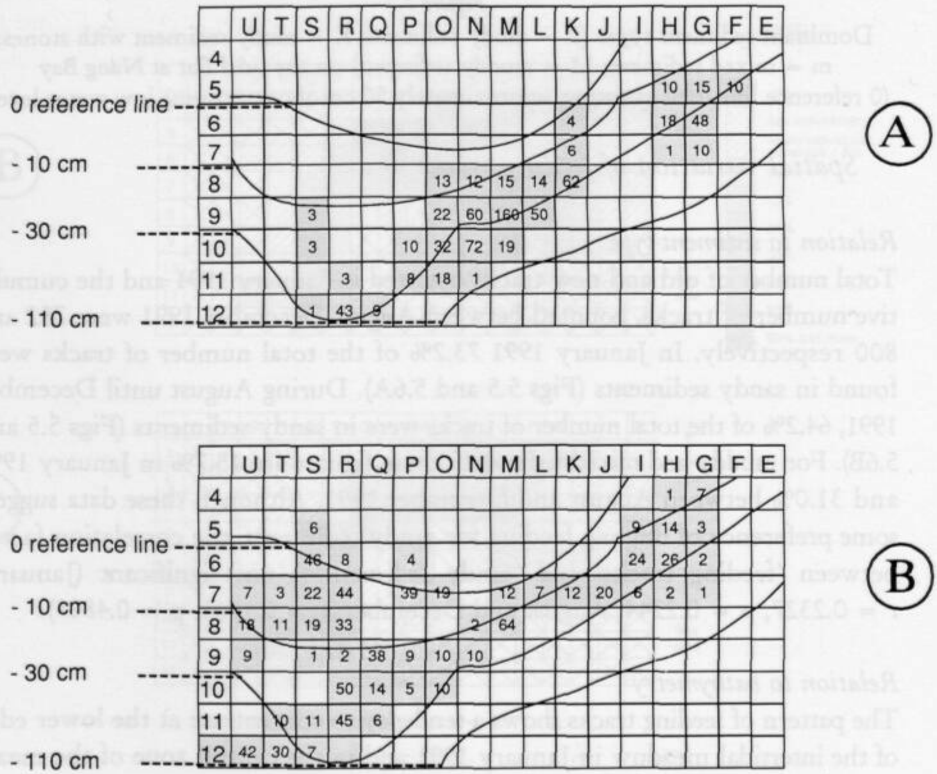


Figure 5.6
Distribution of feeding tracks on the tidal flat at Nang Bay,
A: January 1991, B: August-December 1991

Relation to seagrass species

In January 1991, 77.4% of the quadrats with feeding tracks had 20% or more *Halodule uninervis*, 3.2% had 20% or more *Thalassia hemprichii* and 12.9% had 20% or more *Cymodocea rotundata*. In addition 90.1% of the total number of feeding tracks in January 1991 were found in quadrats with 20% or more *Halodule uninervis*, 0.4% with 20% or more *T. hemprichii* and 2.5% with 20% or more *C. rotundata* (Figs 5.4 and 5.6A).

Between August and December 1991 56.2% of the quadrats with feeding tracks were in quadrats with 20% or more *Halodule uninervis*, 18.7% with 20% or more *T. hemprichii* and 20.8% with 20% or more *C. rotundata*. In addition 55.1% of the total number of feeding tracks were found in quadrats with 20% or more *Halodule uninervis*, 20.3% with quadrats of 20% or more *T. hemprichii* and 23.2% with quadrats of 20% or more *C. rotundata* (Figs 5.4 and 5.6B).

In the meadows distinct swards could be distinguished, dominated by *Halodule uninervis*, with highest densities of feeding tracks (Fig. 5.4A, B, C and Fig. 5.6A, B). The monthly analyses of feeding tracks indicated dugongs regularly revisiting these feeding swards.

Temporal changes in the seagrass meadow

Biomass below-ground and above-ground

The biomass in *Halodule uninervis* meadows at Nang Embayment ranged from 8.9 (±1.5) to 20.9 (±3.9) g DW m^{-2} for the above-ground fraction (Fig. 5.7) and from 58.8 (±14.2) to 147.9 (±29.2) g DW m^{-2} for the below-ground fraction (Fig. 5.8), during the period December 1990 until July 1991.

Biomass of the below-ground fraction of the undisturbed seagrass bed significantly increased ($P < 0.05$) by 65% from May to July 1991 (Fig. 5.8), which coincided with the onset of the rainy season (Fig. 5.9). Then it stabilized during August-November 1991.

The below-ground biomass of undisturbed *Halodule* beds of two samples was significantly lower ($P < 0.05$) during the dry season (beginning of February/mid March 1991) compared to the wet season (mid August/mid November 1991).

Biomass of the above-ground fraction in the undisturbed seagrass bed significantly increased during March to May 1991 (by 64%), followed by a significant decrease (of 43%) during May to June and a stabilization during July to November (Fig. 5.7).

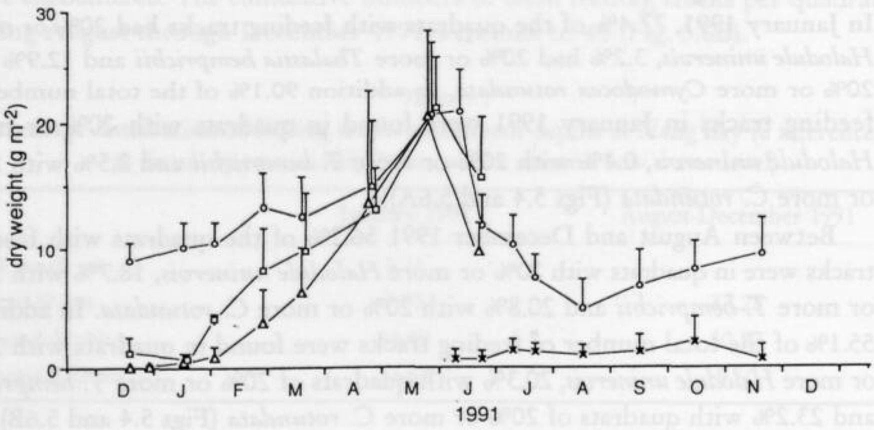


Figure 5.7
Biomass (g DW m^{-2}) of *H. uninervis* above-ground fraction (± standard deviation in vertical lines) at the tidal flat at Nang Bay in undisturbed seagrass bed (○), artificial feeding tracks (□, x) and natural feeding tracks (△)

The decrease of above-ground biomass coincided with spring low tides at midday. Monthly above-ground biomass showed a high positive correlation with 'tidal pattern', defined as the percentage of nights per month, when low tide is equal or lower than 50 cm above ELWS table of Ambon (Table 5.2). This observation confirms the importance of this factor in relation to the dynamics of *Halodule uninervis* above-ground biomass.

The below-ground and above-ground biomass of the artificial tracks and the natural feeding tracks of the sampling period from December 1990 until June 1991 showed a significant increase ($P < 0.05$) reaching biomass levels of the nearby bed (Figs 5.7 and 5.8). Between May and June 1991, above-ground biomass of both artificial and natural track showed a sudden significant decrease similar to the decrease observed for the above-ground fraction of the undisturbed seagrass bed. During the sampling period of June to November 1991, both the below-ground fraction and the above-ground fraction of the artificial tracks did not show significant changes ($P < 0.05$).

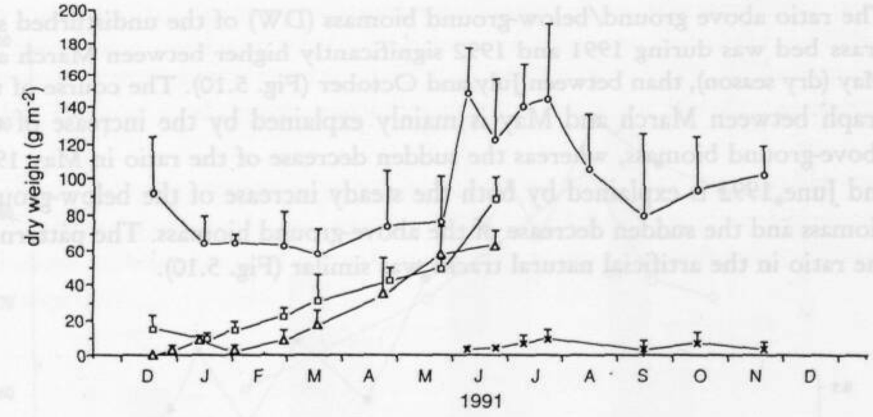


Figure 5.8
Biomass (g DW m^{-2}) of *H. uninervis* below-ground fraction (± standard deviation in vertical lines) at the tidal flat at Nang Bay undisturbed seagrass bed (○), artificial feeding tracks (□, x) and natural feeding tracks (△)

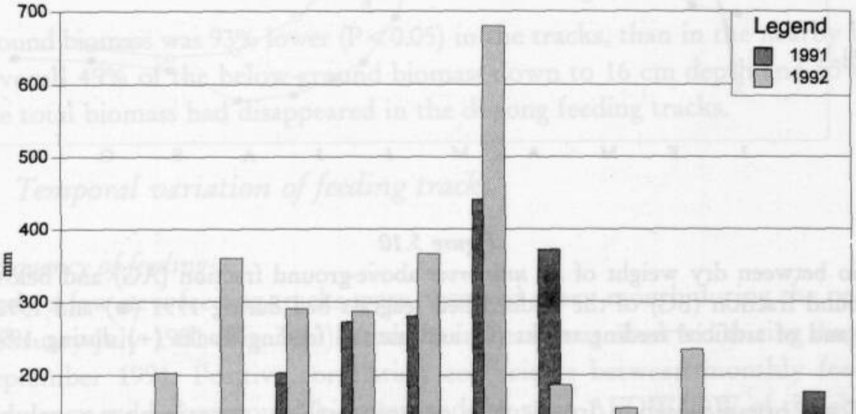


Figure 5.9
Monthly rainfall during 1991 and 1992, measured at the Tulehu meteorological station, East Ambon

Ratio's of different fractions

The ratio above ground/below-ground biomass (DW) of the undisturbed seagrass bed was during 1991 and 1992 significantly higher between March and May (dry season), than between July and October (Fig. 5.10). The course of the graph between March and May is mainly explained by the increase of the above-ground biomass, whereas the sudden decrease of the ratio in May 1991 and June 1992 is explained by both the steady increase of the below-ground biomass and the sudden decrease of the above-ground biomass. The pattern of the ratio in the artificial natural tracks was similar (Fig. 5.10).

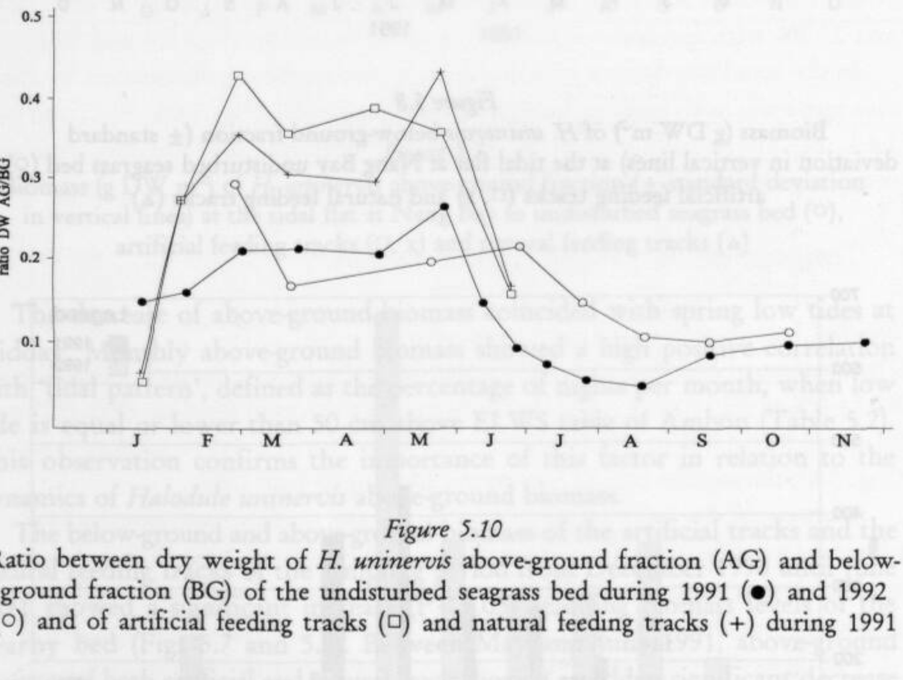


Figure 5.10

Ratio between dry weight of *H. uninervis* above-ground fraction (AG) and below-ground fraction (BG) of the undisturbed seagrass bed during 1991 (●) and 1992 (○) and of artificial feeding tracks (□) and natural feeding tracks (+) during 1991

Total organic carbon (particulate organic carbon, containing e.g. soluble carbohydrates) in the below-ground fraction showed a significant ($P < 0.05$) increase between February and August (Fig. 5.11). After August the ratio showed a slight insignificant decrease.

Sediment depth dependence

Below-ground biomass between 0 and 4 cm was 75% lower inside the grazing tracks ($P < 0.05$) than in the undisturbed bed (Fig. 5.12). At deeper layers no significant differences were observed between track and undisturbed bed. Above-

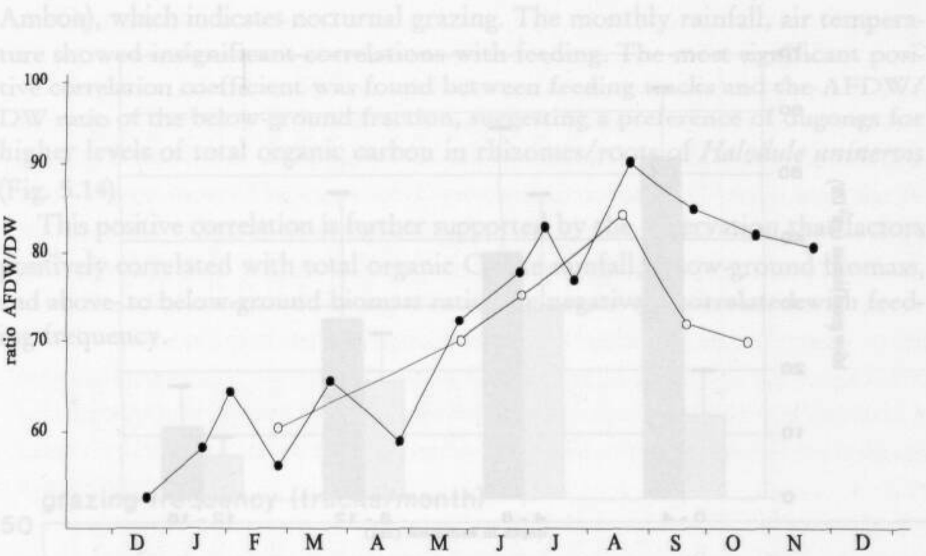


Figure 5.11
Ratio between dry weight (DW) and ash free dry weight (AFDW) of *H. uninervis* below-ground fraction during 1991 (●) and 1992 (○)

ground biomass was 93% lower ($P < 0.05$) in the tracks, than in the nearby bed. Overall 49% of the below-ground biomass down to 16 cm depth and 55% of the total biomass had disappeared in the dugong feeding tracks.

Temporal variation of feeding tracks

Frequency of feeding

Only a few new feeding tracks were observed every month during the period February-July 1991 (Fig. 5.13). A sharp increase was observed during August-September 1991. Positive correlation coefficients between monthly feeding frequency and below-ground biomass, and the ratio AFDW/DW of the above-ground fraction, were insignificant (Table 5.2). Negative correlation coefficients were significant comparing feeding track frequency with biomass of above-ground, the ratio DW above-ground fraction to DW below-ground fraction and tidal fluctuations. The first and second indicate that dugongs might prefer sparse seagrass meadows with low above-ground biomass and high below-ground biomass. The most significant negative correlation was found between feeding track numbers and tidal fluctuations (expressed as the % of nights per month when low tide was equal or lower than 50 cm in the Tidal Table of

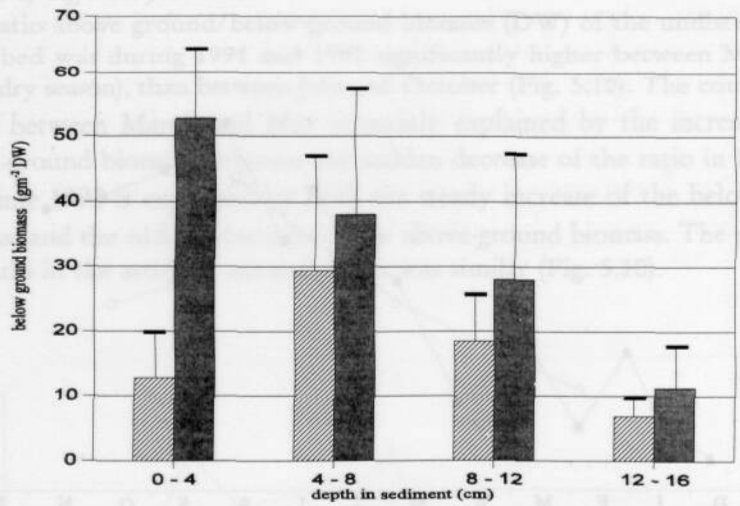


Figure 5.12

Distribution of *H. uninervis* in different depths in sediment from undisturbed seagrass bed (black bars) and feeding tracks (stripped bars) with standard deviation (in vertical lines) in the tidal flat of Nang Bay (samples from June 1991)

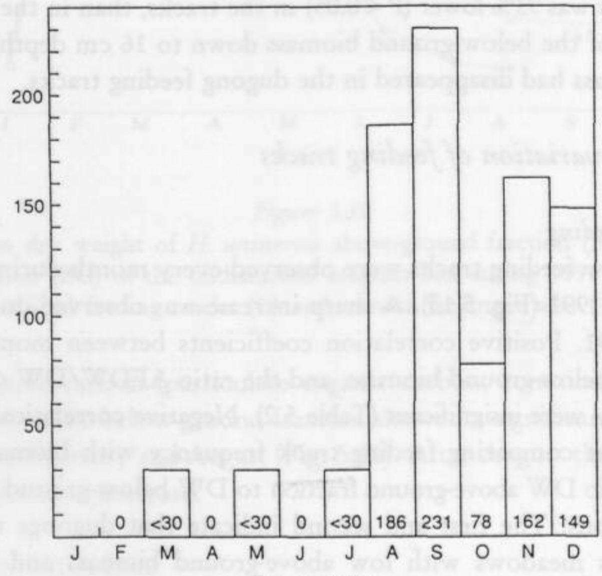


Figure 5.13

Monthly number of feeding tracks (N) in the tidal flat at Nang Bay during January until December 1991

Ambon), which indicates nocturnal grazing. The monthly rainfall, air temperature showed insignificant correlations with feeding. The most significant positive correlation coefficient was found between feeding tracks and the AFDW/DW ratio of the below-ground fraction, suggesting a preference of dugongs for higher levels of total organic carbon in rhizomes/roots of *Halodule uninervis* (Fig. 5.14).

This positive correlation is further supported by the observation that factors positively correlated with total organic C, like rainfall, below-ground biomass, and above- to below-ground biomass ratio, are negatively correlated with feeding frequency.

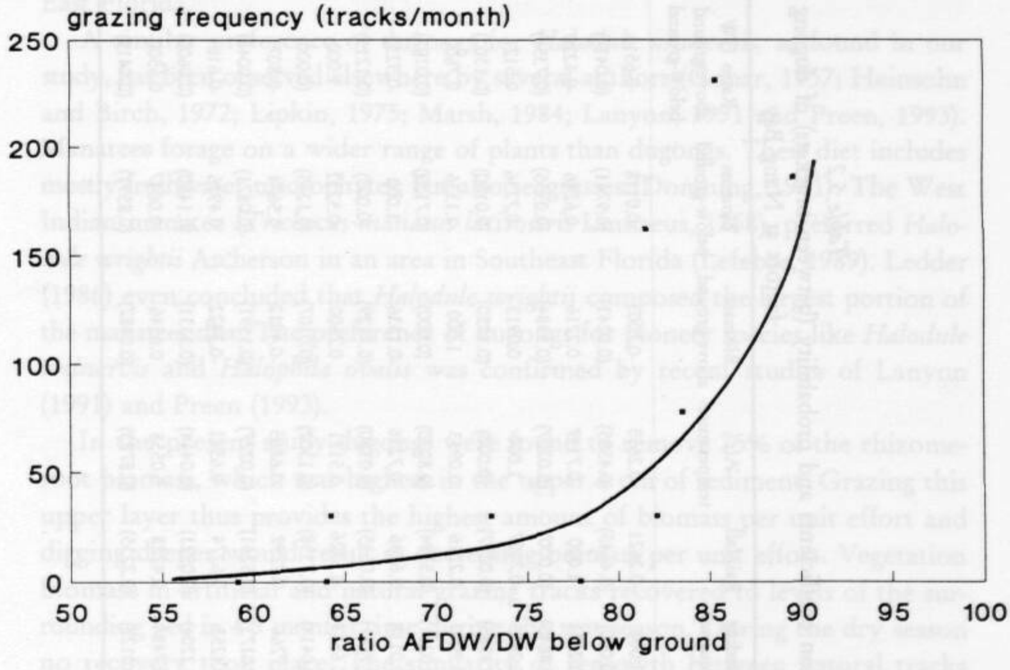


Figure 5.14

Visually fitted line of an exponential correlation between the monthly feeding frequency and the ratio ash free dry weight to dry weight (representing the level of soluble carbohydrates) at Nang Bay

Table 5.2

Partial correlation coefficients and probability (between brackets) of dugong feeding frequency and environmental factors at Nang Bay

	Feeding frequency	Rainfall	Air temperature	Biomass above-ground	Biomass below-ground	Ratio DW above-ground below-ground	Ratio AFDW/DW below-ground	Ratio AFDW/DW above-ground	Tidal pattern
Feeding frequency	1.000	-0.2621	-0.2655	-0.7003	-0.0118	-0.6513	0.7266	0.4253	-0.7484
	(0.000)	(0.4645)	(0.4585)	(0.0241)	(0.9741)	(0.0414)	(0.0173)	(0.2204)	(0.0128)
Rainfall	-0.2621	1.000	-0.7127	0.2216	0.6246	-0.1226	0.2292	0.6274	0.4228
	(0.4645)	(0.000)	(0.0207)	(0.5384)	(0.0535)	(0.7358)	(0.5241)	(0.0521)	(0.2235)
Air temperature	-0.2655	-0.7127	1.000	0.0913	-0.7236	0.5121	-0.6885	-0.6511	0.05558
	(0.4585)	(0.0207)	(0.000)	(0.8020)	(0.0180)	(0.1302)	(0.0277)	(0.0414)	(0.8783)
Biomass above-ground	-0.7003	0.2216	0.0913	1.000	0.1336	0.7600	-0.4812	-0.3422	0.6346
	(0.0241)	(0.5384)	(0.8020)	(0.000)	(0.7129)	(0.0107)	(0.1591)	(0.3331)	(0.0487)
Biomass below-ground	-0.0118	0.6246	-0.7236	0.1336	1.000	-0.5222	0.5674	0.4926	-0.0647
	(0.9741)	(0.0535)	(0.0180)	(0.7129)	(0.000)	(0.1215)	(0.0871)	(0.1480)	(0.8591)
Ratio DW above/below	-0.6513	-0.1226	0.5121	0.7600	-0.5222	1.000	-0.8070	-0.6121	0.6500
	(0.0414)	(0.7358)	(0.1302)	(0.0107)	(0.1215)	(0.000)	(0.0048)	0.0600	(0.0419)
Ratio AFDW/ DW below	0.7266	0.2292	-0.6885	-0.4812	0.5674	-0.8070	1.000	0.6542	-0.6534
	(0.0173)	(0.5241)	(0.0277)	(0.1591)	(0.0871)	(0.0048)	(0.000)	(0.0401)	(0.0405)
Ratio AFDW/ DW above	0.4253	0.6274	-0.6511	-0.3422	0.4926	-0.6121	0.6542	1.000	-0.1847
	(0.2204)	(0.0521)	(0.0414)	(0.3331)	(0.1480)	(0.0600)	(0.0401)	(0.000)	(0.6094)
Tidal pattern	-0.7484	0.4228	0.0558	0.6346	-0.0647	0.6500	-0.6534	-0.1847	1.000
	(0.0128)	(0.2235)	(0.8783)	(0.0487)	(0.8591)	(0.0419)	(0.0405)	(0.6094)	(0.000)

Discussion

Our data indicate that species distribution in the meadow followed to a certain extent the types of sediments. Dugongs at Ambon seem to have preferred grazing in patches of the seagrass bed where the coverage of *Halodule uninervis* was 20% or more. The cover of *T. hemprichii*, cover of *C. rotundata*, the distribution of sediment and water depth affected the spatial distribution of the feeding tracks less. Of the total number of feeding tracks in January 1991 90% were found in restricted feeding swards dominated by *Halodule uninervis*.

The observed pattern of dugongs regularly revisiting these feeding swards may indicate similar patterns of cultivation grazing as described by Preen (1993) for dugongs feeding on *Halophila* meadows in sub-tropical Moreton Bay and by Lefebvre (1990) for manatees feeding on *Halodule uninervis* meadows in South-East Florida.

A similar preference of dugongs for *Halodule uninervis*, as found in our study, has been observed elsewhere by several authors (Gohar, 1957; Heinsohn and Birch, 1972; Lipkin, 1975; Marsh, 1984; Lanyon, 1991 and Preen, 1993). Manatees forage on a wider range of plants than dugongs. Their diet includes mostly freshwater macrophytes, but also seagrasses (Domning, 1981). The West Indian manatee (*Trichecus manatus latirostris* Linnaeus, 1758), preferred *Halodule wrightii* Ascherson in an area in Southeast Florida (Lefebre, 1989). Ledder (1986) even concluded that *Halodule wrightii* composed the largest portion of the manatees diet. The preference of dugongs for pioneer species like *Halodule uninervis* and *Halophila ovalis* was confirmed by recent studies of Lanyon (1991) and Preen (1993).

In the present study dugongs were found to remove 75% of the rhizome-root biomass, which was highest in the upper 4 cm of sediment. Grazing this upper layer thus provides the highest amount of biomass per unit effort and digging deeper would result in decreasing biomass per unit effort. Vegetation biomass in artificial and natural grazing tracks recovered to levels of the surrounding bed in 4-5 months time during the wet season. During the dry season no recovery took place. The similarity of regrowth between natural tracks (where 25% of below-ground biomass remained) and artificial tracks (with no below-ground biomass) indicates regrowth mostly from the edges of the tracks.

The temporal pattern of below-ground biomass of *Halodule uninervis* in Nang Embayment showed a strong positive correlation with rainfall increasing to its maximum during the rainy season. The above-ground biomass at the same time decreased resulting in a 'sparse' seagrass meadow during June-July. The significant increase in below-ground biomass of *Halodule uninervis* during the onset of the rainy season could possibly be explained by an increased nutrient availability caused by significant river input during heavy rains. Welsby (1967), in regard to dugongs in Moreton Embayment in South Queensland, considered that the food supply of dugongs is 'entirely influenced' by the summer rains. This statement is quantitatively confirmed by the findings of the present study with reference to *Halodule uninervis* meadows. The significant decrease of above-ground biomass between May and August 1991 coincided with a shift from nocturnal low tide to spring low tide at daylight, exposing the *Halodule uninervis* meadow to the heat of the sun at mid-day. During rising tide the water above the *Halodule uninervis* meadows was coloured yellow/green, probably by released chlorophyll from the damaged cell structures. This phenomenon was previously reported by Nienhuis *et al.* (1989) for seagrass meadows in the Flores Sea and has also been observed in South Sulawesi seagrass beds (Erftemeijer, 1993b). Thus the sudden decrease in above-ground biomass in June may be explained by the changing pattern of tidal exposure from nocturnal to daylight (exposing the meadows to the heat of the sun), resulting in damage of cell tissues and collapse of above-ground biomass at daylight exposure.

A gradual increase of total organic carbon in the below-ground fraction of *Halodule uninervis* was found during 1991 and 1992. Important factors which may determine dietary preference of dugongs include total N (%), soluble carbohydrates, neutral detergent fibre and tannins. Several authors have reported on the nutritive value of seagrasses in general (Birch, 1975; Murray *et al.*, 1977; Dawes and Lawrence, 1983; Larkum *et al.*, 1989; Lanyon, 1991; Preen, 1993). Most studies indicate that the nutrient value and calorific contents are lower when compared to other vascular plants. Nitrogen and phosphorus contents are low to moderate, comparable with poor terrestrial pastures (Birch, 1975). Based on these nutrient levels Birch (1975) concluded that seagrasses as a diet for dugongs seemed low in both protein and phosphorus. However, Murray *et al.* (1977) suggested high nutritive values for *Halodule uninervis* and *Halophila ovalis*, as concluded from the crude protein value of 19% and low neutral detergent fibre contents. Larkum *et al.* (1989) reported on seasonal fluctuations of soluble hydro carbons in below-ground biomass of seagrass species. Photosynthetically inactive parts of plants always had higher soluble carbohydrate levels than the leaf blades with a particularly marked seasonality in the rhizomes of *Halodule* with values of 40-50% in the rhizomes compared with 13-19% in the leaves. Lanyon (1991) concluded that dietary preference of dugongs is mainly based on high total N(%) levels and low neutral detergent fibre content of seagrass species preferred by dugongs. She did however not cover the importance of seagrass rhizomes in her studies. Preen (1993) suggested possible dietary preference of dugongs in Moreton Embayment based on soluble carbohydrates in *Z. capricorni* Asherson, but did not present scientific prove for this hypothesis.

Statements of several authors (Wake, 1975, quoted by Marsh, 1984; Anderson and Birtles, 1978) that dugongs tend to prefer sparser seagrass stands above denser stands of the same species, were probably based on visual observations of above-ground coverage and did not take below-ground biomass into account. In the case of *Halodule* meadows the observed preference of dugongs for 'sparse stands' can be explained by the coincidence of low above-ground biomass and high levels of soluble carbohydrates in the below-ground fraction.

The present study confirms the dugongs preference for sparse *Halodule uninervis* meadows with a low above-ground biomass and a high below-ground biomass with high levels of total organic carbon. The significant positive correlation between feeding frequency and total organic carbon in the below-ground fraction supports the 'optimal foraging theory' for energy maximisation.

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Chapter 6

Movement and Home Ranges of Dugongs around the Lease Islands, East Indonesia

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and D. Norimarna

Submitted to *Oecologia*

The catch of an adult female dugong (D_4) on 10 October 1994 at Haruku.
This animal was tracked for more than 9 months (photo: Marco Gylstra)

Movement and Home Ranges of Dugongs around the Lease Islands, East Indonesia

Abstract

Four individual dugongs were tracked, with buoyant, tethered, conventional and satellite radio transmitters. The dugongs (three adult females and one immature male) were encircled with a net at a catch site near Haruku island and tracked for between 41 and 285 days. The animals showed individualistic patterns of movement, moving between 2-3 core areas, travelling between 17 and 65 km from the site of capture. One adult female spent most of the time at two distinct inshore seagrass beds separated by about 17 km; she made five trips between the two sites. Two other females made separate trips to two distinct sites, one of them returning to the catch site at Haruku island. The immature male journeyed between two areas about 65 km apart, completing the journey in four days. The patterns of movement confirmed a practice of regular recropping of restricted grazing swards by small loose feeding assemblages rather than fixed herds with a strong social bond. Mean home ranges covered 4.1 km^2 (50% harmonic mean) and 43.4 km^2 (95% harmonic mean).

Introduction

Few scientific records are available on the movements of individual dugongs. Anderson (1982; 1986) observed dugongs in Shark Bay, Western Australia and concluded that seasonal movements are clearly a part of dugong strategy.

Satellite telemetry has been used in a wide range of wildlife studies (Fancy *et al.*, 1988). Marsh and Rathbun (1990) developed a technique for tracking individual dugongs with buoyant, tethered, conventional and satellite radio transmitters and applied to six dugongs caught off the North Queensland coast. The dugongs followed in the study of Marsh and Rathbun (1990) (one immature, one pubertal and four mature males) were caught by bull-dogging or hoop-netting and tracked for between one and 16 months. All spent most of their time in the vicinity of inshore seagrass beds. The only dugong to undertake long-distance movements was the immature male which journeyed between core areas in two bays about 140 km apart three times in nine weeks.

Preen (1993) tracked 13 dugongs in subtropical Moreton Bay including four males (two adults, two sub-adults) and nine females (five adults, four subadults). Six dugongs were tracked through winter, four through spring and summer. Preen (1993) concluded home ranges of the tropical Northern Queensland dugongs to be significantly smaller than home ranges of subtropical Moreton Bay dugongs, when all animals were included. Preen (1995a) recently reported on the preliminary results of telemetry studies in the Gulf of Carpentaria during 1994, where he used conventional and satellite telemetry to follow the movements of five adult dugongs.

The results of the studies of Marsh and Rathbun (1990) and Preen (1993; 1995a) provided information on the movements of individual dugongs in coastal areas of tropical and sub-tropical (both males and females) Australia. The available studies do not cover movements of dugongs in tropical island ecosystems outside Australian coastal waters. The present study covers the first records of dugong movements and home ranges in such a tropical island ecosystem; the Lease Islands, East Indonesia.

Preen (1993, 1995b) made mention of the phenomenon of cultivation grazing by larger herds of dugongs and postulated that in tropical areas the benefits of cultivation grazing may nog be necessary or relevant, in which case there may be no pressure to feed in large herds. De Iongh *et al.* (1995a) and De Iongh and Langeveld (1996a) found quantitative and qualitative evidence in our study area for cultivation grazing practised by small feeding assemblages of dugongs, contradicting with the conclusions of Preen (1993).

The available scientific literature suggests a smaller maximum herd size and a higher dispersion of dugongs in tropical island ecosystems compared to the Australian continental shelf and sub-tropical areas. Anderson (1985) mentioned that the extreme dispersion observed in Torres Strait and Palau compared with Shark Bay and northern Queensland may be a result of disturbance and hunting pressure, but we believe that the pattern is too regular to be solely explained by disturbance factors and the observed practice of cultivation grazing by small feeding assemblages of dugongs may will contribute to the dispersion.

Preen (1993) stated that dugong herds may be more than just feeding assemblages and may also have a social function. Anderson (1982) also assessed that dugongs are 'essential' gregarious, though frequently solitary. We hypothesise that dugongs with reported herd sized ranging from 1 to 674 (Preen 1993) can be classified as 'mildly social' and 'facultative herders' and represent rather feeding assemblages with loose social interaction than fixed herds with a strong social bond.

During previous studies De Iongh *et al.* (1995a, 1995b) described a dugong population at the Lease islands, East Indonesia, and made observations on feeding ecology. They estimated a minimum population of 22-37 animals in the area, depending on coastal seagrass beds.

The aim of the present study is to complete the results of previous research efforts with observations on movements and home ranges of individual dugongs in the Lease islands and find further supporting evidence for the hypothesis that dugong herds practice cultivation grazing rather as feeding assemblages with loose social interaction than as fixed herds with a strong social bond.

Study Site

The study area covers Ambon and the Lease islands (Haruku, Saparua and Nusa Laut), located in the centre of the Maluku Province on the east side of Indonesia (3°30'S,128°E). The islands border the Banda Sea in the South and the Seram Strait in the North (Fig. 6.1).

They are characterized by a mountainous landscape and are surrounded by a shallow shelf of down to 20 m deep and on average 400 m wide. At the East coast of Ambon the widest shelf is found in front of Pantai Nang, at maximum 500 m wide. Seagrass meadows are restricted to this coastal shelf. A sharp drop-off borders the flat. The maximum depth of the Haruku Strait (between the islands Ambon and Haruku) and Saparua Strait (between the islands Haruku and Saparua) is approximately 120 m, and the maximum depth of Saparua Bay is approximately 40 m. In general the shelf areas are sandy, but in estuaries muddy-silty sediment is found which is under continuous influence of weather conditions such as rainfall, waves and tide. The climate of Ambon is characterized by monsoonal seasons. The rainy season occurs during the southeast monsoon, from May until September, the dry season during the north-west monsoon from October until April.

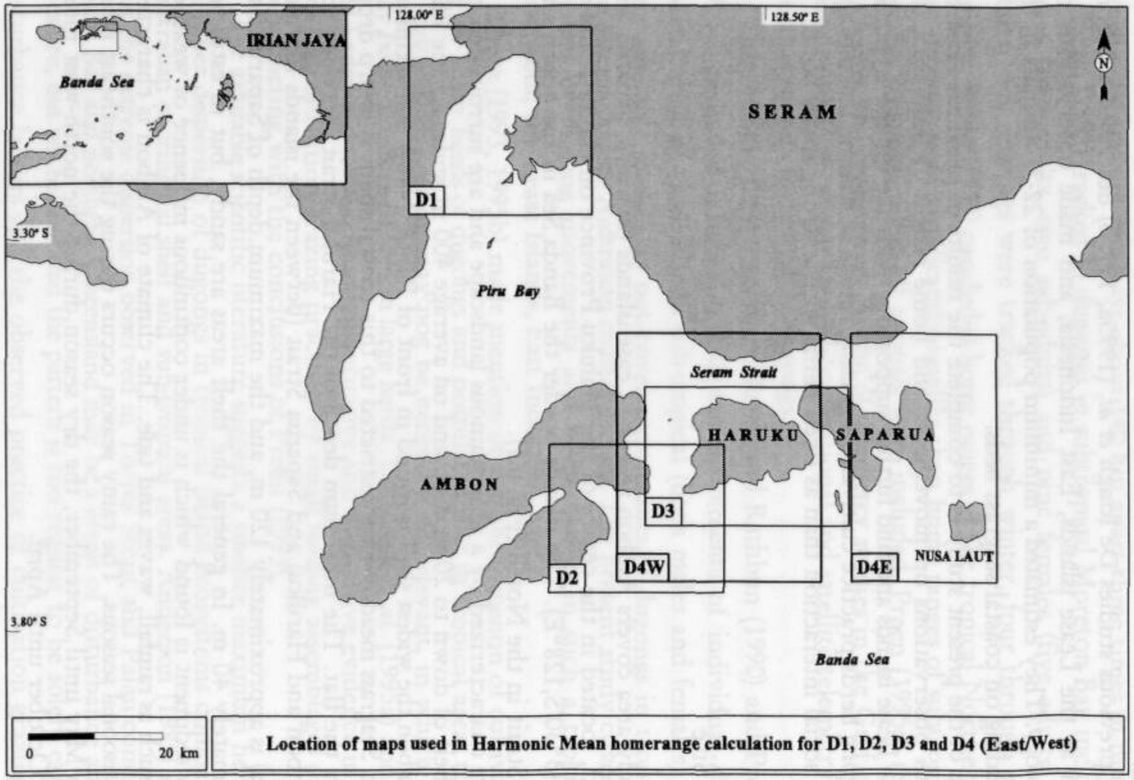

Figure 6.1

Overview map of the study area and location of detailed maps

Methods

Harness attachment

Manatees (*Trichechus manatus*) in Florida have been radio-tracked for several years by an attachment composed of a belt around the caudal peduncle, a semi-rigid tether, and a floating transmitter housing (Reid *et al.*, 1989; Rathbun *et al.*, 1987). Because dugong movements and behaviour are thought to be grossly similar to those of manatees, Marsh and Rathbun (1990) developed an attachment assembly for dugongs based on the successful manatee model (Rathbun *et al.*, 1987). In the present study the attachment assembly developed by Marsh as described by Reid *et al.* (1989) was copied with minor adaptations in the peduncle belt and the attachments to the tether. In December 1993, a prototype attachment assembly was tested on one captive dugong, a 2.90 m-long mature female at the zoological garden in Surabaya. This animal was fitted with a belt, tether and transmitter housing assembly, and closely monitored for three days. The original belt did not properly fit and this problem was overcome by design modifications, involving a steel wishbone and an additional screwlock in the steel buckle. A weak link was included in the tether and each peduncle belt incorporated a corrodible link made of brass and normal steel with an expected life of 6 months.

Conventional telemetry equipment

A VHF transmitter was integrated in each platform transmitter terminal (PTT; Telonics, Mesa, Arizona). The VHF transmitter battery and magnetic on-off switch were enclosed in a housing made of 7.6 cm-diameter PVC pipe. Both ends were capped with a 9 cm-long nose cone, at one end including a 0.25 wavelength whip antenna of 17 cm length. An assembled unit weighed approximately 2.2 kg and was 50 cm long excluding the antenna. The radio frequency was in the 145.0-145.5 MHz range with a pulse duration of 14-17 ms, and a pulse interval of about 1 s. The expected operational life was one year. Transmissions were received using a Telonics TR-2 receiver and a 4-element Yagi beam antenna (land or boat tracking). During trials in June 1993, signals from these transmitters were detected over a line-of-sight range of at least 15 km from the shore (when the observer was positioned about 50 m above sea level).

Satellite telemetry equipment

Each platform transmitter terminal (PTT) (Telonics) was enclosed with three lithium D-cell batteries and a magnetic switch in the same housing as described for the VHF transmitter. Each PTT transmitted a signal at regular intervals throughout the duty cycle at a frequency of 401.650 MHz. Duty cycles were 24 h on and 72 h off, for an expected operational life of 12 months. Long-term and short-term activity sensors and a temperature sensor were incorporated in the PTT. Sensor data were encoded as 16 bit messages following the individual PTT identifier signal. The activity data related to a mercury switch in the housing which tipped more than 90° from the normal vertical position (Fancy *et al.*, 1988). Transmissions included the number of minutes in which the PTT had tipped more than 90° in the previous hour, and the number of actual tips in the previous 24 hours.

Capture and deployment

The immature male dugong (D_1) was located in front of the seagrass meadow at Haruku village on 15 April 1994 and surrounded with a 500 m long and 10 m deep seine net (stretched mesh 40 cm) operated by a crew of four local assistants in a 8.3 m long wooden outrigger canoe. A 4.2 m polyester boat equipped with two 25 HP outboard motors was on standby to perform the tagging procedure and to release the animal from the net. A similar procedure on the same location was followed on 26 April, 1994 to capture an adult female (D_2) and on 10 October 1994 to capture two adult females (D_3 and D_4) of a herd of six animals, which were grazing at the North Haruku meadow. Directly after capture, the peduncle belt, tether and transmitter were attached to the tail stock of the dugongs. Size measurements (total length, axillary girth and basal fluke width) were taken from the animals and they were released within 15 min after capture, to minimize capture stress.

Conventional telemetry

The positions of the tagged dugongs was estimated by triangulation from land. More accurate positions were obtained by homing with a boat (4.2 m long, 25 HP outboard motor). Positions obtained during tracking or homing were verified with a Geographical Positioning System (NAV 5000 DX). During initial tracking after tagging no signals were received from D_2 and it was concluded that the VHF transmitter had broken down. As a consequence, VHF was mostly used to confirm PTT locations of D_1, D_3 and D_4. The PTT of D_1 was recovered by triangulation in Piru Bay, southwest Seram on 5 June 1994, and the PTT of D_3 was recovered using triangulation on 29 November 1994, at Niara village, southeast Haruku. Both PTT's of D_1 and D_3 had broken at the weak link in the tether. A clear disadvantage of VHF telemetry was the fact that D_1, D_3 and D_4 were on most occasions out of range, so that PTT locations were needed for further search. Only D_4 could be tracked on a more regular basis. D_4 was tracked intensively by triangulation and homing when she stayed near Haruku village during October-December and she was regularly sighted.

Satellite telemetry

Service Argos (Toulouse, France) calculated the locations for each PTT by measuring the Doppler effect on the carrier frequency transmitted by the PTT on the basis of messages received by two polar orbiting NOAA Tiros-N weather satellites (Nos. 11 and 12) travelling 820 km above the earth at 28,000 km per hour, as detailed in Fancy *et al.* (1988). The accuracy of locations was tested by anchoring a PTT at the field location of Haruku village for 7 days. Fifteen guaranteed locations (class 1, 2 and 3) were calculated by Service Argos during the period. The estimated locations given by Argos were a mean (±/SD) of 350 m ±160 m from the location determined with a GPS. The concurrent temperature records were within the range of a maximum and minimum thermometer in the coastal waters of the field location. Until June 1994 Argos made available the following categories of location estimates:

Class 3: ≥ 5 messages over > 420 s; very good internal consistency (< 0-15 Hz) and favourable geometric conditions, 5° < distance from ground track < 18°; quality control on oscillator and unambiguous solution; Argos claims 68% of results within a 150 m radius of true latitude and longitude.

Class 2: 4 messages and pass duration of 420 s; good internal consistency (1-5 Hz); geometric conditions 1-5° < distance from ground track < 24°; quality control on oscillator drift and unambiguous solution; Argos claims 68% of results within a 350 m radius circle of true latitude and longitude;

Class 1: ≥ 4 messages during pass duration of 240-420 s interval or only one test to determine the correct solution; good internal consistency (1-5 Hz); geometric conditions 1-5° < distance from ground track < 24°; Argos claims 68% of results within 1 km radius circle of true latitude and longitude;

Class 0: < 4 messages (any locations rejected by the other classes).

From June 1994 Argos modified through a special service Class 0 locations into Class A and Class B locations:

Class A: 3 messages, accuracy not estimated, 2 plausibility tests are done while frequency is calculated;

Class B: 2 messages, accuracy not estimated, 2 plausibility tests are done while frequency is not calculated.

The motion data related to a mercury switch closures, when the housing tipped more than 90° from the normal vertical position. Transmissions from the PTT's included summaries of the number of seconds in the previous minute (short term counter) and the previous 24 h (long term counter) that the switches closed.

Temperature and activity sensor information were received by the satellite(s) on some passes when insufficient signals were received to calculate a location. Such messages are referred to as non-location messages. The end of the tracking records for D_1 and D_2 were determined at the day of recovery by fishermen and checked with the short term activity sensor. The end of the tracking record of D_2 and D_4 was determined at the day data-transmitting stopped and was also checked with the short-term activity counter. During the period that each transmitter assembly was attached to a dugong, data were accessed by personal computer linked to the Service Argos computer in Toulouse via one of the main-frame computers at Leiden University. The QuatroPro spreadsheet programme and the Dbase IV package were used to process the data. Mean minimum speed was calculated over location records within all 24 h satellite cycles.

Home range estimates and statistics

Home ranges were calculated for all the dugongs using a non-parametric method describing home-range in a probabilistic sense (Anderson, 1982). The home range is then calculated as the harmonic mean that accounts for 50% or 95% of the space utilization by the animal (Anderson, 1982). The areas in which each satellite-tagged dugong spent 95% and 50% of its time were calculated and mapped on the basis of guaranteed locations only (excluding class 0, A and B). For home range calculations only the surface covered by sea-area was used and the surface covered by land-area was excluded. All of the given individual's locations were processed simultaneously. VHF data were not included in the home range estimates. All home ranges were mapped using IDRISI-GIS software.

A spreadsheet computer program was used to calculate straight-line distances between consecutive locations within subsequent passes. Distances were calculated within one satellite cycle and were divided by the time in which they were bridged to give the approximate minimum speed of the dugong.

The data on speed were log-transformed to obtain a normally distributed error term.

For comparison of the level of significance of differences between individual speed a one-way analysis of variance was used followed by a Scheffé multiple-comparison test.

Table 6.1

Biological data, location of capture and tracking results of two dugongs caught in April 1994 in Haruku Strait and tracked by conventional and satellite telemetry

Dugong number	D_1	D_2	D_3	D_4
Sex	Male	Female	Female	Female
Body length (m)	1.96	2.90	2.95	2.90
Reproductive status	pubertal	mature	mature	mature
Date of initial capture	15 Apr. 94	26 Apr. 94	10 Oct. 94	10 Oct. 94
Location of capture	Haruku Bay (3°35,37 S, 128°24,81 E)	Haruku Bay (3°35,37 S, 128°24,81 E)	Haruku Bay (idem)	Haruku Bay (idem)
Maximum distance from capture site (km)	65	17	22	47
Transmitter id.	02921	03698	02920	02921
Tagged period (days)	53	98	41	285
Number of 24 h satellite cycles	13	19	11	67
Number of days with satellite messages	24	29	13	81
Mean number of total locations[a] per 24 h cycle (±SD)	4.0 (±1.6) (1-6)	2.8 (±1.8) (0-7)	3.8 (±1.5) (2-6)	4.1 (±2.2) (0-9)
Total number of				
guaranteed locations	33	45	24	179
non guaranteed locations	19	13	17	95
non locations	20	48	14	109
Percentage class				
class 0[b]	26.4	12.3	30.9	24.8
class 1	30.6	19.8	10.9	13.6
class 2	6.9	17.9	18.2	18.3
class 3	8.3	4.7	14.5	14.9
non-locations	27.8	45.3	25.5	28.4
Home range area (km^2)				
95% isopleth[d]	2.00	37.08	53.75	185.43
sea area	1.65	20.22	24.01	127.89
land area	0.35	16.68	29.74	57.54
50% isopleth	1.00	3.99	1.00	16.94
sea area	0.95	2.70	0.18	12.67
land area	0.05	1.29	0.82	4.27
Mean speed b ($km\ h^{-1}$) (±SD) (range)	0.16 (±0.14) n=20 (0-0.4)	0.31 (±0.45) n=27 (0-1.5)	0.47 (±0.70) n=11 (0-2.2)	0.69 (±0.87) n=113 (0-3.7)

a. PTT locations class 0, 1, 2 or 3.

b. PTT location quality 0 (before 15 June 1994) and O, A, B (after 15 June 1994).

c. PTT location quality 1, 2 or 3.

d. D.J. Anderson (1982).

A Mann-Whitney U-test with 95% confidence level was used to compare long-term and short-term activity patterns and temperature between day and night.

Results

Effectiveness of the attachment assembly

Recovery of the transmitter assembly from D_1 and D_3 allowed us to assess its condition 53 days and 41 days after initial capture and deployment. The tethers and transmitters were in good condition, but both tethers had been broken at the weak link. The transmitter was still functioning normally and did not show external damage. The number of operational days for D_1 and D_3 was determined by analysing the results of the activity counters, indicating the date of release of the PTT's. Location records were not received from D_2 and D_4 respectively from 98 and 285 days after deployment and the transmitters were not recovered.

Efficiency of the PTTs

The NOAA 11 and 12 satellites made an average of about seven passes per day over the study area during the times that the PTTs were operational. On average, a satellite was above the horizon for sufficient time to receive a location record.

Table 6.1 summarizes the biological data, data on location of capture and tracking results of D_1, D_2. D_3 and D_4. The mean number of total locations per 24 h cycle showed significant differences between the PTT's, exept for D_1 and D_4 ($P < 0.05$). D_2 showed a higher % of non locations compared with D_1, D_3 and D_4. The maximum number of locations per 24 h-cycle ranged from 6 (D_1 and D_3) to 9 (D_4). A difference in output of supposedly identical PTT's has been noticed before (Fancy *et al.*, 1988).

Day and night activity

Approximately 50% of the total no. of locations obtained for each dugong were at night (Table 6.2). When comparing the long-term activity counters of each dugong a significant sequence was found of $D_1 < D_3 < D_2 = D_4$ (Man Whitney U; $P < 0.001$). The short-term sensors, which measured the number of seconds in the previous minute that the PTT had tipped through 90°, showed significantly higher values at night for the means of D_2 ($U_{51,55} = 2.69$; $P < 0.01$)

Table 6.2
Number of locations and activity pattern of four dugongs and temperature of seawater during night and day time

Dugong	Total no. of locations		Activity counter			Temperature (°C) day				Temperature (°C) night			
			long term* (±s.d.)	short term** (±s.d.)									
	day	night		day	night	(n)	mean	s.d.	range	(n)	mean	s.d.	range
D_1	35	37	17.0 (±40.4)	0.3 (±0.9)	0.8 (±2.9)	(35)	27.0	1.9	18.2-29.6	(37)	27.6	2.7	24.4-42.4
D_2	51	55	80.9 (±97.0)	1.1 (±1.6)	3.3 (±4.3)	(51)	27.7	2.2	24.9-42.6	(55)	27.4	0.6	26.3-29.8
D_3	27	28	61.1 (±121.8)	0.2 (±0.8)	1.3 (±3.0)	(27)	27.8	2.5	16.0-30.5	(28)	28.1	1.2	22.9-29.2
D_4	193	190	95.4 (±155.2)	1.5 (±3.2)	1.9 (±3.9)	(193)	28.2	1.4	15.5-30.0	(190)	28.4	2.7	26.3-35.6

* The number of seconds in the previous 24 h, the PTT tipped through 90°.
** The number of seconds in the previous minute, the PTT tipped through 90°.

and D_3 ($U_{27,28} = 2.03$; $P < 0.05$) compared with day time values. No significant differences were recorded in temperature values between day and night for any PTT ($P < 0.05$).

Movements and home range

D_1, D_2, D_3 and D_4 were tracked for respectively 53, 98, 41 and 285 days (Table 6.1). The only animal to undertake large scale movements outside the study area was D_1 which was classified immature (Marsh *et al.*, 1984). D_1 was tagged on 15 April 1994 in front of Haruku village, but showed movement on April 18, when a fix was received halfway between Ambon and Seram (Fig. 6.2). On April 19, D_1 was located at Latira Bay, South West Seram, 65 km from the capture site. D_1 moved around this region until the PTT was recovered in Latira Bay. D_4 covered a similar distance of 51 km in approximately four days but stayed within the study area (Fig. 6.5).

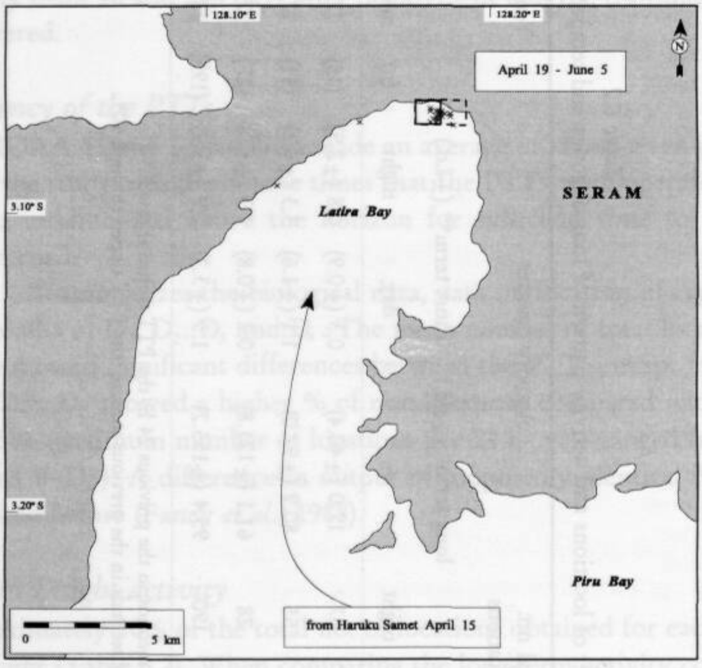

Figure 6.2
Movements of D_1 from Haruku Strait to Latira Bay during April 1994 with home ranges of 50% harmonic mean (line) and 95% harmonic mean (dotted line)

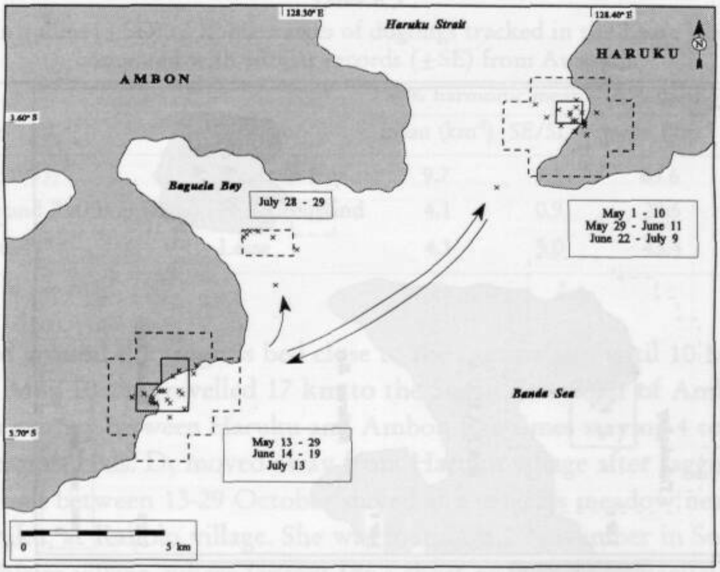

Figure 6.3
Movements of D_2 during April-August 1994 with home ranges of 50% harmonic mean (line) and 95% harmonic mean (dotted line)

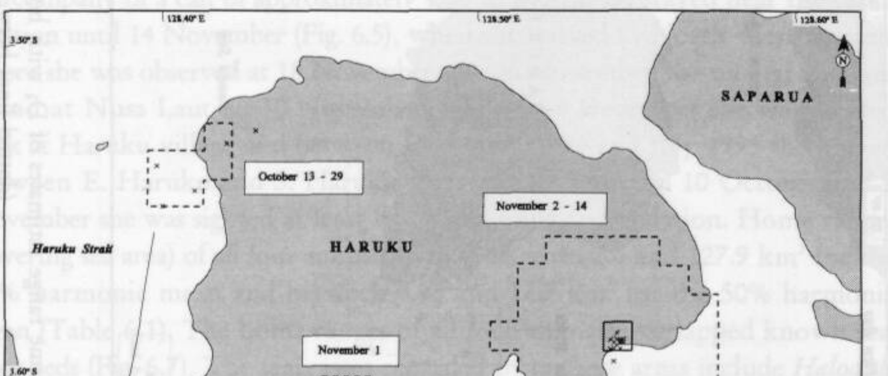

Figure 6.4
Home range estimates of D_3 during October-November 1994 with home ranges of 50% harmonic mean (line) and 95% harmonic mean (dotted line)

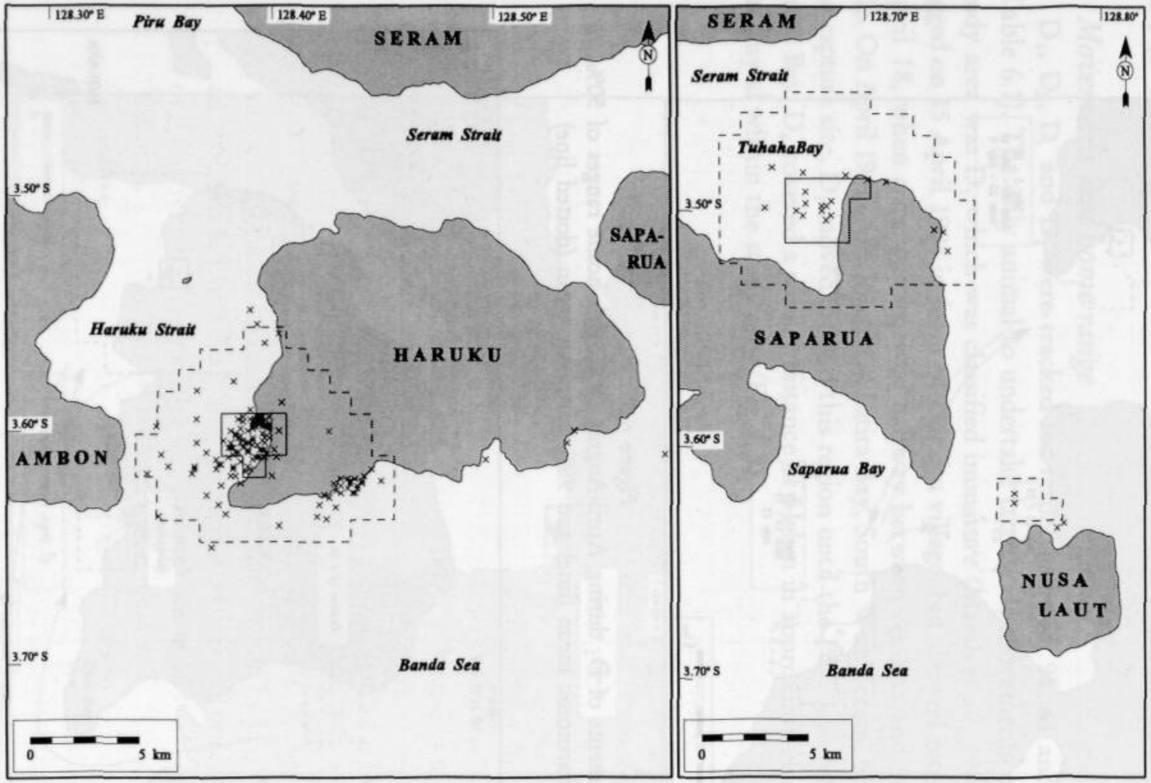

Figure 6.5

Movements and home range estimates of D_4 with home ranges of 50% harmonic mean (line) and 95% harmonic mean (dotted line) between October 1994 and July 1995

Table 6.3
Mean values ($\pm$SD) of home ranges of dugongs tracked in the Lease islands compared with similar records ($\pm$SE) from Australia

			50% harmonic mean		95% harmonic mean	
n	author	location	mean (km^{-2})	SE/SD*	mean (km^{-2})	SE/SD*
13	Preen (1993)	Moreton Bay	9.7	8.1	63.6	8.1
5	Marsh and Rathbun (1990)	N. Queensland	4.1	0.9	29.6	9.2
4	This study	Lease	4.1	5.0	43.4	49.5

* SD refers to our study.

D_2 moved around the seagrass bed close to the capture site until 10 May (Fig. 6.3). On May 10 she travelled 17 km to the South East coast of Ambon. She made this journey between Haruku and Ambon five times staying 4 to 16 days at local seagrass beds. D_3 moved away from Haruku village after tagging on 10 October, and between 13-29 October stayed at a seagrass meadow near North East Haruku, at Kailolo village. She was found on 2 November in South East Haruku, Naira village, where (except for a short round-trip to Baguela Bay on November 18) she stayed until the PTT was recovered (Fig. 6.4). D_4 moved between three core areas at Haruku village, NE Saparua and S. Haruku (Fig. 6.5). D_4 was observed on 12 October (2 days after tagging) close to the catch site in the company of a calf of approximately 1.50 m length. D_4 stayed near the catch location until 14 November (Fig. 6.5), when she moved to North West Saparua where she was observed at 18 November. On 26 November she moved and was found at Nusa Laut on 30 November, while on 8 December she was located back at Haruku village and between December 1994 and July 1995 she moved between E. Haruku and S. Haruku (Fig. 6.6A-J). Between 10 October and 2 November she was sighted at least five times using triangulation. Home ranges (covering sea area) of all four animals ranged between 1.6 and 127.9 km^2 for the 95% harmonic mean and between 0.18 and 12.7 km^2 for the 50% harmonic mean (Table 6.1). The home ranges of all four animals overlapped known seagrass beds (Fig. 6.7). The seagrasses recorded from these areas include *Halodule uninervis, Halophila ovalis, Cymodocea rotundata, Cymodocea serrulata, Syringodium isoetifolium* and *Thalassia hemprichii* (De Iongh and Hein, 1996b). The mean home range size was 43.44 km^2 ($\pm$49.48) ($\pm$SD 417) (95%) and 4.12 km^2 ($\pm$ 5.01) (50%). The mean minimum speeds of D_1, D_2, D_3 and D_4 ranged between 0.16 and 0.69 km h^{-1}, with a significant difference between the means (one-way ANOVA; $F_{3,104} = 15.03$; $P < 0.001$). A Scheffé multiple comparison test confirmed a significant difference of the means ($P < 0.05$).

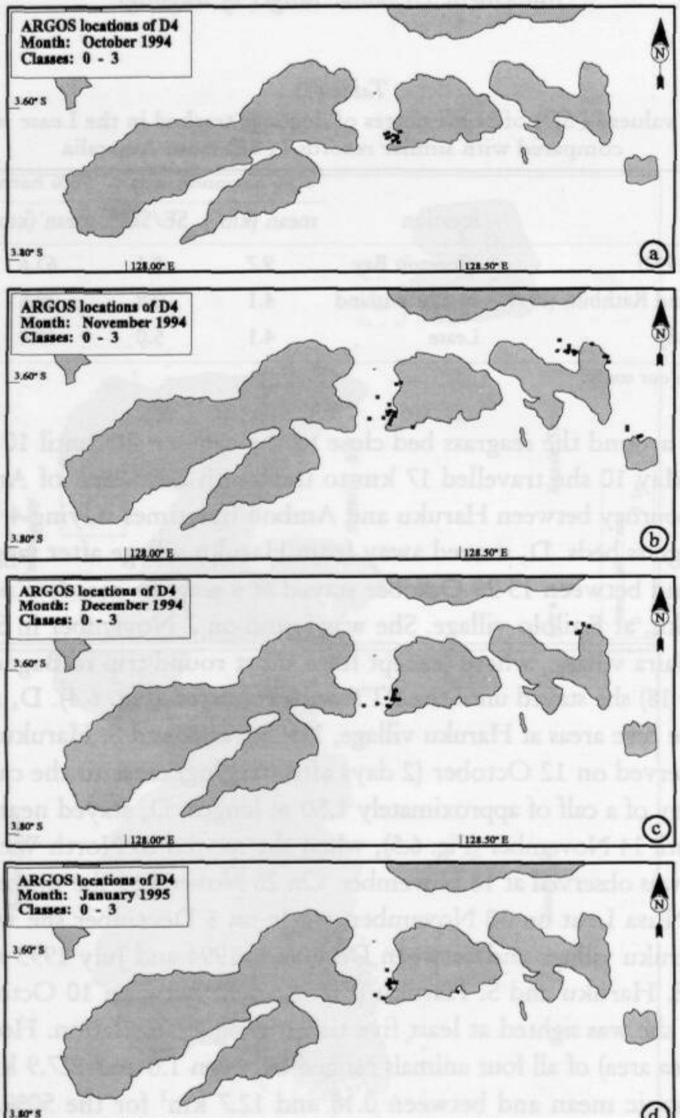

Figure 6.6

Monthly location records of D_4 during October 1994 until July 1995

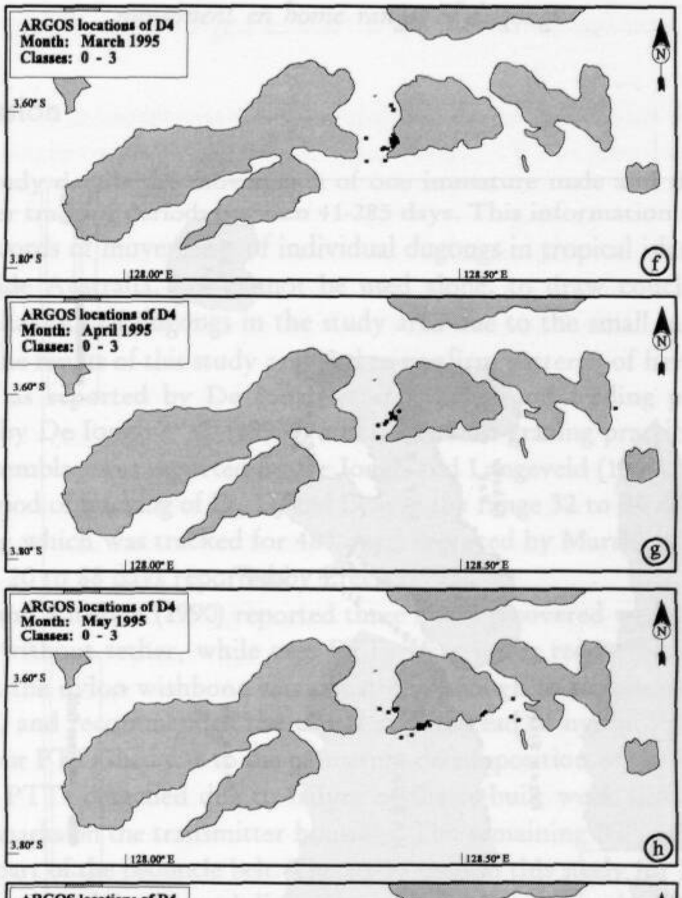

Figure 6.6 (continued)

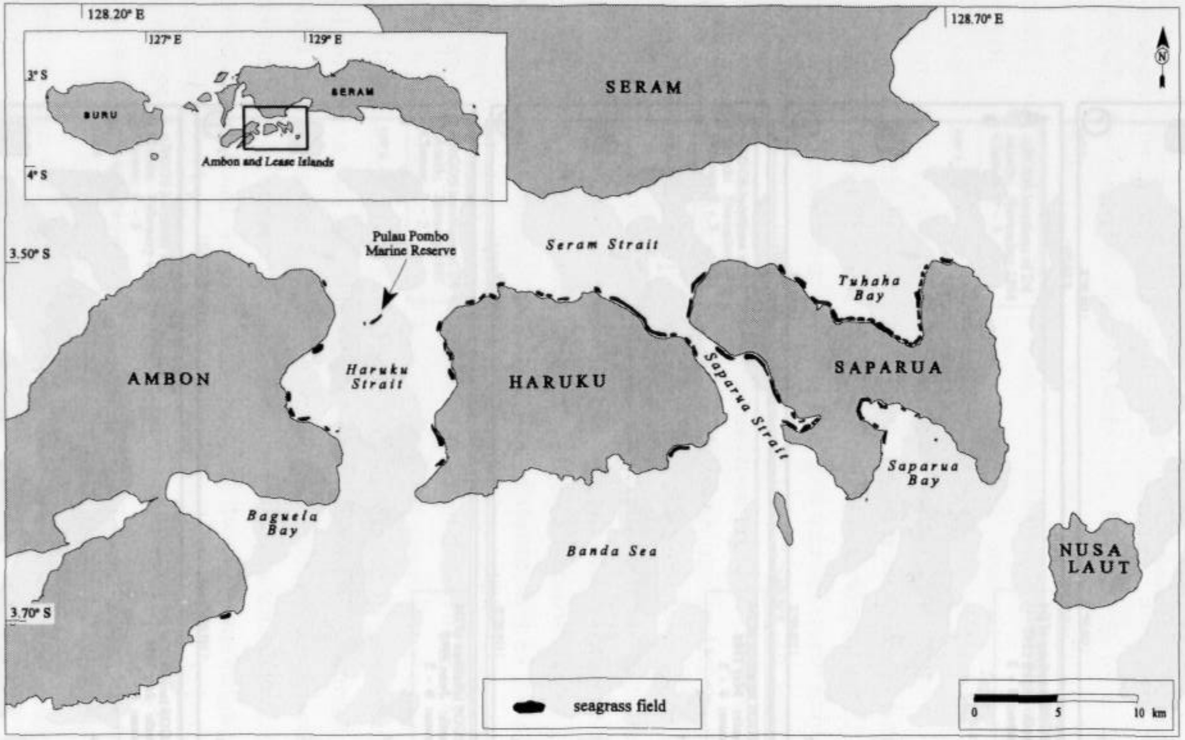

Figure 6.7
Location of seagrass meadows along the coast of Ambon in the Haruku Strait along the coast of Haruku and Saparua island (De Iongh and Hein, 1996b)

Discussion

This study details the movements of one immature male and three adult females over tracking periods between 41-285 days. This information represents the first records of movements of individual dugongs in tropical island ecosystems outside Australia, but cannot be used alone, to draw conclusions on general behaviour of dugongs in the study area due to the small sample size. However the results of this study are used to confirm patterns of herd size and dispersion as reported by De Iongh *et al.* (1995b) and feeding patterns as described by De Iongh *et al.* (1995a) and cultivation grazing practice in small feeding assemblages as reported by De Iongh and Langeveld (1996).

The period of tracking of D_1, D_2 and D_3 is in the range 32 to 94 days (except one dugong which was tracked for 483 days) reported by Marsh and Rathbun (1990) and 20 to 88 days reported by Preen (1993).

Marsh and Rathbun (1990) reported three PTTs recovered with the tether, one PTT without tether, while two PTTs were never recovered. They suspected that the nylon wishbone was not strong enough to sustain wear caused by a PTT, and recommended the use of steel instead of nylon. Preen (1993) reported four PTTs shed due to the premature decomposition of the corrodible link, two PTTs detached due to failure of the in-built weak link following attacks of sharks on the transmitter housings. The remaining PTTs failed at an unknown part of the peduncle belt. The PTTs used in this study for D_1 and D_3 failed due to a break in the weak link. The fact that D_2 was tracked for 98 days and D_4 for 285 days, confirmed that the design of the wishbone resulted in an appropriate functioning of the transmitter attachment for at least two PTTs.

Marsh and Rathbun (1990) used different duty cycles of 8 h on/16 h off (expected life 4 month) and 8 h on/28 h off (expected life 8 month). Preen (1993) used 15 h on/48 h off in winter, while PTTs were on for seven and eight hours on alternate days (15 h on/48 h off) in spring and summer. In our study a duty cycle was deployed of 24 h on/72 h off with the disadvantage of fewer locations but a longer expected life (12 months). Due to the early release of the PTTs this longer life was not capitalized on and the duty cycles applied by Marsh and Rathbun (1990) and Preen (1993) seem more appropriate.

In our study, we found respectively for D_1, D_2, D_3 And D_4 a mean number of locations per 24 h cycle of 4.0, 2.8, 3.8 and 4.1, which is within the range of 2.5 (SE = 0.3) to 3.9 (SE = 0.5) per day recorded by Marsh and Rathbun (1990), but higher when compared with the mean of 1.4 (SE = 0.05) per day recorded by Preen (1993). Considering the shorter satellite cycles used by Marsh and Rathbun and Preen, the performance of our PTT's seems poor. The significant differences in the number of locations per 24 h cycle between the PTT's may reflect a difference in PTT performance. A difference in the output of supposedly identical PTT's, such as recorded in our study, has been reported by Fancy *et al.* (1988) and Keating *et al.* (1991).

The recorded mean minimum speed for D_1, D_2, D_3 and D_4 ranged between of 0.16 km h^{-1} and 0.69 km h^{-1} which is lower than the mean minimum speed reported by Marsh and Rathbun (1990) for a pubertal male, travelling larger distances (1.1 km h^{-1} to 3.6 km h^{1}).

The short-term activity counter recorded differences between day and night, with significantly higher activity at night for D_2 and D_3. Similarly Preen (1993) concluded that, based on records of short-term tip counter, dugongs were significantly more active during night than day, but visual inspection of night and day locations did not indicate any diel pattern of habitat use. The long-term activity counter showed a sequence of $D_1 < D_3 < D_2 = D_4$, which may also be explained by the difference in PTT performance. Marsh and Rathbun (1990) did not find differences in the short-term activity counter, but recorded differences in the long-term activity counter between days when the pubertal male dugong was travelling between Cleveland and Upstart Bays in North Queensland, and days when the animal was near a seagrass bed. Preen (1993) concluded that the short term tip counter records were significantly lower for location records than for non-location records.

Longest distances travelled from the location of tagging for D_1, D_2, D_3 and D_4 were 65 km, 17 km, 22 km and 47 km respectively. Marsh and Rathbun (1990) reported five tagged adult dugongs moving less than 22 km from their site of capture and one pubertal male, making long distance trips of over 140 km, similar to our immature male (D_1).

We recorded a mean home range (covering sea area) of 43.44 km^2 (SD = 49.48) (95% isopleth) and 4.12 km^2 (SD = 5.01) (50% isopleth). Marsh and Rathbun (1990) in North Queensland reported 95% of the fixes in 29.6 km^2 (SE = 9.2) and 50% in 4.1 km^2 (SE = 0.9). The average home range reported by Preen (1993) was 9.7 for the 50% isopleth (SE = 1.6) and 63.6 km^2 (SE = 8.1), based on the 95% isopleth. Preen (1993) concluded that males tended to maintain smaller ranges than females and confirmed significant larger home ranges in Moreton Bay compared with North Queensland when all animals were included, but the difference was not significant when females were excluded. Differences in methodology between home range estimates in our study and in the studies of Marsh and Rathbun (1990) and Preen (1993) do not permit a statistical analyses of the differences, but we conclude that home ranges found in our study are in the same range of those found by Marsh and Rathbun (1990) and surprisingly small.

Preen (1995a) recently reported on the preliminary results of telemetry studies in the Gulf of Carpentaria during 1994. From his preliminary results Preen concluded that the five dugongs were surprisingly individualistic, all showing different patterns of movement, moving over much larger areas than previously thought and showing high social interaction. Each of the dugongs used 1-3 preferred areas 50-400 km apart. The dugongs in our study showed similar individualistic patterns of movement as reported by Preen (1995a), with the immature male travelling 65 km from one core area to another and the three adult females using 2-3 preferred areas 17-47 km apart.

The repeated visits to the Haruku meadow, as observed with D_2 and D_4, can be explained by the observed practice of 'cultivation grazing' resulting in distinct feeding plots with higher *in vitro* digestibility inside the feeding swards, as described for the Haruku meadow by De Iongh and Langeveld (1996a). Cultivation grazing in our study area is practised by small feeding assemblages of dugongs (De Iongh and Langeveld, 1996a). This contradicts with statements of Preen (1993, 1995b) that cultivation grazing by dugongs is only possible by larger herds of dugongs. The results of this study support the hypothesis that dugong herds are rather feeding assemblages with a loose social interaction than fixed herds with a strong social bond. Hartman (1979) also suggested feeding assemblages with loose social interaction for the West Indian manatee.

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Chapter 7

*Maximum sustained Population Size, and Factors Influencing Extreme Dispersion of a Dugong (*Dugong dugon* Müller 1776) Population in Haruku Strait, Eastern Indonesia*

H.H. de Iongh and L.G. Hein

Submitted to *Marine Mammal Science*

Iron harpoon points for dugong hunting of this type, which are still commonly found in the Aru islands, are not found in Ambon and the Lease islands since no deliberate harpoon hunting of dugongs takes place

*Maximum sustained Population Size, and Factors Influencing Extreme Dispersion of a Dugong (*Dugong dugon *Müller 1776) Population in Haruku Strait, Eastern Indonesia*

Abstract

Seventeen seagrass meadows were mapped in the Haruku Strait. Seagrass species coverage, and standing crop (above- and below-ground) per coverage class were calculated and the density of dugong feeding tracks was recorded. The total standing crop of meadows with evidence of dugong feeding was calculated as 32,295 kg DW. The maximum sustained feeding pressure of dugongs was computed with a model as 9 feeding tracks per day per 900 m^2 of seagrass meadow. A maximum population of 15 dugongs can feed sustainably on the seagrass standing crop of Haruku Strait. The analysis of dugong feeding track density confirmed two meadows with evidence of regular recropping by small herds of dugongs of restricted grazing swards. In Haruku Strait accidental capture of dugongs seems a major factor determining dugong population size and the practice of concentrated recropping of grazing swards by small herds of dugongs seems a major factor regulating the distribution and extreme dispersion of dugong herds in the study area.

Introduction

The present study aims to analyse factors influencing dispersion and population size of a dugong population in the Haruku Strait. To describe the population dynamics of a group of individuals one needs information on density, mortality, recruitment as well as immigration and emigration (Lack, 1954).

Population estimates of dugongs so far have been mainly based on aerial survey techniques (Caughly, 1977; Brownell *et al.*, 1981; Marsh 1986; Rathbun and Ralls, 1988; Marsh *et al.*, 1984). Marsh (1992) showed that although aerial surveys can be used for initial population assessments they are not appropriate to monitor changes in size of small populations.

Aerial surveys were carried out in the Lease islands during 1990 and 1992 (De Iongh *et al.*, 1995a), resulting in 5-11 dugongs per survey hour, a maximum herd size of eight and a minimum population estimate of 22-37 dugongs for the study area.

A high dispersion and small herd size (< 8 individuals) has also been reported for Palau (Brownell *et al.*, 1981; Rathbun and Ralls, 1988), Torres Strait (Marsh *et al.*, 1984) and the Philippines (Trono, 1995). Both herd size and the survey rates per hour are much smaller than the maximum herd size of 20 and survey rates of over 150 dugongs/hour reported by Marsh (1985) for tropical Queensland. Also Preen reports maximum herd size of over 150 individuals in sub-tropical areas of Shark Bay, Moreton Bay and the Arabian Gulf (Preen, 1993).

Anderson (1985) suggested that the extreme dispersion observed in Palau and Torres Strait may possibly be a result of social disorganization due to hunting pressure. Our findings confirming dietary preference of dugongs for pioneer vegetations of *Halodule* and *Halophila* (De Iongh *et al.*, 1995b; 1996b) and of small herds of dugongs practising the regular recropping of concentrated feeding swards of mono-specific *Halodule*, surrounded by a mixed seagrass meadow and in mono-specific *Halodule uninervis* and *Halophila ovalis*-meadows (De Iongh *et al.*, 1995b, 1996c; De Iongh and Langeveld, 1996d), and the observations of satellite tracked dugongs revisiting 2-3 core areas (De Iongh *et al.*, 1996a) suggest that the extreme dispersion of the dugong population in our study area is rather a result of this practice than a direct result of hunting pressure as postulated by Anderson (1985).

Based on the above information, we hypothesise that in our study area of a small island ecosystem the observed dispersed distribution and the practice of regular recropping of restricted grazing swards by small herds indicate that this practice may be a major factor determining the extreme dispersion of dugong herds. The present study aims to find supporting evidence for this hypothesis.

In addition the present study covers an analyses of factors influencing dugong population size in the study area. In order to compare the minimum population estimate of 22-37 dugongs, as reported by De Iongh *et al.* (1995a) with the maximum sustained population size in the study area, a computer model is developed to simulate optimal grazing pressure of dugongs and to calculate maximum sustained feeding pressure.

The computer model follows the pattern of herbivory along a productivity optimum as described by several authors (McNaughton, 1979; Belsky, 1986;

Prins *et al.* 1980). Our model does not exclude herbivory along a productivity gradient, as described by Van de Koppel *et al.* (1996), who developed a model to simulate maximum grazing pressure by terrestrial herbivores, which maintain a low level of standing crop in restricted grazing plots, with a higher grazing efficiency when compared with ungrazed dense vegetation. This phenomenon was demonstrated with barnacle geese (*Branta leucopsis*), brent geese (*Branta bernicla bernicla*), hare (*Lepus europeans*) and rabbit (*Orytolagus cuniculus*) foraging on a salt marsh. Although plant biomass in the older and more productive part of the salt marsh was relatively high, there was a reduction of overall digestibility in the ungrazed swards, compared with the grazed swards, which reduced feeding efficiency.

Preen (1993; 1995) suggested a similar foraging strategy of dugongs in subtropical Moreton Bay. He noted seagrass communities which were held at a low level steady state by continued grazing and concluded that cultivation grazing by dugongs may alter species composition, age structure and nutrient status of seagrass meadows.

Materials and Methods

Location

The Haruku Strait located between the islands of Ambon and Haruku, in the Moluccas province, Indonesia (3°30'-3°36' S, 128°19'-128°25' E) (Fig. 7.1). The Haruku Strait is approximately 15 km long and a maximum 11 km wide. In the north it is connected with the Seram Sea and in the south with the Banda seas. The islands both possess a mountainous landscape, the highest mountain of Ambon are 1,036 m., whereas Haruku's highest points is 587 m (Verbeek, 1905). The climate of Ambon is characterized by monsoons (De Iongh *et al.*, 1995a).

The maximum depth of the Haruku Strait is approximately 120 m. A shallow shelf is present along most of the shore. The widest reef flat is found at the Pantai Nang meadow on the East side of Haruku Strait, where it is 500 m wide. A sharp drop off borders the reef flat. In general the reef flats are sandy, but at Pantai Nang a muddy-silty sediment is found.

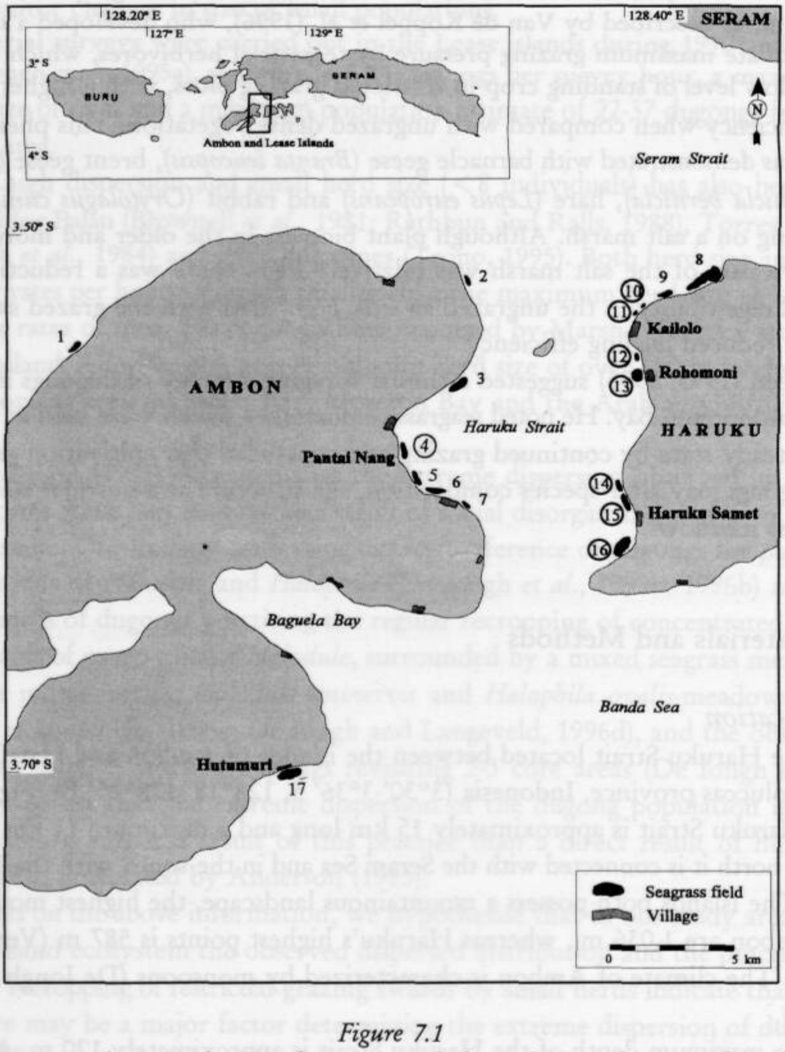

Figure 7.1
Seagrass meadows in the Haruku Strait and along the North coast of Ambon (encircled numbers indicate evidence of dugong feeding)

Distribution of the seagrass meadows

During the study period maps of seagrass meadows were prepared for the whole coastline of the Lease islands but this chapter only covers the results of Haruku Strait. Both the shorelines of Haruku and Ambon bordering the Haruku Strait were surveyed for seagrasses by boat from October 1992 to March 1993. The approximate locations of the seagrass meadows were recorded on a summary map (1:25,000). This field map was prepared from an enlarged topographical map (Weltevreden, 1926) and recent (1989) aerial photographs (1:10,000), which were available for the coast of Ambon but not for Haruku. The position of the seagrass meadows was confirmed with a Geographical Positioning System (NAV 5000X) that obtained coordinates of the northern-most and southern-most edges of the seagrass meadows which are plotted on the summary map. In addition to the summary map, detailed maps on a scale of 1:2,500 were prepared of those meadows with evidence of dugong feeding. The 1:2,500 maps were prepared by transects paralel to the coast at intervals of appoximately 50 meters. Each meadow was covered by at most six paralel transects. The distances were measured with a measuring tape, carried by a snorkler, who was towed behind an outboard powered fibreglass boat of approximately 7 m long at a speed of approximately 3 miles/hour.

Every 20 m along the transects in a quadrat of 5x5 m, the following information was recorded: a) species composition; b) coverage of the seagrass (estimated in percentages); c) the density of dugong feeding tracks. Seagrass species were determined according to Den Hartog (1970), while species coverage was estimated as the leaf area per square meter according to Nienhuis *et al.* (1989). The surface areas covered by *Thalassia Hemprichii* and *E nhalus acoroides* (e.g. Nang) were not included in this study, since these seagrasses are hardly fed upon by dugongs. The following feeding track density classes were determined:

Feeding class		*Class density range (per 25 m²)*	
(A)	Abundant	> 6	feeding tracks
(B)	Frequent	4-6	feeding tracks
(C)	Occasional	1-3	feeding tracks
(D)	None	no feeding tracks	

The following species-coverage classes were identified (highest figures refer to maximum cover observed):

a	*Halodule univervis* mono-specific	1-9%
b	*Halodule univervis* mono-specific	10-25%
c	*Halodule univervis* monospecific	26-50%
d	*Halophila ovalis* mono-specific	5-20%
e	*Halophila ovalis* mono-specific	21-50%
f	*Halodule univervis - Halophila ovalis* mixed	5-20%
g	*Halodule univervis - Halophila ovalis* mixed	21-50%
h	*Halodule univervis - Cymodocea serrulata* mixed	30-60%
i	*Halodule univervis - Cymodocea rotundata* mixed	30-60%

Biomass sampling

During January-March 1993 150 biomass random samples were collected in the different species-coverage classes in seagrass meadows with evidence of dugong feeding. The biomass samples were collected with a plastic corer (diameter of 9.81 cm), to a depth of 15 cm in the substrate. Both above- and below-ground parts of the plant were collected in the sampler. The samples were sieved (1 mm mesh size) and cleaned of sediment. The above-ground fraction and below-ground fraction were separated. The samples were dried for 24 hours in an oven at 90°C, then put in a desiccator for one hour. After cooling dry weight (DW) was measured on an analytical balance.

Relation species-coverage-biomass

The relation established between overall species-coverage and biomass was used as a measure for standing crop per surface area. Nienhuis *et al.* (1989) already suggested that coverage of above-ground parts is a reliable indicator for above-ground biomass.

To determine the strength of the relation between coverage (dependent variable) and biomass (independent variable) for two selected seagrass species in the Haruku Strait (*Halodule uninervis, Halophila ovalis*) a linear regression analysis was carried out between coverage and dry weight (DW), both for above-ground, below-ground and total biomass with the statistical program Computerised Statistics System (CSS). The regression coefficients r and the coefficient of determination r^2 were calculated. The dependent variable was log-transformed, in order to obtain approximate linear relationships and a normally distributed error term.

Standing crop

To examine the relative importance of the various seagrass meadows of the western and the eastern side of the Haruku Strait as feeding habitat for dugongs, the standing crop was calculated of the selected meadows which had evidence of dugong feeding. Average biomass and a standard deviation were calculated for each species-coverage class. For the selected seagrass meadows, the surface area per class was calculated with a gravimetric method. Each individual seagrass meadows was cut with a scissors and weighted on an analytical balance, the same was done with the species-coverage class segments in each meadow. When x is the weight of each segment, y the weight of each meadow and z the surface of the meadow (ha) then the surface of each segment was calculated as $x : y \times z$. The standing crop of the segments was obtained by multiplying the surface area of the segments with the average biomass of the corresponding biomass class. The standing crop of each seagrass meadow was calculated by adding the standing crop of the species-coverage class segments per meadow. Due to a possible seasonal fluctuation of the biomass of seagrass, the calculations are only valid for the research period. The total standing crop of the selected seagrass meadows in the Haruku Strait was obtained by adding the standing crop per seagrass meadow.

Computer model

A simple computer model was developed to calculate the maximum feeding pressure (computer programming language Pascal). The maximum sustained feeding pressure was defined as the maximum feeding pressure at which the meadow was maintained at its lowest level of standing crop, but not depleted. In this model, it is assumed that the maximum sustained feeding pressure depends entirely on the regrowth interval of the seagrass after foraging, which is determined by the speed with which the feeding tracks are recolonized by seagrasses until the biomass inside the feeding track reaches the level of the undisturbed seagrass bed.

Feeding pressure was defined as the number of new feeding tracks per day, in a model area of 30 x 30 m. The regrowth interval was determined as 4 month, which is within the range of 2.5 month (subtidal *Halodule*) and 5 month (intertidal *Halodule*) found by respectively De Iongh and Langeveld (1996d) and De Iongh *et al.* (1995b). Additional calculations have been made for a regrowth interval of 3 months and 5 months to test for the robustness of the model. The seagrass meadow is approximated by a two dimensional field of 150 by 150 units. A unit represents a quadrat of 0.20 by 0.20 m and possesses a number of 0 to 100, indicating the relative biomass per unit. As a consequence the model area covers at maximum $150x150x100=2,250x10^{-3}$ biomass units. A feeding track is defined as 1 by 8 units (0.20 by 1.60 m, based on average feeding track measurements, indicated by field work) and covers at maximum 800 biomass units. The feeding tracks are spread at random through the model area. To make a prediction for maximum theoretical feeding pressure it is assumed that feeding of a unit reduces the biomass to zero. Since in practice dugongs not always reduce biomass in feeding tracks to zero, the model results in a slight over-estimation of maximum sustained feeding pressure.

To allow extrapolation of the results of the model, the following assumptions were made:

- the dugong in the project area is the main herbivore feeding on seagrasses in terms of biomass consumption (Thayer *et al.*, 1984);

- dugongs feed mainly on mono-specific or mixed meadows of *Halodule* and *Halophila* (Preen, 1993; De Iongh *et al.*, 1995b);
- the regrowth period of *Halophila* after reduction to zero is 5 months, similar to *Halodule* (De Iongh *et al.*, 1995b).

Calculation of the maximum sustained population size

The maximum sustained population size related to the total surface area of mono-specific and mixed seagrass meadows of *Halodule* and/or *Halophila* in the study area was calculated, using the following formula:

$$MSPS = \frac{TSC * MFP}{DFC}$$

In which:

MSPS = Maximum Sustained Population Size (number of dugongs)
TSC = Total Standing Crop (kg DW)
MFP = Maximum Sustained Feeding Pressure (fraction consumed as % of total biomass kg DW day^{-1})
DFC = Daily Food Consumption (kg DW day^{-1})

To predict the daily food consumption of a wild dugong, estimations have been made, based on the food consumption of 5.1 kg DW day^{-1} of a captive animal in Surabaya Zoo (De Iongh and Bauer, 1996b). A similar daily seagrass consumption of 5.6 kg DW day^{-1} was reported by Jones (1959).

Results

Distribution of the seagrass meadows

Seventeen meadows were identified in Haruku Strait, North of Ambon and Haruku islands (Fig. 7.1). Details on all these fields are given in Table 7.1. The fields along the North coast of Ambon and Haruku are not considered important as dugong feeding sites, because no feeding tracks were found and the fields were either more or less covered with coral rubble and stones or seagrass cover was poor (<10%). In the Haruku Strait, the fields at the Ambonese side, with the exception of the meadow at Nang (4), similarly did not seem to be of importance for dugong feeding during our fieldwork period. On the Haruku side of the Haruku Strait, all fields except the meadows North of Kailolo (8,9) showed evidence of dugong feeding.

Table 7.1
Details of the seventeen seagrass meadows (indicated in Fig.7.1) which were found along the north and south coast of Ambon (meadow 1, 2 and 17) and in the Haruku Strait (meadow 3 to 16)

Meadow	Location	Species	Surface area	Depth	Remarks
1	Opposite Morela	T, C, Hd	8 ha	1.3 m	stones, coral
2	North of Honimoa	T, C, Hd	1.5 ha	3 m	patchy
3	Pantai Hop	Hd, Hph	3.0 ha	3 m	-
4*	Pantai Nang	E, T, C, Hd, Hph	5.0 ha	2 m	-
5	From P. Nang until Tulehu	E, T, C, Hd	3.0 ha	2 m	-
6	Along the coast of Tulehu	E, T, C, Hd, Hph	3.5 ha	1.5 m	stones, coral
7	Coast Tulehu, opposite Mangrove	E, T, C, Hd	2.0 ha	1.5 m	stones, coral
8	In front of Hatumuri	E, T, C, C	7.0 ha	1 m	-
9	West of Hatumuri	C, C	3.0 ha	1.5 m	seaweed
10*	North of Kailolo	C	0.5 ha	2 m	-
11*	In front of Kailolo	C, Hd	0.5 ha	3 m	-
12*	North of Rohomoni	Hd, Hph	4.5 ha	5 m	-
13*	In front of Rohomoni	E, T, Hd, Hph	3.5 ha	4 m	-
14*	North of Haruku	Hd, Hph	4.0 ha	4-6 m	-
15*	North of Haruku	Hd	4.5 ha	4-6 m	-
16*	South of Haruku	Hd	5.0 ha	4 m	-
17	Hutumuri	Hd	3.0 ha	0-2 m	patchy

* Seagrass meadows with evidence of dugong feeding.
Abbreviations:
T: *Thalassia hemprichii* / Hd: *Halodule uninervis* / E: *Enhalus acoroides* / C: *Cymodocea spp.* Hph: *Halophila ovalis* / Location: Location and name of the field / Species: Species found at the / Tracks: Presence of feeding tracks / Surface area: surface of the field / Depth: Depth of the field, mean neap tide / Remarks: Presence of stones, coral or seaweed

The meadows with evidence of dugong feeding, were grouped as follows: Nang (4), South Haruku (16), North Haruku (14, 15), Rohomoni (12, 13) and Kailolo (10, 11) (numbers refer to Table 7.1 and Fig. 7.1) covering a total surface area of 27.5 ha. Mean feeding track densities were 7.3 (±9.4) for Nang, 16.0 (±15.2) for North Haruku, 3.9 (±6.9) for South Haruku, 3.5 (±7.1) for Kailolo and 2.3 (±5.7) for Rohomoni.

The analysis of feeding track density showed only two seagrass meadows with evidence of concentrated grazing (classified as 'abundant' with >6 tracks/

25 m²) in restricted feeding swards; Nang and North Haruku, confirming findings of De Iongh *et al.* (1995b) for the Nang meadow. Feeding track densities were at maximum 46 tracks/25 m^2 at North Haruku and 21 tracks/25 m^2 at Nang, and the swards covered 0.8 ha and 0.5 ha respectively.

Average biomass per species-coverage class

A linear regression was calculated between seagrass-coverage and above-ground biomass for mono-specific meadows of *Halodule uninervis* and *Halophila ovalis* of which the results are given in Table 7.2. For all the vegetations, the relation was significant ($P < 0.05$) for the research period.

Table 7.2

The relation between cover (dependent variable) and biomass (independent variable), based on a linear regression

Species			Correlation		
			Above ground DW	Below ground DW	Total DW
Halodule uninervis	n=36	r	0.846	0.803	0.832
		R^2	0.715	0.646	0.692
Halophila ovalis	n=17	r	0.792	0.824	0.898
		R^2	0.627	0.679	0.806

n = number of samples / r = correlation coefficient / R^2 = coefficient of determination

Standing crop

The total standing crop per species-coverage class per seagrass meadow is graphically presented in Fig. 7.2 to 7.7 and the corresponding data are presented in Table 7.3. The figures show that the sequence of decreasing importance in terms of Total Standing Crop is as follows: 1) North Haruku (highest), followed by 2) South Haruku, 3) Rohomoni, 4) Kailolo and 5) Nang (lowest). Only the North Haruku meadow and Nang meadow, where evidence of grazing in restricted grazing sward was found, are dominated by mono-specific *Halodule uninervis*, the other meadows by mixed vegetations of *Halodule/Halophila* and *Halodule/Cymodocea* (Fig. 7.7).

Mono-specific beds of *Halodule uninervis* represent the highest total standing crop (15,920 kg DW), followed by meadows of *H. uninervis* - *Halophila ovalis* (7,278 kg DW), *H. uninervis* - *Cymodocea serrulata* (6,013 kg DW), *H. uninervis* - *C. rotundata* (2,006 kg DW) and mono-specific *Halophila ovalis* (1078 kg DW) with the lowest total standing crop (Table 7.3 and Fig. 7.7).

Table 7.3

Average biomass and total standing crop per species cover class

Species	Coverage %	Biomass (g DW m^{-2})	Surface area (m^2)	Total Standing Crop kg (DW)	Ratio AG/BG %/%
Halodule uninervis	1-9	21.9	24,755	542	18/82
	10-25	80.8	71,131	5,747	14/86
	26-50	219.1	43,956	9,631	12/88
Halophila ovalis	5-20	34.9	8,793	307	38/62
	21-50	137.9	5,594	771	24/76
Halodule-Halophila	5-20	43.0	55,381	962	27/73
	21-50	197.6	35,169	6,316	18/82
Halodule-Cymodocea serrulata	30-60	250.8	23,975	6,013	29/71
Halodule-Cymodocea rotundata	30-60	250.9	7,994	2,006	24/76
Total	-	-	276,748	32,292	-

AG = Above-ground, BG = Below-ground, DW = Dry Weight

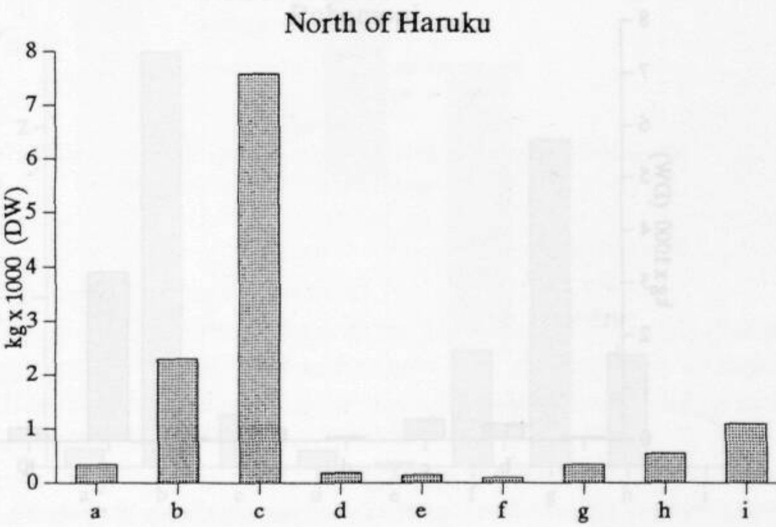

Figure 7.2

Standing crop per species-coverage class for the seagrass meadow at North Haruku (a tot i refer to seagrass species-coverage classes)

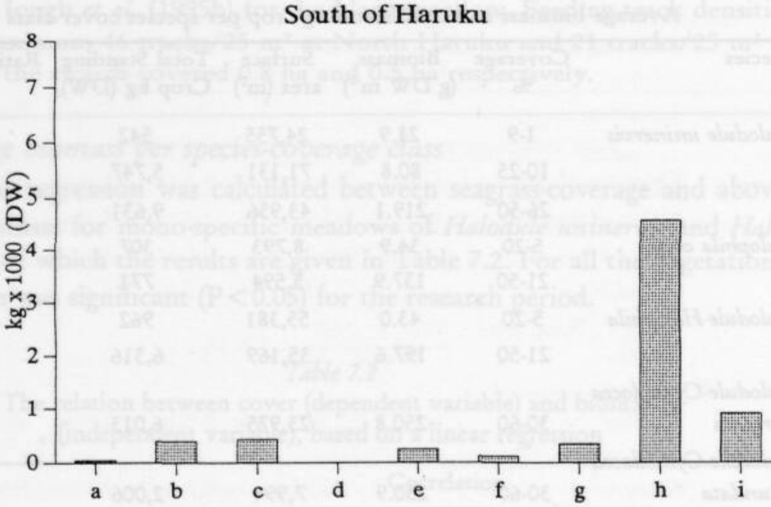

Figure 7.3

Standing crop per species-coverage class for the seagrass meadow at South Haruku (a tot i refer to seagrass species-coverage classes)

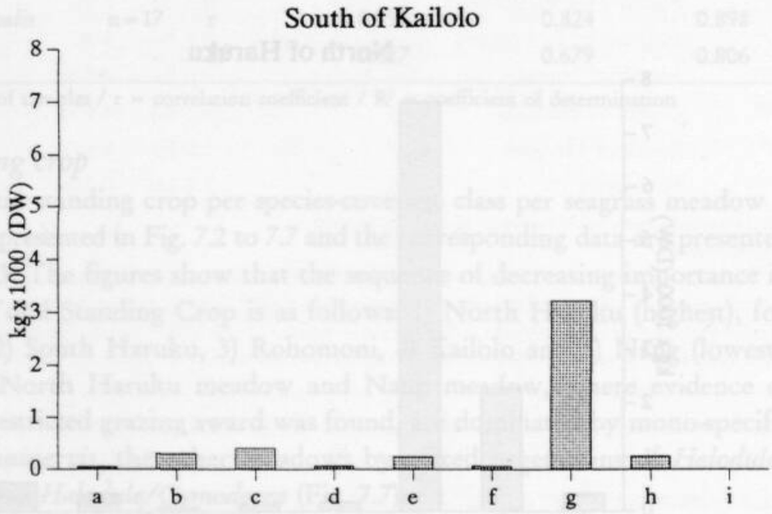

Figure 7.4

Standing crop per species-coverage class for the seagrass meadow of South Kailolo (a tot i refer to seagrass species-coverage classes)

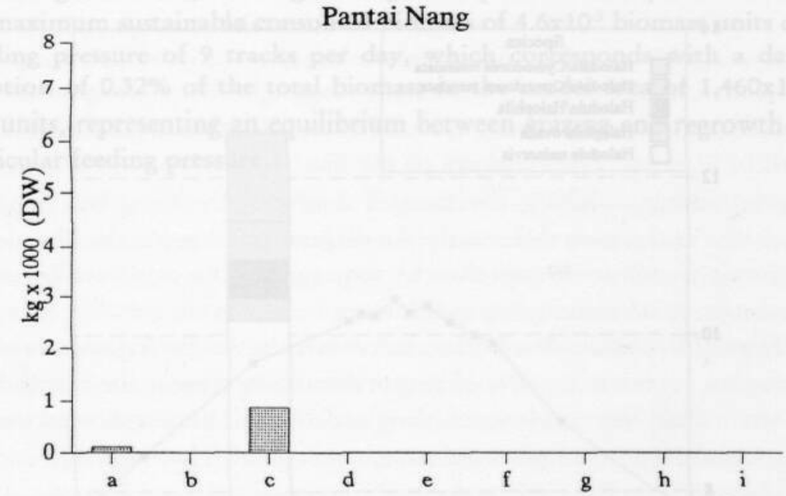

Figure 7.5
Standing crop per species-coverage class for the seagrass meadow of Pantai Nang (a tot i refer to seagrass species-coverage classes)

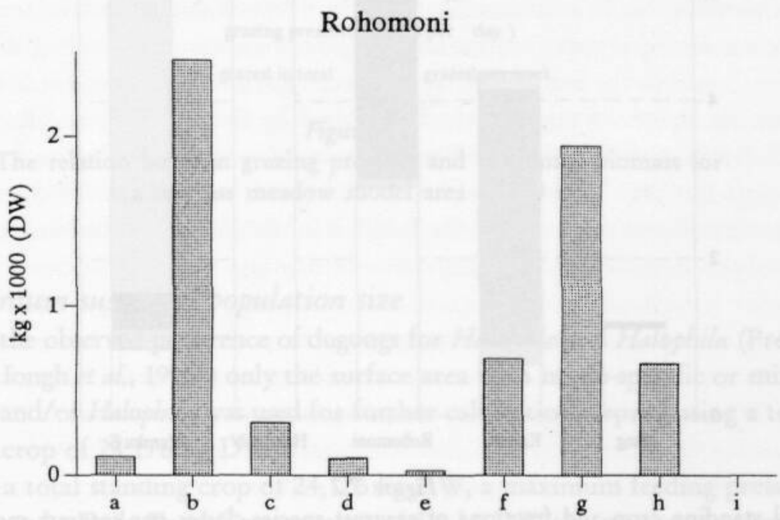

Figure 7.6
Standing crop per species-coverage class for the seagrass meadow of Rohomoni (a tot i refer to seagrass species-coverage classes)

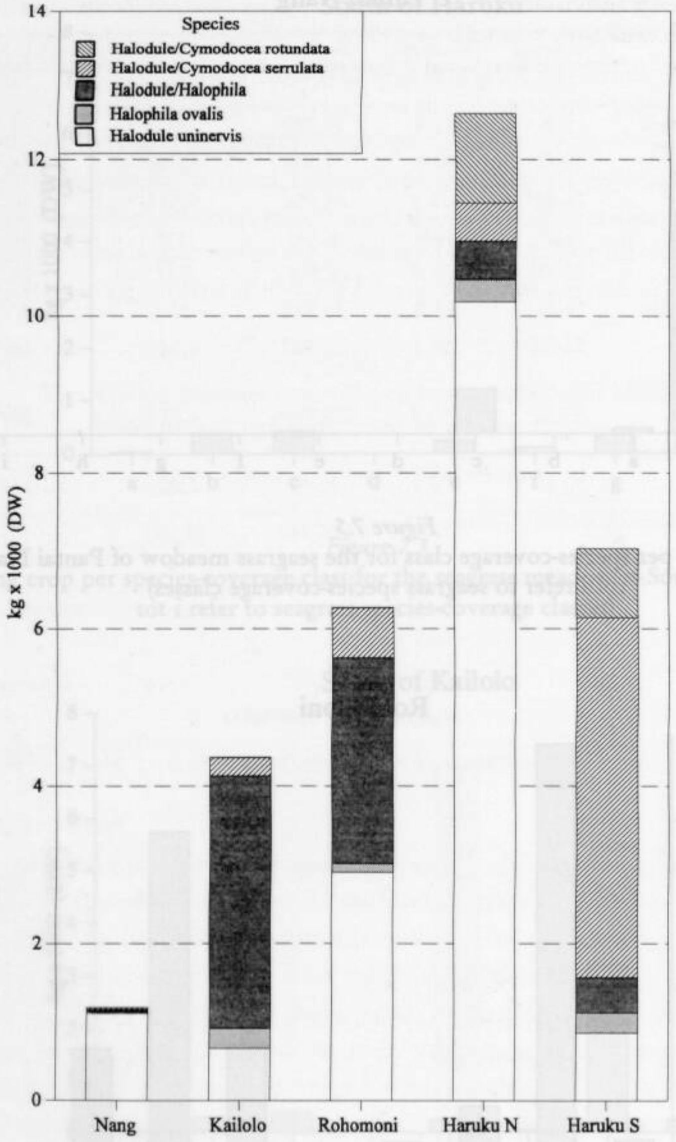

Figure 7.7
Total standing crop and fractions of seagrass species-classes per seagrass meadow

Maximum sustained feeding pressure

The result of the calculations of the maximum sustained feeding pressure is presented in Fig. 7.8. This figure shows the maximum biomass harvest at varying feeding intensities, with a given regrowth period of 4 days. The model shows a maximum sustainable consumed biomass of $4.6x10^{-3}$ biomass units d^{-1} at a feeding pressure of 9 tracks per day, which corresponds with a daily consumption of 0.32% of the total biomass in the model area of $1,460x10^{-3}$ biomass units, representing an equilibrium between grazing and regrowth at that particular feeding pressure.

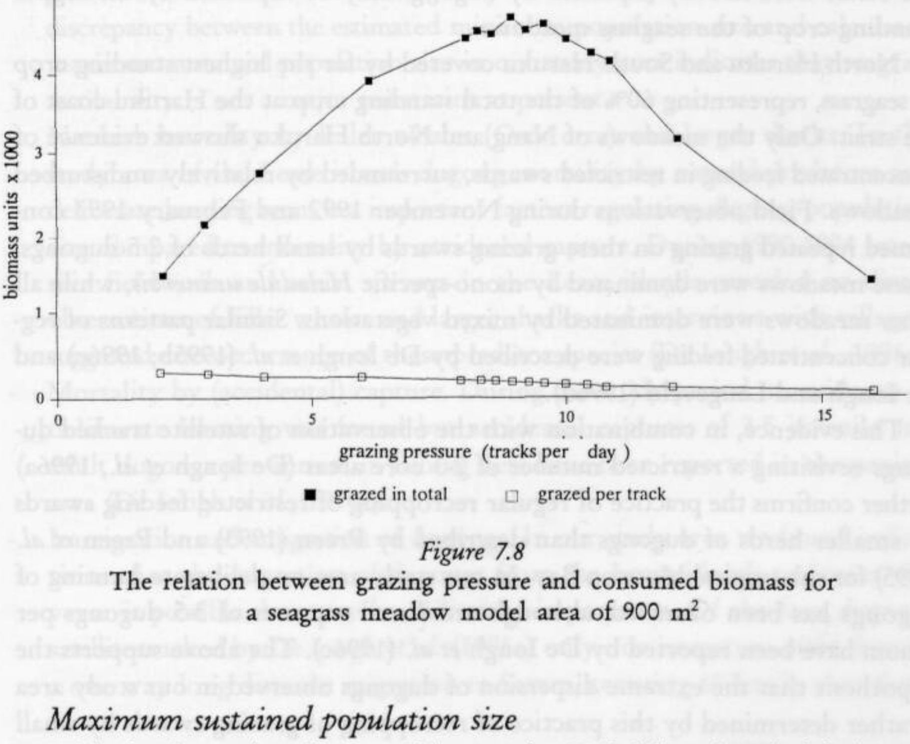

Figure 7.8
The relation between grazing pressure and consumed biomass for a seagrass meadow model area of 900 m^2

Maximum sustained population size

With the observed preference of dugongs for *Halodule* and *Halophila* (Preen, 1993; De Iongh *et al.*, 1995b) only the surface area with mono-specific or mixed *Halodule* and/or *Halophila* was used for further calculation, representing a total standing crop of 24,176 kg DW, .

With a total standing crop of 24,176 kg DW, a maximum feeding pressure of 0.32%, and a Daily Food Consumption of 5.1 kg DW the maximum number of dugongs which could live on a sustainable basis in Haruku Strait is calculated as 15 dugongs.

Discussion

During the snorkling surveys in the Haruku Strait the following meadows have been identified, with evidence of dugong feeding: Nang on the coast of Ambon and North Haruku, South Haruku, Rohomoni and Kailolo on the coast of Haruku. The meadows on the Haruku side were most important for dugong feeding, while at the coast of Ambon only Nang was regularly fed upon. The observation that mainly the seagrass meadows at the Haruku side of the Strait were heavily exploited by dugongs may be explained by the higher standing crop of the seagrass meadows.

North Haruku and South Haruku covered by far the highest standing crop of seagrass, representing 60% of the total standing crop at the Haruku coast of the strait. Only the meadows of Nang and North Haruku showed evidence of concentrated feeding in restricted swards, surrounded by relatively undisturbed meadows. Field observations during November 1992 and February 1993 confirmed repeated grazing on these grazing swards by small herds of 2-5 dugongs. These meadows were dominated by mono-specific *Halodule uninervis*, while all other meadows were dominated by mixed vegetations. Similar patterns of regular concentrated feeding were described by De Iongh *et al.* (1995b; 1996c) and De Iongh and Langeveld (1996d).

This evidence, in combination with the observation of satellite tracked dugongs revisiting a restricted number of 2-3 core areas (De Iongh *et al.*, 1996a) further confirms the practice of regular recropping of restricted feeding swards by smaller herds of dugongs than described by Preen (1993) and Preen *et al.* (1995) for sub-tropical Moreton Bay. In our study area no deliberate hunting of dugongs has been observed, although accidental captures of 3-5 dugongs per annum have been reported by De Iongh *et al.* (1996c). The above supports the hypothesis that the extreme dispersion of dugongs observed in our study area is rather determined by this practice of recropping of grazing swards by small feeding assemblages than by hunting pressure as postulated by Anderson (1985).

The computer model showed a maximum sustained feeding pressure of $4.6x10^{-3}$ biomass units d^{-1}, corresponding to a consumption of 0.32% of the biomass in the model area. The maximum sustained population size for Haruku Strait was calculated as 15 dugongs. With a maximum sustained population size of 15 dugongs for Haruku Strait, taking into account that Haruku Strait covers approximately 12% of the coastal stretch in the study area, this would lead through extrapolation to a maximum sustained population size of 125 dugongs in the study area (assuming equal distribution of dugongs along the coastal stretch). This number is far above the minimum population size for the study area of 22-37 dugongs as estimated by De Iongh *et al.* (1995a).

Major factors affecting the population size in our study area may be:

- Available standing stock of seagrass. Scientific evidence suggests that the availability of seagrass is an important factor regulating dugong population size (Jones, 1969; Heinsohn and Spain, 1974; Preen, 1993; Preen *et al.*, 1995). We have no indications of large scale fluctuations in seagrass standing stock in our study area due to natural disasters or other causes, but increased patterns of land use and mining may have an impact in the future. The discrepancy between the estimated minimum population size and calculated maximum sustained population size in our study area indicates that seagrass availability is not a major constraint at present.
- Natural mortality by killer whales (*Orca orca*) and larger sharks. In the study area of the Lease islands dugong mortality by natural predators and deliberate hunting seem less important factors regulating dugong population size compared to mortality by accidental capture. During 1990-1994 intensive fieldwork and aerial surveys in the Lease islands revealed no direct observations of killer whales and larger sharks and interviews with villagers suggested rare occurrence of these predator species (De Iongh *et al.*, 1996c).
- Mortality by (accidental) capture. During the study period no evidence of deliberate hunting was found but accidental captures of 3-5 juvenile and adult dugongs per annum in fishing nets have been reported in the project area (De Iongh *et al.*, 1996c).
- Immigration and emigration of dugongs. In our study area we found indications that the migration of dugongs from the Lease islands to Seram vise versa is possible, but may be of limited importance. Of the four dugongs satellite-tracked by De Iongh *et al.* (1996a) only one immature male showed a one way long distance migration to Seram, covering 65 km in two days.

We conclude that mortality by accidental capture of 3-5 animals per annum (De Iongh *et al.*, 1996c) may have a significant impact on the actual population size. In our study area dugong population size seems determined by mortality through accidental capture as a major factor, while the extreme dispersion and distribution of dugongs in our study area seems rather determined by the practice of concentrated recropping of grazing swards by small feeding assemblages. This practice may be a response to the low quality of seagrass as a forage for dugongs (De Iongh *et al.*, 1996b). Herbivory along a productivity gradient as described by Van de Koppel *et al.* (1996) could then be part of the dugongs strategy to improve feeding efficiency, but should be confirmed by further investigations.

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Chapter 8

Cultivation Grazing of Dugongs in Haruku Strait, East Indonesia

H.H. de Iongh and P. Langeveld

Submitted to *Biological Conservation*

PVC corer used during scuba diving to take seagrass samples at grazing swards of dugongs

Cultivation Grazing of Dugongs in Haruku Strait, East Indonesia

Abstract

Investigation of intertidal and subtidal Halodule uninervis *dominated meadows in Haruku Strait revealed patterns of regular recropping by dugongs* (Dugong dugon*) of restricted grazing swards. The analyses of spatial and temporal feeding track patterns in digitized computer-maps with 50% and 90% harmonic mean resulted in distinct grazing swards.* In vitro *digestibility was significantly higher inside the grazing sward compared with levels outside the sward, but total nitrogen did not show significant differences inside and outside the sward. A test with grazing intervals revealed overcompensatory growth in grazed tracks compared with a control but the available data did not permit the definition of a regrowth optimum. The present study confirms the hypothesis of the dugongs feeding strategy principally aiming at the maximisation of digestibility rate and energy intake.*

Introduction

De Iongh and Bauer (1996a) suggested that the digestion strategy of the dugong, which is characterised by a slow Gut Passage Rate (GPR) and a high digestibility coefficient for cellulose, may be an adaptation to its low quality forage (seagrass). Its digestion/feeding strategy on seagrass would principally aim at maximising digestibility rate and energy intake rather than total nitrogen (De Iongh *et al.*, 1996a). In this perspective dugongs seem to have developed three adaptations to cope with their low quality diet. First, they have developed a high capacity of cellulose digestion by combining physiological adaptations in their intestinal track with a slow GPR (Lomolino and Ewel, 1984). Secondly, they select more digestible forage by dietary preference for highly digestible pioneer species like *Halodule uninervis* and *Halophila ovalis*. Thirdly, they regularly recrop swards of young seagrass shoots presumable optimizing on digestibility and rate of energy intake. The aim of the present study was to test the latter hypothesis.

De Iongh *et al.* (1995b, 1996b) and De Iongh and Hein (1996c) made mention of concentrated grazing swards, with a high density of feeding tracks surrounded by relatively undisturbed meadows in an intertidal *Halodule* dominated meadow and in subtidal mono-specific *Halodule uninervis* and *Halophila ovalis* meadows, as a possible indication of cultivation grazing by small herds of dugongs in these meadows.

The dispersed distribution of dugongs in the Lease islands as observed by De Iongh *et al.* (1995a) during aerial surveys and the pattern of revisiting a restricted number of 2-3 core areas of three adult dugongs by De Iongh *et al.* (1996d) also confirms the observed pattern of the regular recropping of grazing swards by small herds of dugongs. Preen (1995a) made mention of similar movements of satellite tracked dugongs between 2-3 core areas in tropical North Queensland.

Although the regular recropping of grazing swards covered by *Halodule uninervis*, inside a mixed species meadow may be explained by the benefits of higher digestibility (De Iongh *et al.*, 1996a), the benefits of grazing swards inside mono-specific meadows are not known.

Preen (1993, 1995b) demonstrated that intensive grazing by large herds of dugongs (referred to as cultivation grazing) can have significant effects on seagrass meadows. Cultivation grazing can alter the species composition, the age structure and the nutrient status of seagrass meadows. As a result, relatively high biomass, climax communities can be converted to low-biomass pioneer communities. In his study *H. ovalis* is advantaged by these changes, at the expense of *Z. capricorni* (broad leafed morph). According to Preen (1993, 1995a) this change of species results in a meadow-wide increase in nitrogen levels and decrease in fibre levels.

According to Preen (1993, 1995b) the nutritional benefits of cultivation grazing can only be achieved if dugongs feed in large herds, and affect these changes over large areas. The same was suggested in the study of Prins *et al.* (1980) for geese in a terrestrial ecosystem. According to Preen (1993, 1995b) by feeding in large herds dugongs achieve a sufficient density of feeding trails, over a large enough area to effect an advantageous change in species composition. Preen (1993, 1995b) also stated that it is probable that the dugongs of Moreton Bay suffer from particular nutritional stress and cold water temperatures, especially during winter, and cultivation grazing is an important component of their feeding strategy to maximise the quality of their diet in response to this double stress. In other areas, especially in the tropics, dugongs may not suffer the same nutritional and temperature-related stresses, and other sources of disturbance may substitute for cultivation grazing.

The findings of De Iongh *et al.* (1995b, 1996b) and De Iongh and Hein (1996c) of regular recropping by small herds of dugongs of restricted grazing swards contradict the suggestions of Preen (1993, 1995b).

In the present study the findings of regular recropping of swards by small herds of dugongs in our study area is further analysed and quantified. We think that the dugongs practice of cultivation grazing in our study area is rather a permanent response to its low quality forage than a response to seasonal nutritional stress and low water temperatures during winter.

The 'optimal foraging model' of Pyke *et al.* (1977) and 'clever ungulate model' of Owen Smith and Novellie (1982) are based on the principle that an animal maximises its food intake (quality and quantity) in order to increase its fitness and its ability to survive and reproduce. Maximisation of food intake is expressed in terms of 'costs and benefits', being measured as carbohydrates (or joules), mineral nutrients or digestion efficiency.

Herbivores may have an important impact on the species composition and nutritional properties of plant communities in different habitats. These impacts have been demonstrated in terrestrial grasslands (Ellis *et al.*, 1976; McNaughton, 1979; Belovsky, 1984; Belsky, 1986). Similar impacts have been described for marine and coastal plant communities, including seagrasses (Ogden, 1976; Prins *et al.*, 1980; Lanyon, 1991; Preen, 1993; Preen, 1995b). McNaughton (1979) stated that after grazing, over-compensatory growth is found to occur under favourable growth conditions (sufficient nutrients, water, light).

Belsky (1986) concluded that overcompensation most probably occurs in moderately grazed wetlands where water and nutrients are abundant, soils are not compacted by large mammals, and species grow in monoculture. The mono-specific *Halodule uninervis* meadows in our study area are in accordance with the characteristics mentioned by Belsky (1986).

Van de Koppel *et al.* (1995) presented a model of herbivory along a productivity gradient for geese, hare and rabbit, maintaining a low level of standing crop in restricted grazing plots with a higher grazing efficiency compared with ungrazed dense vegetations, due to higher overall digestibility in the grazed swards. De Iongh and Hein (1996c) suggested a similar model of herbivory for dugongs in Haruku Strait.

The present study aims to find further supporting evidence for the hypothesis of the dugongs feeding strategy following both a pattern of herbivory along a biomass optimum as described by Belsky (1986) and along a productivity gradient as described by Van de Koppel *et al.* (1995). Cultivation grazing by dugongs in our study area is thereby characterised as a permanent response to low quality forage, based on maximisation of digestion rate and energy intake rather than maximisation of total nitrogen.

Study Area

Ambon and the Lease islands

The study area comprises Ambon and the Lease islands (Haruku, Saparua and Nusa Laut), located in the centre of the Maluku Province on the east side of Indonesia (3°30'S, 128°E). The islands border the Banda Sea in the South and the Seram Sea in the North (Fig. 8.1).

The islands of Ambon and the Lease group are characterized by a mountainous landscape. The highest mountain of Ambon reaches 1,036 m, whereas Haruku's highest points is 587 m. A shallow shelf of down to 20 m deep and on average 400 m wide is present along most of the shore. At the East coast of Ambon the widest shelf is found between the villages Waai and Tulehu, it is at maximum 500 m wide. Seagrass meadows are all found on the coastal shelf. A sharp drop-off borders the flat. The maximum depth of the Haruku Strait (between Ambon and Haruku) and Saparua Strait (between Haruku and Saparua) is approximately 120 m, while the maximum depth of Saparua Bay is approximately 40 m. The climate of Ambon is characterized by monsoonal seasons. The rainy season occurs during the south-east monsoon, from May until September, the dry season during the north-west monsoon, from October until April.

Haruku Strait

Two *Halodule* dominated seagrass meadows, fed upon by dugongs, were selected in Haruku Strait for the purpose of this study; an intertidal meadow at Waai (Nang embayment) and subtidal seagrass meadow at Haruku (Fig. 8.1).

The intertidal seagrass bed of Nang embayment is located on a sandy and muddy tidal flat of approximately 6 ha (actual seagrass cover 3 ha), in a mangrove bordered embayment at the East coast of Ambon, near the village of Waai (3° 55' S, 128° 50' E). The embayment is sheltered from the north-west monsoon during the dry season and exposed to waves in the south-east monsoon during the wet season. The edge of the tidal flat has a relatively steep slope, descending to 20-30 m depth at c. 300-400 m from the shore. The seagrass

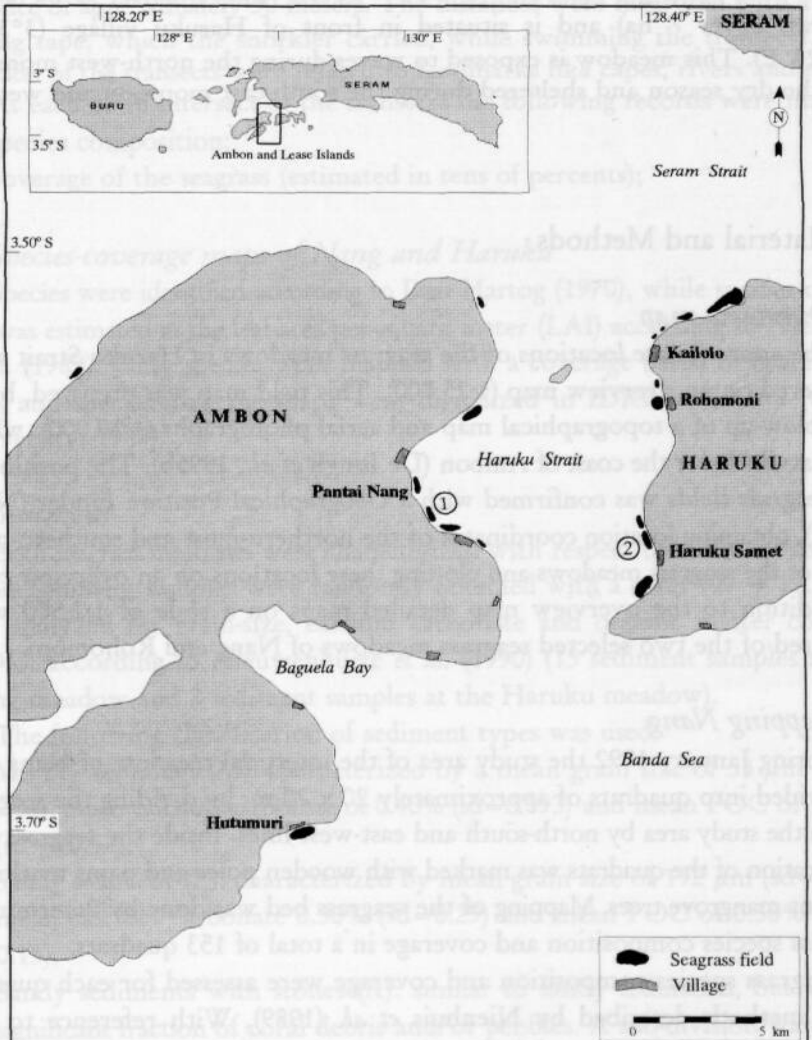


Figure 8.1
Seagrass meadows in the Haruku Strait and along the north coast of Ambon, with the location of the meadows of Nang (1) and Haruku (2)

meadow is under influence of the Rutung river and is visited regularly by villagers from Waai, who gather shellfish at low tide and fish with castnets and gillnets at high tide.

The subtidal seagrass meadow at Haruku covers approximately 15 ha (actual seagrass cover 7 ha) and is situated in front of Haruku village (3°36′ S, 128°24′ E). This meadow is exposed to waves during the north-west monsoon and the dry season and sheltered during the south-east monsoon and wet season.

Material and Methods

Overview map

The approximate locations of the seagrass meadows in Haruku Strait were registered on an overview map (1:25,000). This field map was prepared, based on a blow-up of a topographical map and aerial photographs (1:10,000), which were available for the coast of Ambon (De Iongh *et al.*, 1995b). The position of the seagrass fields was confirmed with a Geographical Position Finder (NAV 5000x), obtaining location coordinates of the northern-most and southern-most edges of the seagrass meadows and plotting these locations on an overview map. In addition to the overview map detailed maps on a scale of 1:2,500 were prepared of the two selected seagrass meadows of Nang and Rohomoni.

Mapping Nang

During January 1992 the study area of the intertidal meadow of Nang was subdivided into quadrats of approximately 20 x 20 m, by dividing the seagrass bed in the study area by north-south and east-west lines. Inside the seagrass bed the location of the quadrats was marked with wooden poles and paint marks on adjacent mangrove trees. Mapping of the seagrass bed was done by determining seagrass species composition and coverage in a total of 153 quadrats.

Seagrass species composition and coverage were assessed for each quadrat using methods described by Nienhuis *et al.* (1989). With reference to the observed dietary preference of dugongs (De Iongh *et al.*, 1995b), cover was only estimated per quadrat for *H. uninervis*, with coverage classes: 'low' (5-20%) and 'high' (20-60%). A species-coverage map was prepared and digitalized with IDRISSI software (Clark University, 1987).

Mapping Haruku

Due to the subtidal character of the North Haruku meadow we could not use similar quadrats as used for the intertidal Nang meadow. During January 1993 snorkling transects were made perpendicular to the coast at a mutual distance of approximately 50 meters. The distances were measured with a measuring tape, which the snorkler carried, while swimming the transects. The position of the transects were related to landmarks like capes, rivers and roads.

At each 20 m intersect of the transects the following records were made:

- species composition;
- coverage of the seagrass (estimated in tens of percents);

Species-coverage maps of Nang and Haruku

Species were identified according to Den Hartog (1970), while species coverage was estimated as the leaf area per square meter (LAI) according to Nienhuis *et al.* (1989). Only species were mapped with a coverage (LAI) of more than 10% and species-coverage maps were digitalized in IDRISI software (Clark University, 1987).

Sediment

Both seagrass meadows were characterized with respect to sediment composition. Sediment samples were randomly obtained with a corer (Ø = 12.5 cm) and analyzed for grain-size, calcium carbonate and organic matter content (POC) according to Nieuwenhuize *et al.* (1990) (15 sediment samples at the Nang meadow and 8 sediment samples at the Haruku meadow).

The following classification of sediment types was used:

- Muddy sediment (M): characterized by a mean grain size of 53 μm (sd = 9.34), mean calcium carbonate of 0.40% (sd=0.093) and mean POC of 1.70% (sd = 0.52);
- Sandy sediment (Z): characterized by mean grain size of 192 μm (sd=9.31), mean calcium carbonate 0.30% (sd=0.29) and mean POC of 0.38% (sd = 0.15);
- Sandy sediments with stones (K): similar to sandy sediments, but with a significant fraction of coral debris and/or pebbles. A sub-division was made between coarse sand with pebbles and stones < one inch (2.54 cm) and very coarse sand with stones and pebbles > one inch.
- Mixed sediment (m): characterized by a mean grain size of 167.16 μm (sd = 79.70), mean calcium carbonate of 0.25% (sd=0.12) and mean POC of 0.62% (sd = 0.20).

Feeding tracks

In Nang embayment new feeding tracks were counted per quadrat by monthly monitoring of the quadrats in the seagrass meadow at low tide, during

February-May 1992. The monthly number of new feeding tracks per quadrat was noted.

In Haruku, due to the subtidal character of the meadow the quadrat method used at Nang was not applicable and feeding tracks were counted monthly during January-December 1993 by snorkling transects parallel to the coastline, at a mutual distance of approximately 50 m. All new feeding tracks at each 25 m intersect, covering a stretch of 25 m width at each side of the transect, were noted. The fresh feeding tracks per quadrat (20x20 m) at Nang and per transect intersect (25x50m) at Haruku were plotted in maps monthly. New feeding tracks were identified through comparison of the monthly plotted maps and through markings of counted tracks with stones.

Grazing intervals

In order to investigate the effect of dugong grazing intervals on seagrass biomass and production, artificial feeding tracks were made in *Halodule uninervis* with a coverage of 20-60% (Nang) and 10-50% (Haruku). In each meadow 5 replicates of 5 tracks were made, resulting in a total of 25 tracks per meadow. The tracks of 60 cm long, 10 cm width and 10 cm depth were made using an iron frame (10x10 cm). Within this frame the rhizomes were cut with a knife, all the seagrass (including rhizomes) were removed by hand and the track was refilled with clean sand.

The replicate artificial tracks were sampled with a 10x10 cm iron frame at time intervals of 2, 4, 6, 8 and 10 weeks, in the centre of the track. Thus regrowth in the samples was only affected by regeneration at the edges. In addition, monthly biomass samples were taken in the undisturbed surrounding meadow with five replicates. All samples were sieved (1 mm mesh size). The above-ground fraction and below-ground fraction of seagrass were separated and dry weight (DW) was analyzed according to Ott (1990). The samples were dried for 24 hours in an oven at 70°.

Sampling grazing tracks Nang

In the Nang meadow six replicate samples were taken with a PVC corer (Ø = 12.5 cm) inside and outside grazing tracks. The samples were sieved (1 mm mesh size) and cleaned from sediment, and processed the same way as the biomass sampling.

Total C and N content of dried, powdered plant tissue was measured on a Carlo-Erba NA 1500 C-/N-Analyzer (Allen, 1974). Due to the available quantity of seagrass no further analyses was done for *in vitro* digestibility.

Sampling grazing tracks Haruku

In the Haruku meadow nine replicate samples were taken with a PVC corer (Ø = 12.5 cm) inside and outside the feeding tracks, which had recently been recolonised. The samples were processed and dried as the samples for biomass.

Of each sample approximately 15 gr (total biomass) was taken apart and dried in a stove at 70°C to constant weight. The *in vitro* digestibility of seagrass samples was analyzed according to Tilley and Terry (1963). Total N was measured after destruction with a mixture of H_2SO_4, Se and salicyclic acid with a Skalar San-plus autoanalyzer. Due to variations in the available quantity of seagrass per sample not all analyses could be performed with the same number of replicates.

Statistics

The spatial distribution of new feeding tracks in the seagrass meadows of Nang and North Haruku over a certain time span was analyzed, using MC PAAL software, which represents a non-parametric method in a probabilistic sense (Anderson, 1982). Feeding pressure was calculated as the 50% or 95% harmonic mean and mapped with IDRISSI GIS software. The significance of differences between the means of sediment samples and biomass samples was determined with a Wilcoxon two-sample test ($P < 0.05$).

The significance of differences of samples from inside and outside feeding tracks between the means of total C and N (%) for Nang and *in vitro* digestibility and total N (%) for Haruku were analyzed with a Mann Whitney U-test (Zar, 1984).

Results

Mapping

The results of mapping of Nang embayment and Haruku are shown in Figs 8.2 and 8.3. Of the meadow at Nang embayment 45% consisted of *Halodule* dominated seagrass cover, while the remaining surface covered a mixed meadow of *Cymodocea rotundata* and *Thalassia hemprichii*, and *Enhalus acoroides* (Fig. 8.2). Of the Haruku meadow 73% consisted of *Halodule uninervis* dominated seagrass cover, 27% consisted of *Halophila ovalis* dominated seagrass cover (Fig. 8.3).

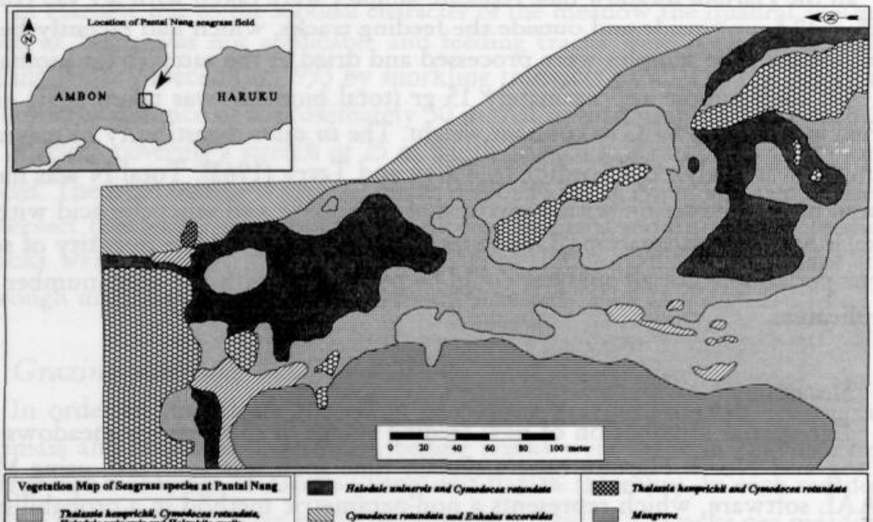


Figure 8.2

Seagrass species-coverage map of the intertidal meadow of Nang in January 1992

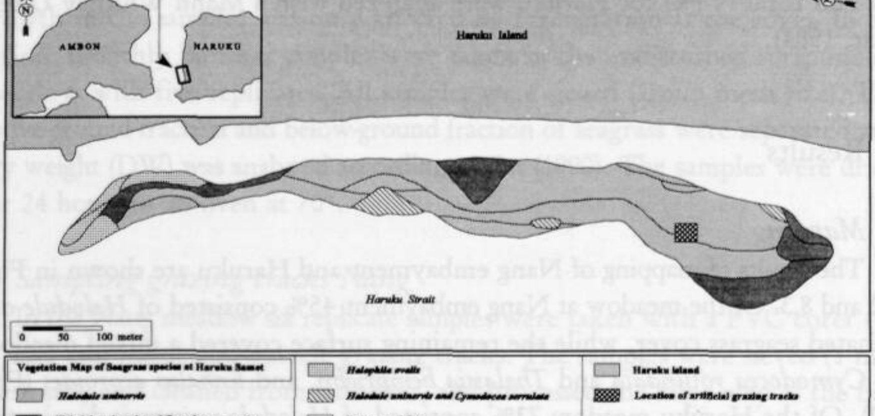


Figure 8.3

Seagrass species-coverage map of the subtidal meadow of Haruku in January 1993

Sediment

The results of the sediment analyses are summarised in Table 8.1. All sediments sampled can be characterized as sandy sediments and the means of $CaCO_3$ (%) show significantly higher values in Haruku than in Nang ($P < 0.05$), but no significant differences are observed in grain size, Total N (%) and POC (%) between both meadows ($P < 0.05$).

Table 8.1
Mean values ±SD of sediment parameters from Haruku and Nang
(* indicates significant difference between the means)

	(n)	Total nitrogen (% of DW)	P.O.C. (% of DW)	$CaCO_3$ (%)	Grainsize (μ)
Nang	6	0.06 ± 0.02	0.40 ± 0.24	0.41 ± 0.27*	198.9 ± 5.9
Haruku	8	0.06 ± 0.02	0.31 ± 0.16	1.37 ± 0.42*	188.1 ± 18.1

P.O.C. = organic matter content
n = number of samples

Feeding tracks

The cumulative results of the mapping of feeding tracks at Nang embayment during February-May 1992 are presented in Fig. 8.4A. One distinct grazing plot with a high concentration of feeding tracks can be distinguished through analyses of the 50% harmonic mean. An analyses of the spatial distribution of feeding tracks on 19 February, 9 March and 14 May confirms a consistent pattern of concentrated feeding in a maximum of three restricted feeding plots (Figs 8.4B-8.4F).

The cumulative results of the mapping of feeding tracks (50% harmonic mean) at Haruku meadow during January-June 1993 and during July-December 1993 shows consistently at least two distinct feeding plots with repeated concentrations of feeding tracks (Figs 8.5 and 8.6).

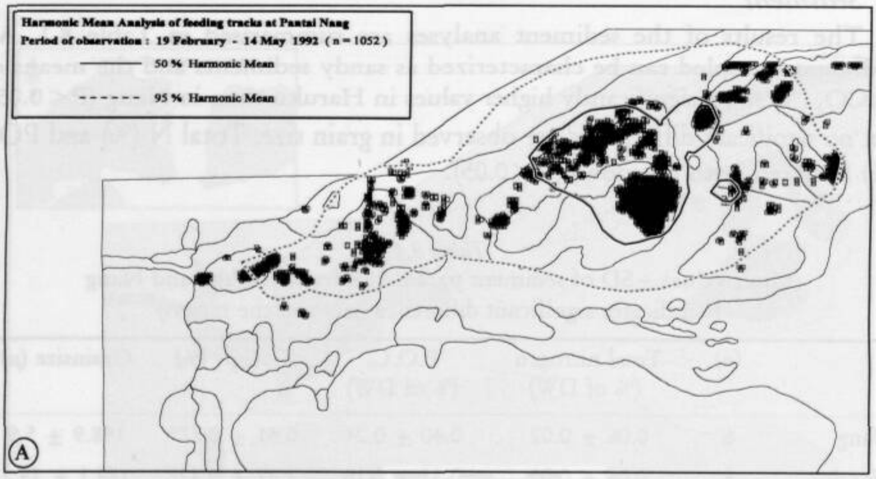


Figure 8.4

Grazing swards at the Nang meadow, represented by the 50% harmonic mean (line) and the 90% harmonic mean (dotted line) of the accumulated number of feeding tracks during February-May 1992 (A) and based on new feeding tracks recorded at 19 February (B), 9 March (C), 22 March (D), 6 April (E) and 14 May (F) (n refers to number of tracks counted)

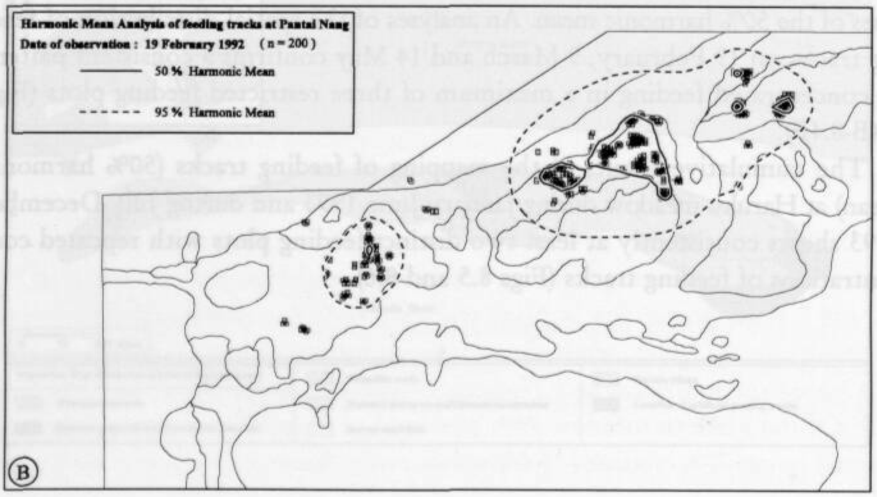


Figure 8.4B

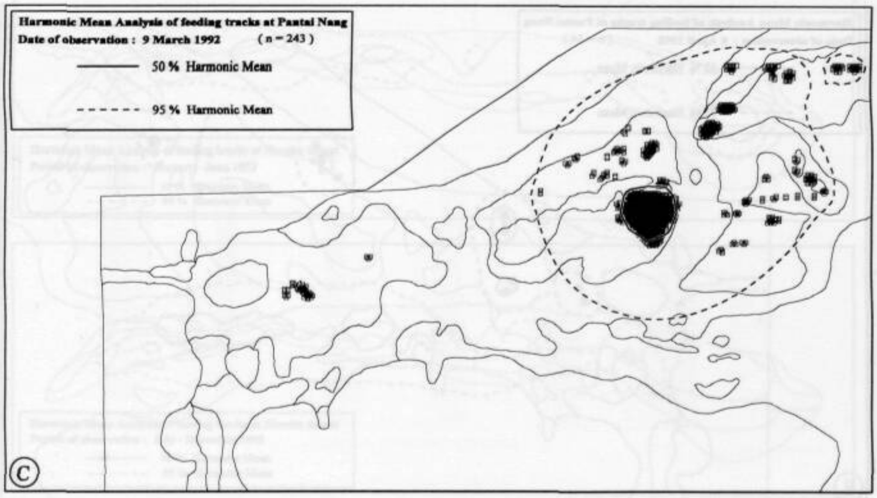


Figure 8.4C

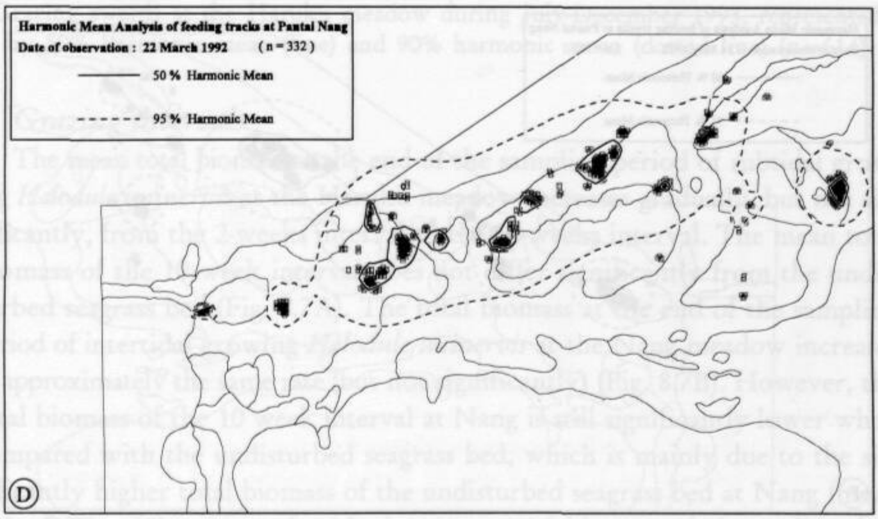


Figure 8.4D

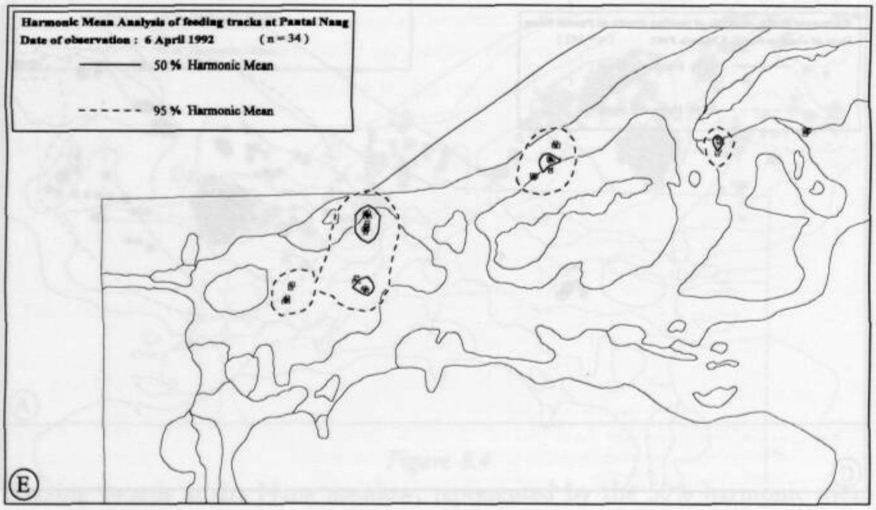


Figure 8.4E

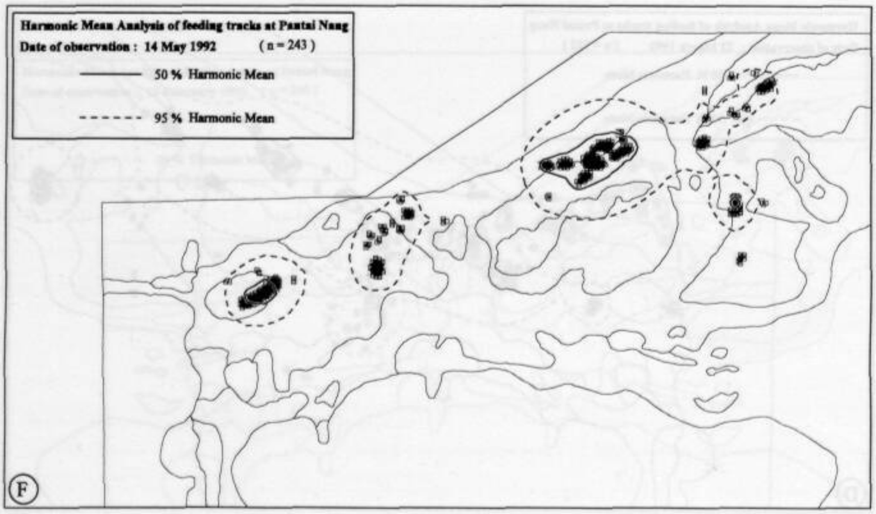
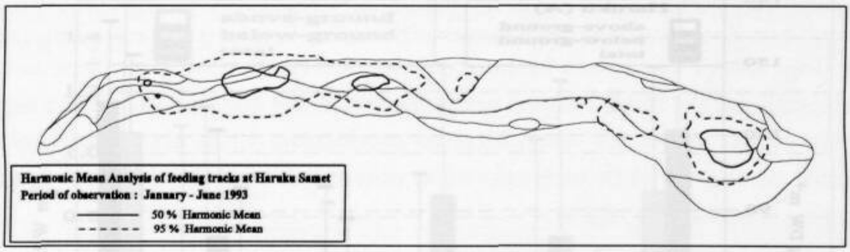


Figure 8.4F



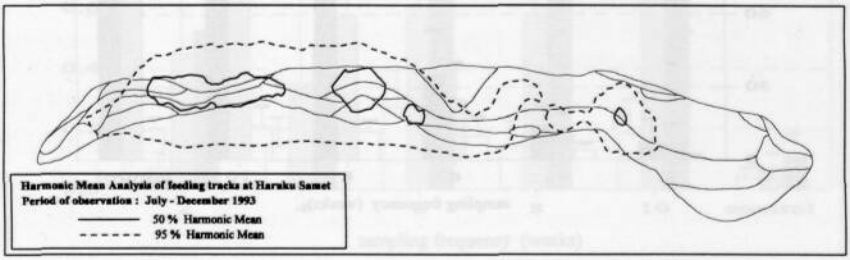


Figure 8.5 (boven)

Grazing swards at the Haruku meadow during January-June 1993, represented by 50% harmonic mean (line) and 90% harmonic mean (dotted line) (n=786)

Figure 8.6 (onder)

Grazing swards at the Haruku meadow during July-December 1993, represented by 50% harmonic mean (line) and 90% harmonic mean (dotted line) (n=614)

Grazing intervals

The mean total biomass at the end of the sampling period of subtidal growing *Halodule uninervis* at the Haruku meadow increases gradually, but not significantly, from the 2-weeks interval to the 10-weeks interval. The mean total biomass of the 10 week interval does not differ significantly from the undisturbed seagrass bed (Fig. 8.7A). The total biomass at the end of the sampling period of intertidal growing *Halodule uninervis* at the Nang meadow increases at approximately the same rate (but not significantly) (Fig. 8.7B). However, the total biomass of the 10 week interval at Nang is still significantly lower when compared with the undisturbed seagrass bed, which is mainly due to the significantly higher total biomass of the undisturbed seagrass bed at Nang (mean 271 gDW ±19) compared with the mean total biomass of the undisturbed seagrass bed at Haruku (mean 136 gDW ±41).

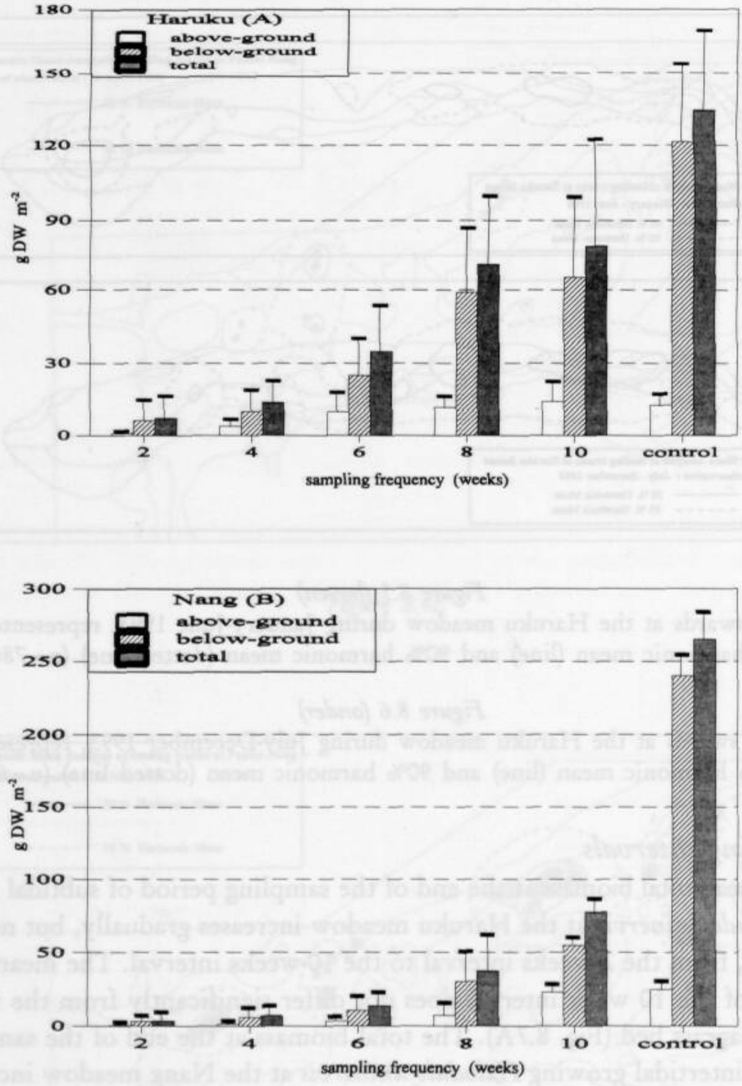


Figure 8.7

Mean values (±SD) of total, below-ground and above-ground biomass (g DW m^{-2}) of *Halodule uninervis* at the end of the sampling period for sampling intervals of 2, 4, 6, 8 and 10 weeks after the start of regrowth, compared with biomass of the undisturbed seagrass bed (control) at the sub-tidal Haruku meadow (A) and the intertidal Nang meadow (B)

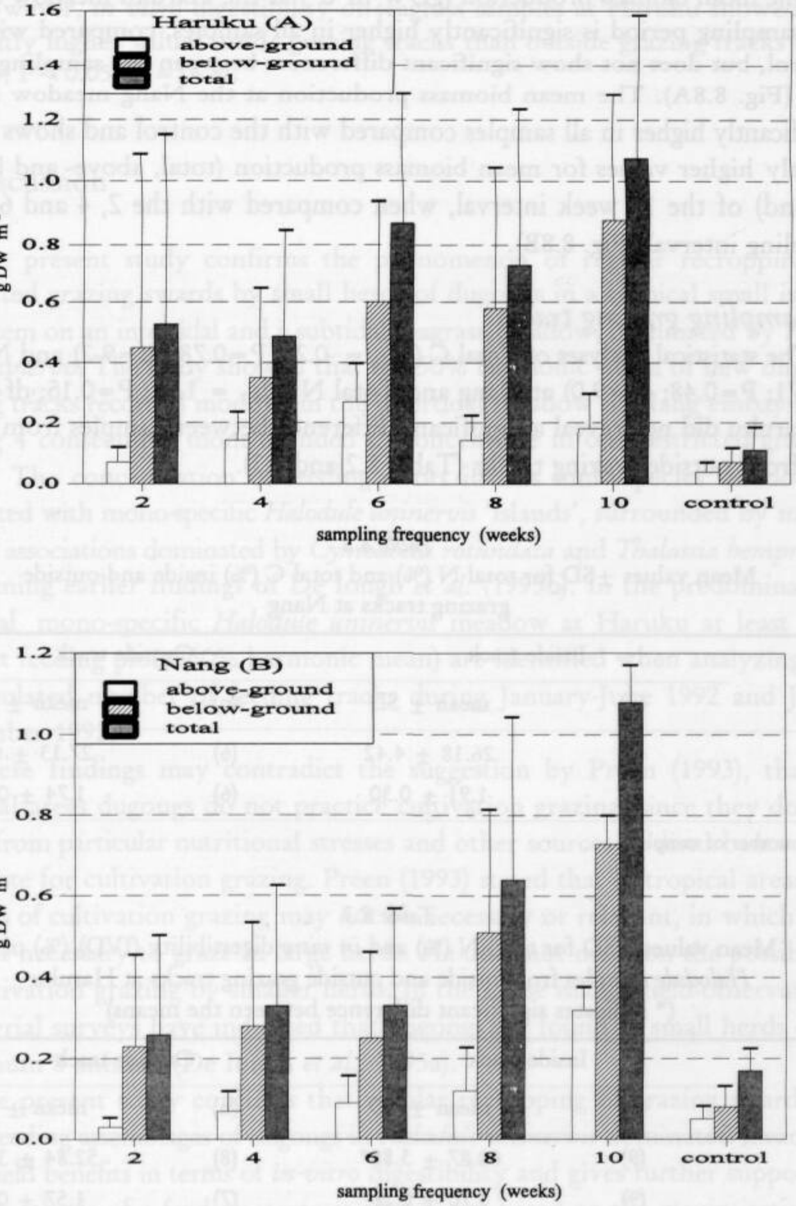


Figure 8.8

Mean values (±SD) of total, below-ground and above-ground biomass (g DW $m^{-2}d^{-1}$) of *Halodule uninervis* for sampling intervals of 2, 4, 6, 8 and 10 weeks after the start of regrowth, compared with biomass production of the undisturbed seagrass bed at the sub-tidal Haruku meadow (A) and the intertidal Nang meadow (B)

The mean biomass production (gDW $m^{-2}d^{-1}$) at the Haruku meadow during the sampling period is significantly higher in all samples, compared with the control, but does not show significant differences between the sampling intervals (Fig. 8.8A). The mean biomass production at the Nang meadow is also significantly higher in all samples compared with the control and shows significantly higher values for mean biomass production (total, above- and below-ground) of the 10 week interval, when compared with the 2, 4 and 6 week sampling interval (Fig. 8.8B).

Sampling grazing tracks

The statistical analyses of Total C ($U_{6,6}$ = -0.28; P=0.78; df=9.2) and N ($U_{6,6}$ = 0.71; P=0.48; df=9.0) at Nang and Total N ($U_{9,7}$ = 1.51; P=0.15; df=10.7) at Haruku did not reveal a significant difference between samples from inside and from outside grazing tracks (Table 8.2 and 8.3).

Table 8.2

Mean values ±SD for total N (%) and total C (%) inside and outside grazing tracks at Nang

	Inside track		Outside track	
	(n)	mean ± SD	(n)	mean ± SD
C	(6)	26.18 ± 4.42	(6)	27.13 ± 6.03
N	(6)	1.91 ± 0.30	(6)	1.74 ± 0.47

n = number of samples

Table 8.3

Mean values ±SD for total N (%) and *in vitro* digestibility (IVD) (%) of *Halodule* samples from inside and outside grazing tracks at Haruku (* indicates significant difference between the means)

	Inside track		Outside track	
	(n)	mean ± SD	(n)	mean ± SD
IVD	(9)	60.87 ± 3.88*	(8)	52.84 ± 3.01*
N	(9)	1.70 ± 0.26	(7)	1.57 ± 0.43

n = number of samples

However, *in vitro* digestibility of seagrass samples at Haruku showed significantly higher values inside grazing tracks than outside grazing tracks ($U_{9,8} = 4.43$; $P < 0.05$; df = 14.8).

Discussion

The present study confirms the phenomenon of regular recropping of restricted grazing swards by small herds of dugongs in a tropical small island ecosystem on an intertidal and a subtidal seagrass meadow, dominated by *Halodule uninervis*. The study showed that the 50% harmonic mean of new dugong feeding tracks recorded monthly in the intertidal meadow of Nang embayment during 4 consecutive months tended to concentrate in one restricted grazing sward. The concentration of feeding effort in this multi-species meadow is associated with mono-specific *Halodule uninervis* 'islands', surrounded by multi-species associations dominated by *Cymodocea rotundata* and *Thalassia hemprichii* confirming earlier findings of De Iongh *et al.* (1995b). In the predominantly subtidal mono-specific *Halodule uninervis* meadow at Haruku at least two distinct feeding plots (50% harmonic mean) are identified when analyzing the accumulated number of feeding tracks during January-June 1992 and June-December 1992.

These findings may contradict the suggestion by Preen (1993), that in tropical areas dugongs do not practice cultivation grazing, since they do not suffer from particular nutritional stresses and other sources of disturbance may substitute for cultivation grazing. Preen (1993) stated that in tropical areas the benefits of cultivation grazing may not be necessary or relevant, in which case it is not necessary to graze in large herds. He does not mention the possibility of cultivation grazing by smaller herds. In the Lease islands field-observations and aerial surveys have indicated that dugongs are found in small herds of at maximum 8 animals (De Iongh *et al.*, 1995a).

The present study confirms that regular recropping of grazing swards by small feeding assemblages of dugongs in *Halodule uninervis* dominated meadows may yield benefits in terms of *in vitro* digestibility and gives further support to the hypothesis of a feeding strategy on seagrass based on the maximisation of digestion rate and energy intake rather than total nitrogen (De Iongh *et al.*, 1996a).

The benefit of an increased *in vitro* digestibility in our study is achieved in two ways:

1. At the Nang meadow dugongs create, through the regular recropping of grazing swards, more digestible (De Iongh *et al.*, 1996a) pioneer vegetations of *Halodule uninervis*, surrounded by less digestible mixed vegetations of *Thalassia hemprichii* and *Cymodocea rotundata*.
2. At the Haruku meadow, dugongs create through regular recropping restricted grazing swards inside a mono-specific *Halodule uninervis* meadow with lower biomass, but with higher *in vitro* digestibility.

Seagrasses may respond to cropping or clipping of leaves by decreasing levels of lignin or ash and increasing total nitrogen in new growth (Bjorndal, 1980; Dawes and Lawrence, 1983; Thayer *et al.*, 1984; Zieman and Wetzel, 1980). An increase of total nitrogen in new growth after feeding by dugongs was not found in our study, but an increased *in vitro* digestibility (IVD) was confirmed. The 'clipping-effect' of increased nitrogen levels may not occur when dugongs forage, because they do not clip leaves of seagrasses (like green turtles), but consume the entire plant, including leaves, rhizomes and roots. Thus, in our study the regular recropping of grazing swards allows dugongs to maximise the quality of their diet not only by increasing the area of early successional species of seagrass, but by increasing the digestibility of grazed seagrasses generally. This 'cultivation' effect by dugongs does not directly increase the food per bite, or food per dive, as the intense grazing tends to lower the biomass of seagrass, but leads to an increase in digestibility, which may compensate for the lower intake per bite.

A similar 'cultivation' effect as observed for dugongs in the present study has been observed for manatees in Florida (Lefebvre and Powell, 1990). Florida manatees, with muzzles less specialised for bottom feeding, crop circular patches (mean 27 m^2). Interestingly, there is some evidence that they return to the same patches in subsequent years.

The test with grazing intervals showed that in terms of overcompensatory growth all grazing intervals seem to yield a significantly higher level of seagrass regrowth, when compared with a control (Nang and Haruku) and a grazing interval of 10 weeks yields a significantly higher level of regrowth, when compared with shorter grazing intervals (Haruku). It is concluded that the results of this study support the model of overcompensatory growth as described by Belsky (1986), but the available data do not permit the definition of a regrowth optimum at certain grazing intervals.

Based on the significantly lower values of *in vitro* digestibility and the lower biomass of seagrass inside feeding patches compared with the undisturbed surrounding meadow, we conclude that the available data also suggest that the patterns of cultivation grazing practised by small herds of dugongs in the Lease islands seem to follow the model of herbivory along a productivity gradient as described by Van de Koppel *et al.* (1996) with a higher overall digestibility of the grazed swards. Our findings of small herds of dugongs using certain core areas on a regular basis may have important implications for the management and conservation of the remaining dugong population.

In an earlier study (De Iongh and Hein, 1996c) we concluded that in the only marine reserve in our study area (Pulau Pombo), no dugong core areas with grazing swards are found. We suggest that the protection of certain core areas, like the Haruku and Nang meadows, as dugong sanctuaries, is an important conservation measure. The declaration of dugong sanctuaries should coincide with the enforcement and enhancement of traditional conservation systems, like the local 'sasi laut' with inshore protected areas and restricted seasonal fishing practice.

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Chapter 9

Synthesis:
The Nutritional Ecology of the Dugong in Tropical Small Island Ecosystems

A Lingulid Brachiopod, which local villagers claim to be fed upon by dugongs; several authors report on omnivory among dugongs

Synthesis:
The Nutritional Ecology of the Dugong in Tropical Small Island Ecosystems

For a better understanding of this chapter, which integrates the main findings of my study I would like to refer to Fig. 9.1, which covers a qualitative model of plant-herbivore interactions between seagrasses and dugongs.

Feeding/digestion strategy

Lomolino and Ewel (1984) suggested that sirenians feeding and digestion strategy in general may be characterized by slow gut passage rates (GPR) and postgastric digestion of highly digestible forage. This strategy is quite distinct from that of ruminants (pregastric digestion and slow passage rates) and terrestrial non-ruminants (post gastric digestion with rapid passage rates).

Histologically, the dugongs small intestine differs from that of most other mammals (Marsh *et al.*, 1977). In the typical case, the mucosal structure of the small intestine consists of long villi, abundant absorptive cells and scattered goblet cells. The occurrence of goblet cells and mucus secreting gastric glands throughout the main sac of the dugongs stomach is a most unusual if not unique arrangement and should give the dugong stomach a greater capacity to secrete mucus than most mammalian simple stomachs.

A comparison of the dugongs digestibility coefficients with those of other herbivores was presented by Burn (1986). The digestibility coefficient for cellulose of the dugong compare particularly well with those of another sirenian, the manatee. This agreement is not surprising, since these species are closely related, have similar digestive apparatus, and consume similar diets. However, Marsh *et al.* (1977) conclude that the stomach of the West African manatee (*Trichechus senegalensis*) is less specialized than that of the dugong. According to Burn (1986) dugongs appear to be as efficient as other herbivores in their ability to digest nitrogen (crude protein). Such is not the case regarding cellulose. The dugong is more efficient at digesting cellulose than sheep, horses and cows. This disparity is most likely due to the difference in the rate of passage in these species (Burn, 1986). Efficiency of cellulose digestion has been shown to be proportional to the rate of passage in terrestrial herbivores since slower rates of passage allow more microbial cellulose fermentation to occur (Parra, 1978).

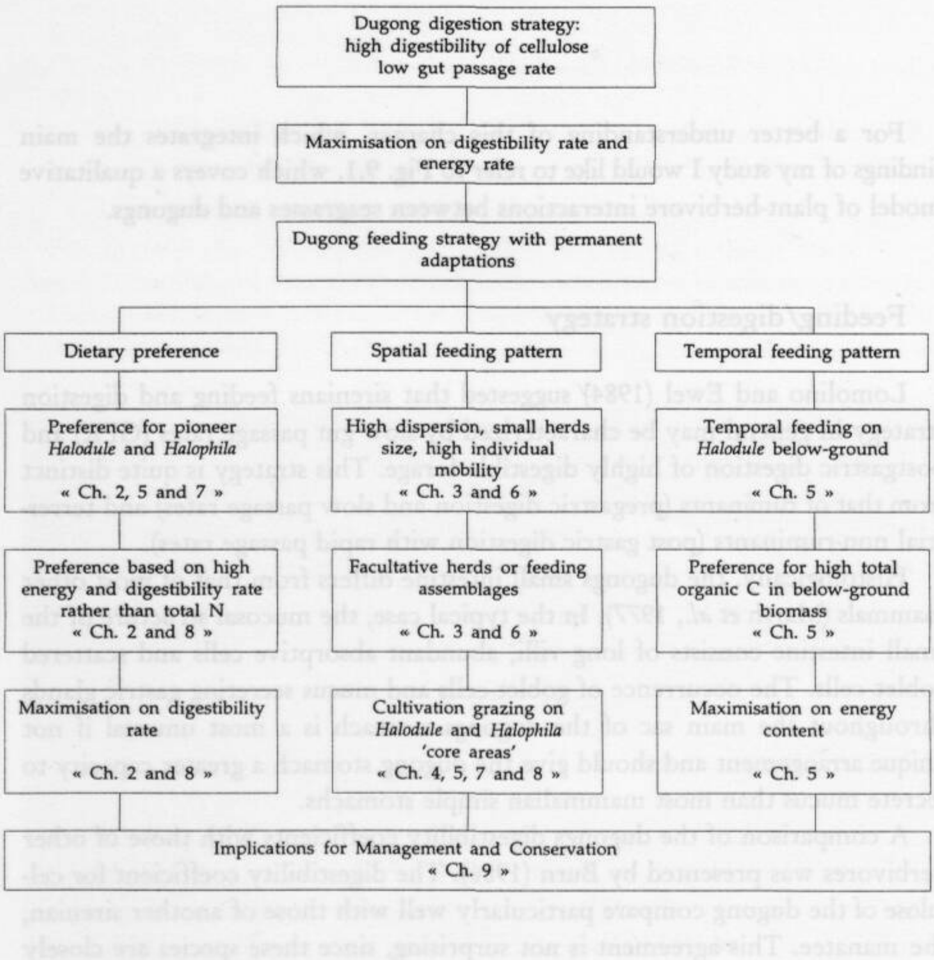

Figure 9.1
Qualitative model of the plant-herbivore interactions between seagrasses and dugongs in small island ecosystems

According to Thayer *et al.* (1984) a relatively high percentage of the organic matter content of seagrass is neutral detergent fibre (NDF). NDF in herbivore forage consists of cellulose, lignin and hemicellulose (Van Soest, 1982). According to Bjorndal (1980) in *Thalassia testudinum* NDF consists for 45.3% of cellulose, 4.6% of lignin and 9.0% of hemicellulose. Lignin levels are associated with digestibility, because lignin forms complexes with cellulose and hemicellulose, blocking structural carbohydrates from the activity of digestive enzymes (Bjorndal, 1980).

In the present study I found supporting evidence for the hypothesis that the dugongs digestion and feeding strategy consists of three adaptations to cope with the low quality forage which seagrass represents: (1) as part of their digestion strategy, they have developed a high capacity of cellulose digestion by combining physiological adaptations in their intestinal track with a slow GPR (Marsh *et al.*, 1977; Lanyon, 1991); (2) as part of their feeding strategy, they select more digestible forage through dietary preference for small and soft pioneer species like *Halophila ovalis* and *Halodule uninervis* (Chapters 2, 5 and 7); (3) also as part of their feeding strategy, they create more digestible forage by regularly recropping plots of young leaves and shoots through cultivation grazing (Chapters 4, 5, 7 and 8). Thus, in my view, cultivation grazing of dugongs seems rather a *permanent* adaptation to cope with low quality forage in tropical and sub-tropical regions, than a response to stress conditions in subtropical regions as suggested by Preen (1993).

These adaptations may also explain most of the dugongs social organization, including population size and density, dispersion and herd size, movements and home range and its feeding ecology, including dietary preference and temporal and spatial feeding patterns.

Social Organization

Evidence on the social organization of dugongs is limited and mainly covers the results of aerial surveys (Brownell *et al.*, 1981; Rathbun and Ralls, 1988; Marsh *et al.* 1984; Preen, 1993) and some fieldstudies (Jonklaas, 1961; Jarman, 1966; Heinsohn *et al.*, 1979; Anderson and Birtles, 1978; Anderson, 1982; Preen, 1993).

Evidence gathered through aerial surveys in my study indicate a dispersed pattern of distribution of low numbers of dugongs in a small tropical island ecosystem with a narrow coastal shelf (Table 9.1). The number of dugongs per survey hour in my study area was 5-11 dugongs/hour (Chapter 3), which

Table 9.1

Summary of the results of aerial surveys in tropical island ecosystems, tropical Australia and sub-tropical areas

	Location	Dugongs/ hour (±SD)	Max. Herd size	No. of aerial surveys	Number observers	Transect width (m)	Altitude (m)	Reference
Tropical island ecosystem	Lease	5	8	1	3	400	135	De Iongh *et al.*, 1995
	Lease	11	3	1	3	400	135	De Iongh *et al.*, 1995
	Palau	7.5	7	1	3	1000	150-300	Rathbun and Ralls, 1988
	Palau	5.4	?	1	2	1600	275	Brownell *et al.*, 1981
	Philippines	1.9	?	1				Trono, 1995
	Torres Strait	9.2	6	1	2	1600	275	Marsh *et al.*, 1984
Tropical Australia	NE Queensland	43.8 (±37.7) (10-114)	20	5	2	1600	275-300	Heinsohn *et al.*, 1976
	NE Queensland	17.8	–	7	2	1600	275	Ligon, 1976
	NE Queensland	–	20	6	4	400	137	Marsh and Saalfeld, 1987
Sub-tropical waters	Shark Bay	154.4 (±160) (0-480)	104	11	2	1600	275	Anderson, 1982
	Arabian Gulf	3 (±2.1) (0-6)	577	6	2	300-430	107-152	Preen, 1989

compares with the results of aerial surveys in other tropical island ecosystems; resp. 5.4 and 7.5 dugongs/hour in Palau (Brownell *et al.*, 1981; Rathbun and Ralls, 1988), 9.2 dugongs/hour in the Torres Strait (Marsh *et al.*, 1984), and 1.9 dugongs/hour in the Philippines (Trono, 1995).

The dispersion of dugongs in these areas is much larger, than in North-East Queensland, where numbers of resp. 17.8 and 43.8 dugongs/hour were reported (Heinsohn *et al.*, 1976; Ligon, 1976) and the number of 154.4 dugongs/hour reported for Shark Bay (Anderson, 1982). Similarly maximum herd size recorded during my 1990 and 1992 surveys, resp. 8 and 3 is similar to the maximum herd size reported for other tropical island ecosystems like 7 in Palau (Rathbun and Ralls, 1988), and 6 in Torres Strait (Marsh *et al.*, 1984), but much smaller than the maximum herd size of 20 reported for North-East Queensland (Heinsohn *et al.*, 1976; Marsh and Saalfeld, 1987) and 104 in Shark Bay (Anderson, 1982) and 577 in the Arabian Gulf (Preen, 1989). In fact distinct herds of 100 or more dugongs have been recorded from only four areas: Moreton Bay (South-East Australia), Shark Bay (West Australia), Arabian Gulf and Cape York (North Australia), the first three locations representing sub-tropical areas (Preen, 1993).

Anderson (1985) suggested that the extreme dispersion observed in tropical island ecosystems like Palau and Torres Strait may possibly be a result of social disorganization due to hunting pressure and disturbance. I believe that the observed pattern of larger herd size in sub-tropical areas and smaller herd size in tropical island ecosystems is, however, too regular to be solely explained by disturbance factors. Contrary to Anderson (1985), I believe that a higher dispersion over smaller herds in tropical island ecosystems reflects differences in social organisation related to cultivation grazing practice in smaller feeding assemblages when compared to sub-tropical areas, rather than patterns of disturbance (Chapter 6, 7 and 8).

With reference to the social organization of dugongs, Anderson (1982) assessed that dugongs are 'essentially gregarious, though frequently solitary'. Preen (1993) concluded that dugong herds are more than solely feeding assemblages because they show social interaction, herds persist during low tide periods and dugongs travel to and from feeding areas in groups. However, evidence presented by Preen (1995) during satellite and radio-tracking in North Queensland and during the present study in the Lease islands (Chapter 6) confirms that the social bond of dugongs is probably highly unstable. Based on the results of these studies, I believe that dugong herds are rather feeding assemblages with loose social interaction than fixed herds with a strong social bond.

Florida manatees also regularly form large aggregations, occasionally comprising 200-300 individuals (Reynolds and Wilcox, 1986). Aggregations of manatees occur around warm water sources (natural springs and power station outfalls) during cold periods in winter (Reynolds and Wilcox, 1985, 1986). Away from the warm water refuges, manatees are described as 'mildly social, essentially solitary' (Hartman, 1979). Reynolds (1981) considered manatees to be moderately social. Reported mean group sizes range from 1.9 (Irvine *et al.*, 1978) to 3.0 (Odell, 1980 cited in Reynolds, 1981). Lefebvre and Powell (1990) recorded a maximum group size of six, although 54% of the cumulative total of 215 manatees were solitary.

Hartman (1979) considered the social bond of manatees highly unstable and stated that all associations (except the cow-calf and the mating or oestrous herd) are temporary groupings. This confirms a similar social structure in loose feeding assemblages rather than fixed herds among manatees compared to the dugongs in my study.

Movements and Home Range

Few scientific records are available on the movements of individual dugongs. Anderson (1982) observed dugongs in Shark Bay, Western Australia. On the basis of photographs and sketches 15 dugongs were recognised more than once by divers.

Satellite telemetry has been used in a wide range of wildlife studies (Fancy *et al.*, 1988). Marsh and Rathbun (1990) developed a technique for tracking individual dugongs using buoyant, tethered, conventional and satellite radio transmitters and applied to six dugongs caught off the North Queensland coast. To date, only four studies are known, using this method on dugongs (Marsh and Rathbun, 1990; Preen, 1993; 1995a and my study, Chapter 6). The first three studies were carried out in coastal shelf areas of Australia. The dugongs followed in the study of Marsh and Rathbun (1990) (one immature, one pubertal and four mature males) were caught by bull-dogging or hoop-netting and tracked for between one and 16 months in North Queensland. All animals spent most of their time in the vicinity of inshore seagrass beds using overlapping home ranges (95% isopleth) of 4 to 23 km^2. The only dugong to undertake long-distance movements was the pubertal male which journeyed between core areas in two bays about 140 km apart three times in nine weeks.

Preen (1993) tracked 13 dugongs in sub-tropical Moreton Bay including four males (two adults, two sub-adults) and nine females (five adults, four sub-adults). Six dugongs were tracked through winter, four through spring and summer. During the tracking periods (mean=50 days) dugongs occupied an average range of 64 km^2. Partly due to their movements outside the Bay, the dugongs occupied larger home ranges in winter than in other seasons. The larger ranges may have also resulted from a need to feed over wider areas during the period of low seagrass abundance. Within their home range, some of the dugongs sequentially used distinct sub-ranges, in which they concentrated their activities for periods of up to 35 days, before moving to a new area. A similar pattern was noticed for large dugong herds observed during aerial surveys: they tended to feed in the same location for periods of up to at least 31 days, before moving to a new feeding area. One tracked dugong displayed wide-ranging exploratory behaviour after abandoning one sub-range, and before adopting a second. Such behaviour may allow the dugongs to sample the nutrient status of seagrasses over a wide area before selecting a new feeding area.

The findings of my study correspond particularly well with the findings of Preen (1995a), who recently reported on the preliminary results of telemetry studies in the Gulf of Carpentaria during 1994, but did not provide information on sex of the animals and home range. Like in my study, Preen concluded that the five dugongs were surprisingly individualistic, all showing different patterns of movement, moving over much larger areas than previously thought and showing high social interaction. Each of the dugongs used 1-3 preferred areas 50-400 km apart. The five dugongs collectively used just five preferred areas. Aerial surveys have confirmed that herds of 50-200 dugongs occurred at each of these preferred sites. So although they move about a lot, and move about independently of one another, they have all been moving among the same five dugong herds. Significantly, very few were seen on the shoreline aerial surveys that were not in these herds.

To date, the only observations on movements and home range of dugongs, using conventional and satellite telemetry, in a tropical small island ecosystems with a narrow coastal shelf are reported in my study (Chapter 6). I tracked three adult females and one immature male for between 51 and 285 days. Similar to the findings of Preen (1995a), the animals showed a surprisingly individualistic pattern of movement, moving over large areas. The immature male moved 65 km in as little as two days and stayed in a core area in S. Seram for 42 days, until the PTT was released. The three adult females used 2-3 preferred areas 17-55 km apart, where they stayed a maximum of 42 days, each returning at least once to a preferred core area. One adult female dugong made five roundtrips between two core areas were she stayed a maximum of 8 days. The recorded mean home range (50% isopleth) covering sea area in my study was

4.1 km^2, in the same range as mean home ranges (50% isopleth) of 9.7 km^2 recorded by Preen (1993) in sub-tropical Moreton Bay and 4.1 km^2 recorded by Marsh (1990) in tropical North Queensland. I conclude that in all reported studies dugongs move along restricted core areas where feeding takes place in larger (Preen, 1993) or smaller (my study) feeding assemblages. This confirms the observed pattern of cultivation grazing by small (facultative) herds of dugongs in restricted feeding swards in the Lease islands. In my study individual dugongs which were followed through satellite/VHF tracking move around a limited number of core areas, covering distances of up to 55 km, possibly joining up with other feeding assemblages at grazing plots, where concentrated feeding takes place. Dugongs in my study area show a highly individual and opportunistic patterns of movement (Chapter 6), and stayed a maximum of 42 days at a core area, but mostly between 1-8 days. Two couples of animals tagged separately in the same herd during April and October 1994, never moved together after tagging. My study confirms the hypothesis that dugongs in the Lease islands perform cultivation grazing in facultative feeding assemblages with a loose social interaction rather than through grazing in fixed herds with a strong social bond.

Dietary Preference

Several authors suggested dietary preference of dugongs for 'soft' and 'sparse' pioneer species such as *Halodule uninervis* and *Halophila ovalis* (Gohar, 1957; Heinsohn and Birch, 1972; Lipkin, 1975; Johnstone and Hudson, 1981). Heinsohn and Spain (1974) reported the consumption of brown algae by dugongs in tropical North Queensland after extensive damage to seagrass beds caused by a cyclone. Based on the analyses of 95 North Queensland dugongs Marsh *et al.* (1982) concluded that the generic composition of stomach contents probably reflects that of the seagrass beds in the areas where the dugongs were captured and is not necessarily indicative of discrimination in selecting food. They also stated that even local differences in dietary intake indicated by their study [and by Gohar (1957), Heinsohn and Birch (1972), Lipkin (1975) and Johnstone and Hudson (1981)] may be, at least partly, an unavoidable artefact of the sampling. It is an important observation that in the study of Marsh *et al.* (1982) *Halodule* and *Halophila*, representing pioneer species, were by far the most dominant food item and present in 95% and 89% of the stomachs respectively, while seagrass rhizomes were present in all stomachs.

The results of my study (Chapters 2, 5 and 7) correspond with the findings of Preen (1993), who studied dugongs in sub-tropical Moreton Bay and found that they fed on very sparse seagrass beds of delicate species of *Halophila* and *Halodule* more frequently than on other seagrass beds. He found quantitative evidence suggesting that dugongs in Moreton Bay preferred seagrasses in the following decreasing order: *Halophila ovalis* > *Halodule uninervis* > *Halophila spinulosa* > *Syringodium isoetifolium* > *Cymodocea serrulata*. In my study I confirmed dietary preference of dugongs in the Lease islands for the pioneer species *Halodule uninervis* and *Halophila ovalis* (Chapters 2, 5 and 7). I also found a similar decreasing sequential order as described by Preen (1993) for sub-tropical Moreton Bay, for dugongs in a tropical evironment; *Halodule uninervis* > *Cymodocea rotundata* > *Syringodium isoetifolium* > *Thalassia hemprichii* (Chapter 2).

The studies mentioned above provide a sufficient scientific basis, to conclude dietary preference for dugongs to show a consistent picture from sub-tropical areas to tropical areas. Several authors have attempted to explain the factors, influencing dietary preference of dugongs. Lanyon (1991) stated that dietary preference of dugongs is based on high total nitrogen and low neutral detergent fibre. Several authors have reported omnivory in wild ranging dugongs (Hirakasa, 1932; Anderson, 1989; Preen, 1993; Preen, 1995c) and in captive dugongs (Jones, 1956). Preen (1993, 1995c) showed that dugongs in sub-tropical Moreton Bay (South-East Australia) may have significant quantities (in 69% of samples and 29% of wetweight) of ascidians (a source of animal protein) in their stomach. He suggested omnivory to be a response to seasonal nutritional stress, combined with the physiological and energetic stresses caused by cold water temperatures at the edge of the species range. Also, Anderson (1989) reported dugongs deliberately foraging on invertebrates in sub-tropical Shark Bay (West Australia). In my study I cited reports of local fishermen claiming they had seen dugongs feeding on Lingulid Brachiopods and *Sipunculus* sp., but these statements could not be confirmed by scientific evidence (Chapter 4). However, very few fresh stomach contents were available for analyses. Omnivory may play a more significant role in the foraging strategy of dugongs, than previously supposed (Chapter 2). In this perspective dugongs can be characterised as 'facultative omnivores' and principal selection of seagrass on total nitrogen seems less likely. In my study I found a significant positive correlation of dietary preference with *in vitro* digestibility of the whole plant and total organic carbon of below-ground biomass and not with total nitrogen (Chapter 2, 5 and 8). Preen (1993) suggested soluble carbohydrates as a possible important factor for diet selection by dugongs. The importance of seagrass rhizomes and roots as a food source for dugongs has been stressed by Anderson (1991) and Erftemeijer *et al.* (1993a), but was not studied by Lanyon (1991). In my study I gave evidence that dietary preference of dugongs for pioneer species like *Halodule* and *Halophila* is based on a strategy of maximising both digestion rate and energy intake rather than total nitrogen (Chapter 2, 5 and 8).

Several authors suggested that dugongs tend to prefer sparser seagrass stands above denser stands of the same species (Wake, 1975, quoted by Marsh, 1984; Anderson and Birtles, 1978). I confirmed in my study that the dugongs preference for seemingly 'sparse' stands of intertidal mono-specific *Halodule uninervis* meadows in the Lease islands, can be explained by a coincidence of low above-ground biomass and high below-ground biomass in combination with high levels of carbohydrates in the below-ground fraction (Chapter 5). I also found indications that cultivation grazing by small herds of dugongs in *Halodule uninervis* dominated meadows may yield benefits in terms *in vitro* digestibility (Chapter 8). Cultivation grazing by dugongs does not directly increase the food per bite, or food per dive, but leads to an increase in digestibility.

The above cited evidence confirms the hypothesis of dugongs having developed in the course of their evolution permanent adaptations to their low quality forage through: (1) a high digestibility coefficient for cellulose in combination with a slow GPR (Chapter 2); (2) dietary selection on highly digestible pioneer species, like *Halodule uninervis* and *Halophila ovalis* (Chapters 2, 5 and 7); and (3) recropping plots of young highly digestible shoots through cultivation grazing (Chapter 4, 5, 7 and 8).

Cultivation Grazing

An impact of environmental stress on herding size has been observed for terrestrial herbivore densities of African elephants (*Loxodonta africana*) caused by a restriction in available savannah habitat which led to an increase in group size (Laws, 1975). Preen (1993, 1995b) postulated that seasonal nutritional stress and cold water temperatures during winter in sub-tropical areas and a response to this double stress by the phenomenon of 'cultivation grazing', would be a major factor for the observed difference in herd size of dugongs between sub-tropical and tropical areas. Cultivation grazing occurs when herds of dugongs forage intensively in an area, effecting a high level of seagrass removal over a large area. Cultivation grazing allows dugongs to improve the quality of their diet by: (1) maintaining the meadow at a younger, actively growing stage, so the seagrasses contain less fibre, (2) converting the meadow to a lower pioneer stage composed of preferred and nutritionally superior seagrasses, and (3) concentrating the regrowth vegetation into areas that can be efficiently cropped. The nutritional benefits of these modifications to the seagrass meadows would maximise the fitness of individual dugongs. McNaughton (1979) postulated that the fitness benefits gained by individual animals, through increased foraging efficiency, could lead to the development of herding behaviour in ungulates. According to Preen (1993, 1995b), due to their mode of feeding, these benefits can only be achieved if the dugongs feed in large herds.

Preen (1993, 1995b) also states that in tropical areas, the benefits of cultivation grazing may not be necessary, or relevant, in which case there may be no pressure to feed in large herds. According to Preen (1993, 1995b) there are three reasons why feeding behaviour of dugongs in tropical areas may differ from dugongs in sub-tropical and temperate regions: (1) dugongs in tropical areas would not suffer the physiological stresses of cold water; (2) *Z. capricorni* is the dominant species in Moreton Bay, but is relatively uncommon in most tropical areas. Due to high levels of fibre, *Z. capricorni* is the least digestible of seagrasses so far examined from Queensland. One of the results of cultivation grazing in Moreton Bay is the spatial containment of the species. If the arrest of the expansion of *Z. capricorni* is one of the principal benefits of 'cultivation' grazing, then it simply may not be necessary in other areas, where this species is not dominant; (3) seagrasses in tropical areas experience a number of disturbances and limitations that may effectively perform the same role as cultivation grazing. The combined effect of cyclones, turtle grazing, exposure (in inter-tidal zones) and turbid water interrupt the successional development of seagrass communities.

The findings of my study contradict with the conclusions of Preen (1993, 1995b) since I observed concentrated recropping of grazing swards inside both intertidal and subtidal seagrass meadows in the Lease islands, caused by cultivation grazing practice of small herds of dugongs (2-6 animals). These small herds could sufficiently disturb the seagrass bed through a dense grazing pattern, to maintain mono-specific meadows (*Halodule uninervis*) of low standing crop (Chapters 4, 5, 7 and 8).

The principal effect of cultivation grazing in an intertidal multi-species meadow in my study area (Nang) was the creation of mono-specific *Halodule uninervis* pioneer meadows surrounded by multi-species associations (Chapter 5, 7 and 8). This pattern of grazing leads, similar to patterns described for Moreton Bay by Preen (1993, 1995b), to the spatial containment of less favoured species, like (in my study) *Thalassia hemprichii* and *Cymodocea rotundata*.

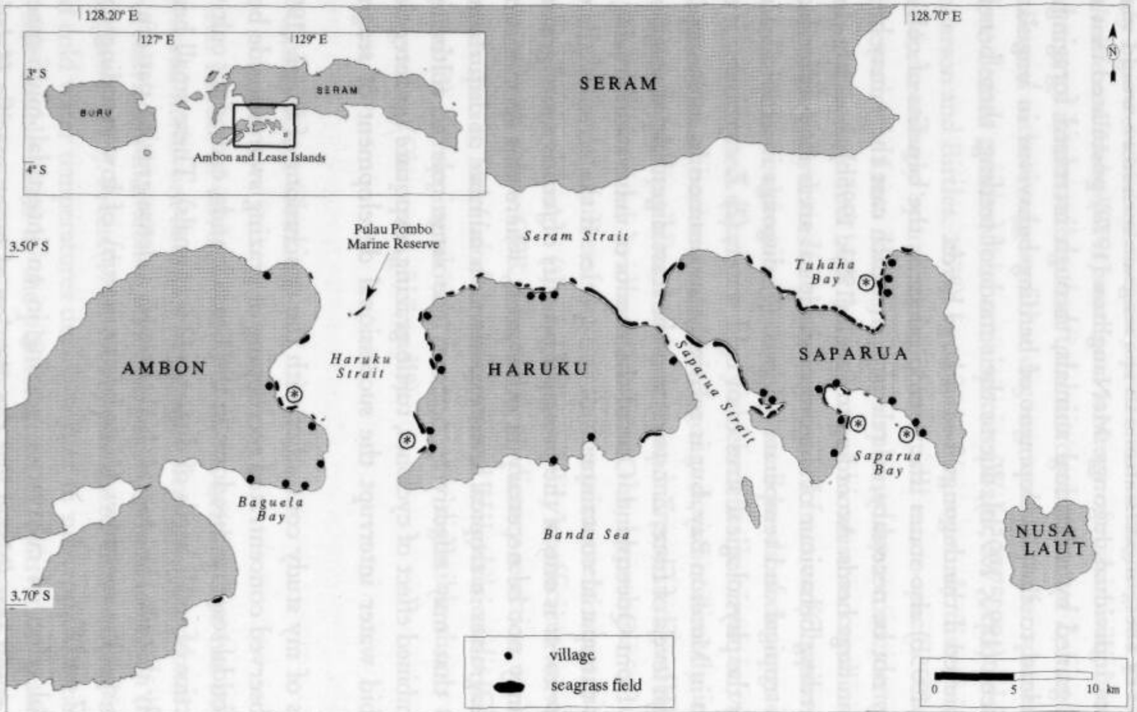

Figure 9.2

Map representing the seagrass meadows along the coast of Ambon in the Haruku Strait and along the coast of Haruku and Saparua, and the location of five 'core areas' ⊛

The principal effect of cultivation grazing in a subtidal mono-specific *Halodule* meadow in my study (Haruku) was a higher *in vitro* digestibility inside the grazing plots, compared with the undisturbed meadow (Chapter 8). This phenomenon has not been described by Preen (1993, 1995b) for Moreton Bay. Cultivation grazing in mono-specific meadows results in patches with lower standing crop, but with a higher *in vitro* digestibility, indicating a feeding strategy along a productivity gradient as described by Van de Koppel *et al.* (1996).

During my study I have identified at least five permanent grazing swards with concentrated, regular patterns of recropping by dugongs (Figure 9.2). I concluded that dugongs in these plots rather grazed in facultative feeding assemblages with loose social interaction than in fixed herds with a strong social bond (Chapter 6). Cultivation grazing benefits all individual dugongs through an increased rate of digestibility and energy intake, but lowers the amount per bite and overall biomass in the grazing swards.

With a computer model I calculated the maximum sustained population size for Haruku Strait as 15 dugongs and for the study area as 125 dugongs (Chapter 7). With estimated minimum population of 22-37 dugongs for the study area mortality by accidental capture by man may be a major factor determining population size but the practice of cultivation grazing by small herds of dugongs rather seems to determine the extreme dispersion of dugongs in our study area.

McNaughton (1983) postulated that gregariousness in grazing animals may be a trend in the course of evolution because in herds they may be less subject to predation and because of the increase in foraging efficiency that accrues to individuals as a result of changes in vegetation structure that follow herd grazing. Predation, however, had not prevented green turtles (Bjorndal, 1980; Ogden, 1980; Thayer *et al.*, 1984) from maintaining individual foraging patches of seagrass. Similarly, I have concluded that predation pressure does not influence small dugong herds foraging in restricted swards in the Lease islands (Chapter 7).

A similar 'cultivation' effect as observed for small groupings of dugongs in the present study has been observed for small herds of manatees in Florida (Lefebvre and Powell, 1990). They concluded that Florida manatees, with muzzles less specialised for bottom feeding, do not produce feeding trails in the manner of dugongs. Instead, when they feed on seagrasses, they crop circular patches (mean 27 m^2). Interestingly, there is some evidence that they return to the same patches in subsequent years.

My study confirms thereby that the practice of recropping permanent grazing swards through cultivation grazing is practised by dugongs in both subtropical and tropical areas and could be part of a permanent evolutionary pattern of adaptations of the dugong as a species in response to its low quality forage.

Implications for Conservation and Management

Main objective of the research programme was to provide basic scientific data, required for the proper conservation and management of remaining dugong populations. The dugong thereby is considered to be a flagship species for coastal conservation efforts in the region, including environmental education and awareness raising. Coastal areas throughout Asia are threatened by habitat destruction through unsustainable fishing practice (dynamiting, the use of cyanide), while inshore seagrass meadows are impacted by land based activities resulting in excessive sedimentation.

The observations reflect the results of an in depth study of a relatively small area, and should therefore be interpreted with care. However it is the first extensive study of dugongs in Indonesia and since the situation in the Lease islands represents the situation of a large share of the remaining dugong populations in tropical small island ecosystems outside Australia, the results of this study will be of interest to professionals and institutions involved in coastal conservation and management of similar ecosystems.

Since 1990 the ongoing research in the Lease islands has covered the dynamics of seagrass meadows in Haruku Strait, a sea strait between the islands Ambon and Haruku, the impact of dugong feeding on seagrass meadows and the movements and behaviour of dugongs.

Expatriate and Indonesian researchers and students worked together, to map seagrass beds, analyze seagrass biomass and standing crop, make observations on and follow the movements of individual dugongs. Aerial surveys conducted during 1990 and 1992 had revealed the presence of a minimum population of 22-37 animals in the coastal waters of the Lease islands (Chapter 3), being in interaction with a larger unidentified population around Seram island, North of Lease (as was proved by following a satellite tagged immature male dugong; Chapter 6). Dugongs in the Lease islands depend to a large degree on seagrass meadows situated on the narrow coastal shelf, which is at most 500 meters wide. Most of the meadows in our study area are situated in front of coastal villages (Fig. 2). Field observations, the use of satellite telemetry and interviews with local villagers confirmed that the investigated dugongs consistently recropped grazing swards at two to three 'core areas' (Chapter 4, 5, 7 and 8).

Cultivation grazing is practised by small feeding assemblages, and individual dugongs returned to the same feeding swards at regular intervals of time (Chapter 6). During my study I identified a total number of five 'core areas', where small herds of dugongs practised cultivation grazing (Fig. 9.2). Local villagers and researchers could distinguish certain individuals by colour and size. The seagrass dynamics and dugong feeding patterns of two particular meadows in Haruku Strait showed a high degree of complexity, in the sense that dugongs adapted their feeding strategy to the characteristics of these individual seagrass meadows. An intertidal meadow only showed feeding peaks during August-October (at the end of the rainy season), when the monthly means of total organic carbon content in the below-ground biomass of these *Halodule* dominated meadows was at its maximum (Chapter 5).

The available scientific information suggests that the protection of certain core areas, like the Haruku meadow, as a dugong sanctuary is an important conservation measure. The declaration of dugong sanctuaries should coincide with the enforcement and enhancement of traditional community-based conservation systems, like the local 'sasi laut' with inshore protected areas and restricted seasonal fishing practice.

My study gave indications that Indonesian adult female dugongs may be larger in size than Australian dugongs, but the available data did not allow a statistical analyses. However, the analyses of skin samples confirms that Indonesian dugongs are genetically different from Australian dugongs (Chapter 4).

With respect to dugong populations in the study area I conclude that these had in the past significance in terms of protein production and use of other products such as oil, ivory and bones, while in the present their significance is moreover as a biological indicator of the quality of the environment, a socio-cultural significance in terms of ancestral believes, as a touristic object, and as a flagship species for coastal conservation programmes.

Based on my research I conclude that the main threats to dugong populations in the study area are the following:

- (accidental) capture of dugongs in fishing nets (gillnet and beachseine) used by local fishermen. I concluded that at least 3-5 dugongs are captured annually in fishing nets, part of which are immature or sub-adult (Chapter 4);
- destruction of major dugong habitats. Although I concluded that the seagrass meadows in my study area are still in good condition a major threat is

formed by the siltation of large sediment loads carried by rivers from the densily populated coastal zone (Chapter 7);
- the recently planned construction of a goldmine near Haruku village forms a major threat for the seagrass meadow at Haruku, considered of major importance for dugongs in the study area (Chapter 7).

Observing the above mentioned threats, I recommend the Regional Planning Board (BAPPEDA) at Ambon to develop an Integrated Coastal Zone Management plan (ICZM) with a full integration of conservation values of dugongs and other endangered species for the study area and other priority zones of the Moluccas Province.

Under the umbrella of the ICZM the Provincial Office of the Directorate General for Nature Conservation (PHPA) is recommended to develop a Dugong Conservation Action Plan (DCAP) according to Tomlinson (1993).

The main objectives of this DCAP are:

1. the identification and promotion of key dugong populations and habitat, and
2. the promotion of a sustainable relationship between the local communities and dugongs.

I recommend the following elements to be included in the DCAP:

1. Staff and students of the National Research Institute for Oceanology (P_3O/LIPI) and the Pattimura University (UNPATTI) should be trained in research methodology covering dugong biology and seagrass dynamics in the project area. Continued research and data gathering should be implemented by P_3O/LIPI and UNPATTI, covering the following major themes:
   a. An inventory of the distribution and abundance of dugong populations in the study area and other priority zones. Preliminary aerial surveys should be conducted in potential habitat areas such as shallow sheltered regions. Correction factors, which account for perception bias and availability bias should be applied (Marsh and Saalfield, 1987).
   b. Habitat surveys should cover coastal areas, which support dugongs. For the mapping of seagrass meadows the methodology can be used, developed in my study (Chapter 7). I recommend also the establishment of regular monitoring programmes.
   c. The status of identified dugong populations in terms of their genetic diversity, kinship and social organisation can be determined using biopsy sampling. The results of such investigations would provide information

on the degree of separation of dugong populations, and the implications of the conservation of genetic diversity. I recommend to cooperate with the School of Biological Sciences at the James Cook University in Townsville, Australia.

d. Incidental mortality and other sightings of dugongs should be monitored. Interviews with fishermen could provide information on time, date, location and method of capture. I recommend to set up a network of reporting of incidental kills and sightings.

e. Carcass analyses will provide information on the age, sex structure, length of the pre-reproductive period, and age-specific data on fecundity and mortality. It would also support the identification of geographic variation.

f. *Movements and home ranges of dugongs can be monitored through the* satellite tracking of tagged dugongs, as conducted in my study (Chapter 6). This research will provide information on seasonal and short term movements, social organisation and habitat use.

2. I recommend the implementation of an information and awareness campaign. Rural target groups should be reached through the production and distribution of a dugong poster, dugong leaflets and T-shirts with dugong print, among government offices, village leaders, school teachers and pupils and households in the project area. The production and distribution should be in close cooperation with the Asian Wetland Bureau, the Directorate General for Nature Conservation (PHPA), WWF Jakarta, Oceanarium Ancol in Jakarta and the Yayasan Hualopu in Ambon.

3. I concluded that the existing marine reserve in Pulau Pombo is insignificant for dugong conservation. The research on dugong-seagrass interactions, as carried out under the terms of this project, proved that the intertidal and subtidal monospecific seagrass meadows of *Halodule uninervis* outside the Pulau Pombo area are more important for dugongs than the sparse seagrass meadows at Pulau Pombo. Therefore, I propose dugong sanctuaries to be established at a selected number of five 'core areas' in Haruku Strait, Saparua Bay, North East Saparua and Piru Bay (Fig. 9.2). These sanctuary areas should be mapped and a proposal should be submitted to the Governor of the Moluccas Province and the Director General Nature Conservation (PHPA) for the status of 'Protected Area'

4. I concluded that at least 3-5 dugongs per annum are a victim of (accidental) capture in fishing nets in the study area (Chapter 4) During the period of calving, neonate dugong calves often fall victim to fishermen nets. An adaptation in fishing intensity during this critical period, may reduce mortality among neonate calves and thus reinforce dugong populations in the area. I recommend also that during periods of high *Halodule* rhizome and root biomass, in certain (intertidal) sanctuary zones, like Nang, fishing with gill-nets will be restricted.

5. I recommend the support of controlled eco-tourism on dugongs. My study shows that particularly the observation point at the cliff adjacent to Paperu village at Saparua Bay has a potential as a touristic site. Eco-touristic excursions could be organised to this observation cliff as part of an overall programme of tour operators, while revenues should be channelled to the villagers of Paperu.

6. Last but not least I strongly recommend the enforcement of national and international legislation, such as Goverment Regulation No. 5 of 1990 and the CITES convention on international trade at the provincial level. I refer in particular to the trade of cigarette pipes carved from dugong ivory or ribs, during my study still for sale in the tourist shops of Jalan Pattimura, Ambon City.

More general recommendations for action at the national level, which form a *conditio sine qua non* for the proper implementation of conservation and management measures at the local level, are the following:

a. the preparation of a National Dugong Conservation Strategy and Action Plan;
b. the enforcement of the existing international and national laws and regulations with respect to dugong catches and the trade in dugong products;
c. continued research and data gathering on dugong migration, distribution and reproduction;
d. the implementation of an information and awareness campaign to promote community based conservation, on a national scale;
e. the preparation and implementation of coastal zone management plan, including sanctuaries and protected areas of dugongs.

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Summary

The dugong is regarded as a rare and endangered species, listed as 'vulnerable' in the IUCN Red Data Book (IUCN, 1988). Dugongs are protected by Indonesian Law by Government Regulation No 5 of 1990. Few scientific records are available on the abundance, distribution and behaviour of the dugong in Indonesia. Dugongs are scattered throughout Indonesia, usually in very low numbers. Little is known of the smaller populations other than that they occur around Kupang Bay (Timor), Arakan Reef (North Sulawesi), Togian Island, Teluk Tomini (Central Sulawesi) and other small bays and straits around Sulawesi including the Spermonde Islands, South Kalimantan and Bangka-Belitung Islands (Karimata Strait). Towards the end of 1979 dugongs were apparently still fairly numerous around the Aru Islands, their last known area of abundance. Previous to this study, apart from the Aru islands, no scientific reports are available on the presence of dugongs in the Moluccas Province. Through an aerial survey of dugongs in coastal waters of Ambon and the Lease Islands (Haruku, Saparua, Nusa Laut) during 1990 and 1992 the presence of a minimum population of 22-37 animals was confirmed. The study was part of the Dugong Conservation and Management Project, funded by the European Development Fund, a project jointly implemented by the Environmental Study Centre of the Pattimura University in Ambon and the Foundation AID Environment in Amsterdam.

Dugongs are known to feed on intertidal and subtidal meadows of the seagrasses *Halodule uninervis* and *Halophila ovalis*. These species are often found in low density stands. When dugongs feed on morphologically small-leafed seagrasses such as *Halodule* and *Halophila*, they uproot and consume the entire plant, including rhizomes and roots. This method of feeding produces characteristic feeding trails.

Recent literature also describes the phenomenon of cultivation grazing with dugongs regularly recropping a restricted grazing sward. Cultivation grazing of dugongs in recent literature is described as response to seasonal stress factors and is only practised by large herds of dugongs in sub-tropical regions.

In the present study the hypothesis is tested, that cultivation grazing is part of a feeding strategy of dugongs, aiming at maximisation of energy and digestibility rate, and that it is not a response to seasonal stress factors and also practised by smaller herds of dugongs in tropical areas.

Chapter 1 gives an introduction into the scientific literature, covering dugong feeding ecology. The dietary preference of a captive adult female dugong in Surabaya Zoo is described in Chapter 2. A cafeteria experiment showed dietary preference for seagrass taxa offered. In spite of the fact that the animal had been exclusively fed with leaves of *Syringodium isoetifolium* during the past 19 years, the experiment resulted in a sequential order from high to low preference: *Halodule uninervis* > *Halophila ovalis* > *Cymodocea rotundata* > *Syringodium isoetifolium* > *Thalassia hemprichii*. A correlation analyses between dietary preference for the selected species and different seagrass parameters showed a significant positive correlation with *in vitro* digestibility and a significant negative correlation with total calcium content. In contrast dietary preference did not show a significant correlation with Neutral Detergent Fibre (NDF), total nitrogen content, total phosphorus content, total magnesium content, total natrium content and total kalium content. Only the *in vitro* digestibility of *H. uninervis* (63%) and *H. ovalis* (50%) seemed sufficient to maintain the basic metabolism of the dugong, whereas all other seagrasses showed a digestibility below basic metabolic requirement.

Chapter 3 covers the results of two aerial surveys with the aim to assess dugong populations in the project area. During December 1990 and August 1992 aerial surveys of dugongs were made following the coastline of the Lease islands in East Indonesia. The aerial surveys followed a strip transect covering the coastal shelf and totalling 3.5 hours of observation. During the first survey a total of 17 dugongs was observed one of which was a neonate calf, during the second survey 10 dugongs were seen but no neonate calf. The minimum population of dugongs was estimated to be between 22-37 animals. The population is probably in interaction with a larger unidentified reservoir of animals in coastal waters of nearby Seram.

Field observations were made on wild ranging dugongs, captive live dugongs and captured dead specimen (Chapter 4). Snorkling and scuba diving surveys revealed information on the interaction with seagrass meadows, modes of surfacing, surfacing and submerging times and behaviour in the presence of scubadivers. Dugongs showed a pattern of concentrated grazing by regularly recropping a restricted grazing sward inside a mono-specific *Halophila ovalis* meadow. In addition observations are reported on the size ranges of captive live animals from Indonesian Zoos and dead animals obtained from accidental catches of dugongs. The analyses of size measurements indicates that these animals are of a very large size class, when compared with Australian dugongs.

Chapter 5 gives an insight in the seagrass distribution and seasonal changes in biomass and total organic carbon. These variables were studied in intertidal meadows dominated by *Halodule uninervis* between December 1990 and December 1992 in Nang Bay on the East coast of Ambon. Both below-ground and above-ground biomass of *Halodule uninervis* significantly increased during the transition period from the dry season to the wet season between February and May. Above-ground biomass of *Halodule uninervis* decreased significantly during the wet season (between May and August), when low tide occurred in day time, and only slow recovery took place until November. Below-ground biomass remained high until November, resulting in a significant decrease of the ratio of above-ground to below-ground biomass during the period between May and August, and in a 'sparse' visible seagrass meadow, with a non-visible high below-ground biomass between August and November. Total organic carbon level in the below-ground plant parts gradually increased between May and August with a peak value in August. Dugong grazing removed 93% of the shoots and 75% of the below-ground biomass of the upper 4 cm deep layer of sediment. Seagrass biomass in freshly grazed feeding tracks had restored to levels of the nearby seagrass bed after five months during the onset of the wet season. No significant restoration took place during the dry season. The frequency of dugong grazing showed a strong positive correlation with total organic carbon level in the below-ground plant parts, indicating that the dugongs preference for the *Halodule uninervis* seems to be based on a strategy of a high net rate of energy intake.

Four individual dugongs were tracked, using buoyant, tethered, conventional radio and satellite transmitters (Chapter 6). The dugongs (three adult females and one immature male) were caught with a surrounding net and tracked for between 53 and 285 days. One adult female spent most of the time at two distinct inshore seagrass beds, separated by about 17 km. She made five trips between the two sites. Two other females made round-trips to Saparua and Nusa Laut, both returning to the core area at Haruku island. The immature male journeyed between two core areas, about 65 km apart, completing the journey in as few as four days. The three adult females used 2-3 preferred areas 17-47 km apart. The movements between a limited number of core areas support the observed patterns of recropping of restricted grazing swards by loose feeding assemblages at the Haruku meadow.

Dugong maximum sustained feeding pressure, in relation to standing crop of seagrass meadows is covered by Chapter 7. *Halodule* and *Halophila* dominated seagrass meadows, fed upon by dugongs, were mapped in the Haruku Strait. Seagrass species coverage, and standing crop (above- and below-ground) per coverage class were calculated. The total standing crop of meadows with evidence of dugong feeding was calculated as 32,295 kg DW. The maximum sustained feeding pressure of dugongs was computed with a model as 9 feeding tracks per day per 900 m^2 of seagrass meadow. A maximum population of 15 dugongs can feed sustainably on the seagrass meadows of Haruku Strait and the maximum sustained population size in the study area was estimated as 125 dugongs. It was concluded that mortality by (accidental) capture is a major factor regulating population size but the practice of regular recropping of restricted grazing swards by loose feeding assemblages is a major factor regulating herd size, distribution and dispersion.

Chapter 8 covers the phenomenon of 'cultivation grazing' of dugongs in the Lease islands. Investigations of intertidal and subtidal *Halodule uninervis* dominated meadows in Haruku Strait revealed patterns of 'cultivation grazing' by dugongs. The analyses of spatial and temporal feeding track patterns in IDRISI GIS maps with 50% and 90% harmonic mean resulted in distinct feeding swards. *In vitro* digestibility was higher inside the feeding swards, but total nitrogen content (%) did not show significant differences inside and outside feeding swards. The present study confirms the hypothesis of increasing foraging efficiency and dietary selection by dugongs on high *in vitro* digestibility and cultivation grazing as a permanent adaptation to a low quality forage.

In Chapter 9, the results of the previous chapters are evaluated and integrated and the implications for conservation and management are discussed. The two major threats for dugong populations in the study area are defined as (accidental) capture (at present) and habitat destruction (in the future). It is recommended to develop a Dugong Conservation Action Plan (DCAP) as part of an integrated coastal zone management plan, covering future research, training and education, an information and awareness campaign, the establishment of dugong sanctuaries, restrictions in fishing with gillnets and law-enforcement on trade in dugong products. The importance of the involvement of local communities and traditional conservation (*sasi laut*) is stressed.

Samenvatting

De dugong heeft volgens het IUCN Red Data Book de status van 'bedreigde soort' (IUCN, 1988). Dugongs worden ook door de Indonesische wetgeving beschermd (Government Regulation No. 5, 1990).

In Indonesië is relatief weinig bekend over de verspreiding en het gedrag van de dugong. Uit een beperkt aantal wetenschappelijke bronnen blijkt, dat de dugong over de gehele Indonesische archipel voorkomt in kleine verspreide populaties. Dugong populaties zijn bekend van Kupang Baai (Timor), Arakan Rif (Noord Sulawesi), de Tobian eilanden en Teluk Tomini (Centraal Sulawesi) en andere baaien en zeestraten rond Sulawesi, West Sumatra, Zuid Kalimantan, de Kleine Sunda eilanden, de Molukken en Irian Jaya.

Rond 1979 waren dugongs nog talrijk rond de Aru eilanden, één van de laatste gebieden met een grote dugong populatie. In de Molukken zijn slechts uit de Aru-eilanden kwantitatieve gegevens bekend over dugong-vangsten en -verspreiding.

Deze studie omvat het eerste diepgaande onderzoek naar de ecologie van de dugong in de Molukken en Indonesië als geheel. Het onderzoek werd uitgevoerd in het kader van het 'Dugong Conservation and Management Project', gefinancierd door de Europese Unie, uitgevoerd in samenwerking met het milieu instituut (PSL) van de Pattimura Universiteit op Ambon en de Stichting AID Environment in Amsterdam. Gedurende 1990 en 1992 werd door middel van een luchttelling met een Cessna-vliegtuig in de kustzone van Ambon en de Lease eilanden (Haruku, Saparua en Nusa Laut) een minimum populatie geschat van 22-37 dugongs.

Uit onderzoek is bekend dat dugongs foerageren op zeegrasvelden die gedomineerd worden door pioniersoorten zoals *Halodule uninervis* en *Halophila ovalis*. Tijdens het foerageren in deze velden trekken dugongs karakteristieke langwerpige 'voren' en consumeren zowel bovengrondse- (blad) als ondergrondse- (rhizomen en wortels) biomassa. Daarbij wordt ook melding gemaakt van het verschijnsel 'cultivation grazing', waarbij dugongs regelmatig terugkeren naar dezelfde graasplek. Dit verschijnsel zou volgens de meest recente literatuur vooral bij grote kuddes dugongs in de sub-tropen zijn waargenomen en een respons zijn op seizoensgebonden stress factoren, zoals een verlaagde voedingswaarde van het zeegras en een lage watertemperatuur in de winterperiode van sub-tropisch Australië.

In de huidige studie wordt de hypothese getoetst dat het verschijnsel van 'cultivation grazing' deel vormt van een voedselstrategie gericht op maximalisatie van 'energie' en 'verteerbaarheid' en dus niet een reactie vormt op seizoensgebonden stress factoren, waarbij 'cultivation grazing' ook bij kleinere kuddes dugongs in de tropen plaatsvindt.

Hoofdstuk 1 geeft een inleiding over de beschikbare wetenschappelijke literatuur betreffende de voedselecologie van de dugong.

In Hoofdstuk 2 worden de resultaten besproken van een voedselpreferentieproef met een dugong in de dierentuin van Surabaya. Een zogenaamd 'cafeteria experiment' gaf aan dat de dugong voorkeur had voor bepaalde zeegrassoorten. Ondanks het gegeven dat dit dier de afgelopen 19 jaar in gevangenschap permanent was gevoederd met *Syringodium isoetifolium*, resulteerde het experiment in een voorkeurreeks van *Halodule uninervis* > *Halophila ovalis* > *Cymodocea rotundata* > *Syringodium isoetifolium* > *Thalassia hemprichii*. Een correlatieanalyse tussen voedselpreferentie en verschillende zeegras variabelen gaf een significant positieve correlatie met *in vitro* verteerbaarheid en een significant negatieve correlatie met totaal calcium. De correlatie tussen voedselpreferentie en Neutral Detergent Fibre (NDF), totaal stikstof, totaal fosfor, totaal magnesium, totaal natrium en totaal kalium was daarentegen niet significant. Slechts de *in vitro* verteerbaarheid van *H. uninervis* (63%) en *H. ovalis* (50%) leek voldoende om het basale metabolisme van de zeekoe te onderhouden, bij andere zeegrassen leek de *in vitro* verteerbaarheid hiervoor onvoldoende.

In Hoofdstuk 3 worden een tweetal luchtopnames besproken die werden uitgevoerd met het doel een schatting te maken van de minimum populatie in het projectgebied. De luchtopnames werden uitgevoerd gedurende december 1990 en augustus 1992 en volgden eenzelfde traject langs de kustzone van de Lease eilanden. Het traject betrof een strip-transect met een totaal aantal van 3,5 observatie-uren. Gedurende de eerste luchtopname werden in totaal 17 dugongs, waaronder een kalf, waargenomen; gedurende de tweede opname werden in totaal 10 dugongs, maar geen kalveren geobserveerd. Op basis van deze gegevens werd een minimum populatie schatting gemaakt van 22-37 dugongs in het onderzoeksgebied. Ook werd geconcludeerd dat de populatie waarschijnlijk in contact staat met een grotere populatie bij het eiland Seram.

Veldwaarnemingen werden gedaan naar wilde dugongs in Saparua baai, levende dugongs in Indonesische dierentuinen en dode, gevangen dugongs in het onderzoeksgebied (Hoofdstuk 4). Dugongs bleken regelmatig te foerageren in een begrensde graasplek binnen een mono-specifiek *Halophila ovalis* veld. Bovendien werden data verzameld over de lengte en andere maten van levende en dode dugongs. Het onderzoek gaf ook een aanwijzing, dat volwassen vrouwelijke dugongs in de Indonesische Archipel tot een grotere lengte klasse behoren dan een vergelijkbare groep vrouwelijke dieren uit Australië.

Hoofdstuk 5 beschrijft de seizoensdynamiek gedurende een jaar van een door *Halodule uninervis* gedomineerd zeegrasveld in de getijdenzone voor wat betreft biomassa van boven- en ondergronds materiaal en totaal organisch koolstof (C). Boven- en ondergrondse biomassa vertoonden een significante stijging gedurende de overgang van de droge naar de natte tijd tussen februari en mei. De bovengrondse biomassa van *Halodule uninervis* nam significant af gedurende de natte tijd van mei tot augustus, in de periode dat extreem laagwater midden op de dag viel. De ondergrondse biomassa bleef hoog tot november, waardoor de ratio boven- tot ondergrondse biomassa gedurende mei tot augustus afnam, en waarbij gedurende augustus tot november sprake was van een spaarzame bovengrondse bedekking met een hoge ondergrondse biomassa. De gehaltes van totaal organisch C in de ondergrondse biomassa gaven een significante stijging gedurende mei tot augustus met een piek in augustus. Dugongs die foerageerden in het zeegrasveld consumeerden 93% van de bovengrondse en 75% van de ondergrondse biomassa van de bovenste 4 cm in het sediment. De biomassa in verse graassporen herstelde zich binnen vijf maanden in de regentijd. De maandelijkse foerageer frequentie (uitgedrukt als het aantal graassporen per maand), vertoonde een significante positieve correlatie met het totaal organisch C in de ondergrondse biomassa. Dit geeft een sterke aanwijzing, dat de voedselstrategie van dugongs in dit zeegrasveld gebaseerd is op een maximalisatie van energie.

Vier individuele dugongs werden gevolgd met behulp van satelliet en radio telemetrie (Hoofdstuk 6). De dugongs (drie volwassen vrouwtjes en een onvolwassen mannetje) werden gevangen bij Haruku met een ringnet en gevolgd gedurende 53 tot 285 dagen. Een volwassen vrouwtjesdier verbleef het merendeel van de tijd bij twee verschillende zeegrasvelden, op ongeveer 17 km afstand van elkaar. Zij maakte vijf oversteken tussen de twee zeegrasvelden. Twee andere vrouwtjes dugongs maakten uitstapjes naar Zuid Haruku, Saparua en Nusa Laut, maar keerden weer terug naar de vangstplaats bij Haruku. De jonge mannelijke dugong overbrugde in vier dagen tijd een afstand van 65 km naar het nabij gelegen Seram. De drie vrouwelijke dieren gebruikten 2-3 'kernlokaties', die 17 tot 47 km uit elkaar lagen. Dit patroon van het regelmatig opzoeken van 'kernlokaties' bevestigt de hypothese van 'cultivation grazing' door kleine groepen dugongs in ons onderzoeksgebied.

Hoofdstuk 7 beschrijft de maximale duurzame begrazingsdruk van dugongs in relatie tot de zeegras biomassa en 'standing crop'. Hiervoor werden zeegrasvelden in Haruku straat gekarteerd. De bedekkingsgraad van zeegrassoorten en de 'standing crop' per categorie bedekkingsgraad werden berekend op basis van random biomassa monsters. De totale 'standing crop' van zeegrasvelden die benut werden door dugongs werd berekend als 32.295 kg DW. De maximale duurzame begrazingsdruk van dugongs werd berekend met een computermodel als 9 graassporen per dag per 900 m^2 zeegrasveld. Op basis van dit model werd geconcludeerd dat maximaal 15 dugongs op een duurzame basis kunnen foerageren in Haruku straat, terwijl de totale maximaal duurzame populatie grootte voor het gehele onderzoeksgebied op 125 dugongs werd geschat. Op basis van deze onderzoeksgegevens werd geconcludeerd dat mortaliteit door 'vangst' de belangrijkste factor lijkt te zijn die de populatiegrootte beïnvloedt in het onderzoeksgebied, terwijl de verspreiding en kuddegrootte vooral worden bepaald door het patroon van 'cultivation grazing' door kleine groepen dugongs op vaste graasplekken.

Hoofdstuk 8 geeft een kwantitatieve analyse van het verschijnsel 'cultivation grazing' in het onderzoeksgebied. Onderzoek in twee door *Halodule uninervis* gedomineerde zeegrasvelden, in het littoraal en sublittoraal, bevestigde een patroon van regelmatig foerageren in begrensde graasplekken. De *in vitro* verteerbaarheid van zeegras binnen de graasplek bleek significant hoger dan buiten de graasplek, maar totaal stikstof vertoonde geen significant verschil.

In Hoofdstuk 9 worden de voorgaande hoofdstukken geanalyseerd en geïntegreerd en conclusies worden getrokken voor de bescherming en het beheer van dugong populaties in het projectgebied. Het huidige onderzoek bevestigt de hypothese, dat 'cultivation grazing' deel is van een voedselstrategie, gericht op maximalisatie van energie en verteerbaarheid als adaptatie aan zeegras als 'inferieure' voedselbron en ook wordt waargenomen bij kleinere kuddes in tropische gebieden. Die kuddes zijn meer foerageer-groepen met een los sociaal verband dan vaste kuddes met een sterke sociale binding.

De belangrijkste bedreigingen voor dugong populaties in het onderzoeksgebied zijn: (1) mortaliteit door visnetten (momenteel) en (2) vernietiging van dugong habitat (in de toekomst) door sedimentatie als gevolg van landbouw en mijnbouw. Het Regionale Plannings Bureau BAPPEDA en de Natuurbeschermingsdienst (PHPA) worden geadviseerd als onderdeel van een geïntegreerd plan voor het beheer van kustgebieden, een Actie Plan op te nemen voor de bescherming van zeekoeien. In dit Actie Plan worden de volgende thema's uitgewerkt: vervolg onderzoek naar dugongs en hun habitat, training en onderwijs, een programma voor de bewustmaking van lokale gemeenschappen, het instellen van beschermde gebieden voor dugongs, beperkingen voor het gebruik van kieuwnetten door vissers en de strikte toepassing van bestaande nationale en internationale wetgeving, vooral met betrekking tot de handel in dugongproducten. Het belang van de betrokkenheid van lokale dorpsgemeenschappen middels traditionele systemen van beheer (*sasi laut*) wordt benadrukt.

Ringkasan

Menurut IUCN Red Data Book (Buku Daftar Merah IUCN) duyung mempunyai status jenis yang terancam (IUCN 1988). Duyung-duyung juga menurut undang-undang Indonesia adalah dilindungi (Government Regulation No.5 1990). Di Indonesia adalah relatif sedikit diketahui tentang penyebaran dan perilaku dari duyung. Dari suatu jumlah sumber-sumber ilmiah yang terbatas ternyata bahwa duyung meliputi keseluruhan kepulauan Indonesia terdapat dalam penyebaran populasi-populasi kecil. Populasi-pupolasi duyung yang terkenal dari teluk Kupang (Timor), Karang Arakan (Sulawesi Utara), pulau-pulau Tobian Teluk Tomini (Sulawesi Tengah) dan Teluk-teluk serta selat-selat yang lain sekitar Sulawesi, Sumatra Barat, Kalimantan Selatan, dan pulau Bangka-Belitung (Selat-selat Karimata), Maluku dan Irian Jaya.

Sekitar tahun 1979 duyung-duyung masih berjumlah besar sekitar pulau-pulau Aru, salah satu dari daerah-daerah terakhir dengan suatu jumlah populasi besar duyung. Di Maluku hanya dari data-data kuantitatif pulau-pulau Aru diketahui tentang hasil-hasil tangkapan, penyebaran duyung.

Studi ini mencakup penelitian mendalam yang penting menurut ekologi dari duyung di Maluku dan di Indonesia secara keseluruhan. Penelitian telah dilaksanakan dalam rangka dari 'Dugong Conservation and Management Project' yang dibiayai oleh Uni Eropa, dilaksanakan dalam kerja sama dengan Institut Lingkungan Alam PSL dari Universitas Pattimura di Ambon dan Yayasan AID Environment di Amsterdam. Selama tahun 1990-1992 melalui alat-alat dari suatu penghitungan udara dengan suatu pesawat Cessna di daerah pantai dari Ambon dan pulau Lease (Haruku, Saparua dan Nusa Laut) diduga paling kurang antara 22-37 duyung.

Dari penelitian telah diketahui bahwa duyung-duyung mengambil bahan makanan pada padang-padang rumput laut yang hampir diliputi oleh jenis-jenis perintis seperti *Halodule Uninervis* dan *Halophila Ovalis*. Selama dalam mengambil bahan makanan pada padang-padang ini duyung-duyung menyerupai sifat khusus melintang panjang 'trails' dan mengambil pada kesempatan itu 'biomassa' baik daun lapisan bagian atas maupun lapisan bagian bawah (rhizomen dan akar-akar). Pada waktu itu juga dibuat laporan dari gejala-gejala yang terjadi 'cultivation grazing', dimana duyung-duyung secara teratur kembali ke tempat-tempat yang sama. Gejala ini menurut kebanyakan literatur yang terakhir terutama pada kawanan hewan besar duyung-duyung di subtropis yang diamati adalah merupakan suatu jawaban pada faktor-faktor tekanan keterikatan musim, seperti menurunnya kadar gizi dari rumput laut dan rendahnya temperatur air dalam periode dari sub tropis Australia.

Studi sampai saat ini dimana hipotesa diuji bahwa gejala dari 'cultivation grazing' sebagian membentuk dari suatu strategi makanan kearah pada maksimalisasi dari energi dan kemungkinan dicernakan. Jadi bukan suatu reaksi membentuk pada faktor-faktor tekanan keterikatan musim, dimana 'cultivation grazing' juga terjadi pada kawanan hewan kecil duyung-duyung di daerah-daerah panas.

Bab 1 memberikan kata pengantar tentang literatur ilmiah yang tersedia mengenai ekologi makanan dari duyung.

Dalam bab 2 dibicarakan mengenai hasil-hasil dari suatu percobaan pilihan utama makanan dengan satu duyung dalam kebun binatang di Surabaya. Yang disebut 'Cafetaria experiment' di laporkan bahwa duyung memberikan pilihan kepada jenis-jenis rumput-rumput laut tertentu. Kendati dengan kenyataan diatas ini bahwa duyung-duyung 19 tahun terakhir dalam kurungan tetap telah diberikan makanan dengan *Syringodium isoetifolium*. Dalam eksperimen menghasilkan dalam suatu urutan pengutamaan dari *Halodule uninervis* > *Halophila ovalis* > *Cymodocea rotundata* > *Syringodium isoetifolium* > *Thalassia hemprichii*. Garis regresi antara pilihan utama makanan sebagai variabel ketergantungan dan berbeda-beda variabel ketidak ketergantungan memberikan suatu arti positip hubungan dengan *in vitro* kemungkinan dicernakan dan suatu arti negatip hubungan dengan jumlah calcium. Korelasi antara pilihan utama makanan Neutral Detergent Fibre (NDF) jumlah zat lemas, jumlah pospor, jumlah magnesium, jumlah natrium dan jumlah kalcium adalah kebalikan, tidak memberikan arti. Hanya *in vitro* kemungkinan dicernakan dari *H. uninervis* (63%) dan *H. ovalis* (50%) rupanya memadai sebagai metabolisme dasar dari sapi laut untuk dipelihara. Dengan rumput laut lain rupanya *in vitro* kemungkinan dicernakan untuk ini tidak mencukupi.

Dalam bab 3 dibicarakan dua pemotretan dari udara yang telah dilaksanakan dengan tujuan membuat penaksiran dari populasi minimum dalam daerah proyek. Pemotretan dari udara ini telah dilaksanakan selama desember 1990 dan agustus 1992 dan diikuti dengan perjalanan yang sama melalui daerah pantai dari pulau-pulau Lease. Perjalanan ini bertalian dengan suatu 'strip-transect' dengan jumlah sebanyak 3,5 jam pengamatan. Selama pemotretan udara pertama telah diamati sebanyak 17 duyung, diantaranya diamati seekor anak duyung yang masih muda. Selama pemotretan udara yang ke dua diamati sebanyak 10 dogong, tetapi tidak diadakan pengamatan pada anak-anak duyung yang muda. Didasari dari data-data ini telah dibuat suatu penaksiran populasi minimum dari 22-37 duyung di daerah penelitian. Juga telah diambil kesimpulan bahwa populasi sangat mungkin mempunyai hubungan dengan populasi yang besar dekat pulau Seram.

Pengamatan-pengamatan lapangan telah diadakan tentang duyung-duyung liar di teluk Saparua, duyung-duyung yang masih hidup di kebun-kebun binatang Indonesia dan duyung-duyung yang mati, duyung-duyung yang ditangkap dalam daerah penelitian (Bab 4). Duyung-duyung ternyata secara teratur mengambil bahan makanan dalam suatu tempat rumput yang dibatasi dalam suatu mono khusus padang *Halophila ovalis*. Tambahan pula data dikumpulkan tentang panjang dan ukuran-ukuran lain dari duyung-duyung yang hidup maupun yang mati. Keterangan-keterangan memberikan juga petunjuk bahwa duyung-duyung betina dewasa dalam daerah penelitian kami termasuk pada golongan panjang, kemudian kelompok hewan betina dapat dibandingkan dari Australia.

Bab 5 menggambarkan situasi dinamik musim selama satu tahun dari satu yang didominasi oleh padang *Halodule uninervis* dalam zona pasang naik dan surut yang menyangkut 'biomassa' dari bagian atas dan bawah tanah dan jumlah organis zat arang (C). Bagian atas dan bawah 'biomassa' menampakkan kenaikan arti selama peralihan musim kering ke musim hujan antara Februari dan Mei. 'Biomassa' bagian bawah tanah dari *Halodule uninervis* berkurang arti selama musim hujan dari Mei sampai Agustus, dalam lingkaran waktu dimana permukaan air surut sangat ekstrim yang terjadi pada tengah hari. 'Biomassa' bagian bawah tanah berada tetap tinggi sampai November, oleh karenanya kenapa bagian atas dan bawah 'biomassa' berkurang selama bulan Mei sampai Agustus, pada mana selama Agustus sampai November terjadi penghematan 'biomassa' penudungan bagian atas tanah dengan 'biomassa' bagian bawah tanah yang tinggi. Kadar-kadar dari jumlah organis C dalam 'biomassa' bagian bawah tanah memberikan kenaikan arti selama bulan Mei sampai Agustus dengan puncak dalam bulan Agustus. Duyung-duyung yang mengambil makanan di padang-padang rumput laut menikmati 93% dari bagian atas dan 75% dari bagian bawah tanah dari 4 centimeter paling atas dari endapan. 'Biomassa' dalam jejak-jejak rumput yang segar kembali kepada keadaan semula dalam waktu lima bulan dalam musim hujan. Frekuensi pengambilan bahan makanan tiap-tiap bulan (dinyatakan dalam jumlah jejak-jejak rumput per bulan) menampakkan suatu arti positip berhubungan dengan jumlah organis C dalam 'biomassa' bagian bawah tanah. Dengan ini memberikan petunjuk kuat bahwa strategi makanan dari duyung-duyung di padang rumput laut didasari kelihatannya pada suatu strategi dari energi sebanyak mungkin.

Empat ekor duyung telah diikuti dengan bantuan dari satelit dan radio pengukur jarak jauh (Bab 6). Duyung-duyung (tiga betina dewasa dan satu jantan belum dewasa) telah ditangkap dekat Haruku dengan suatu jala lingkar dan diikuti selama 53 sampai 285 hari. Satu betina binatang dewasa bertempat tinggal hampir waktu terbanyak dekat dua padang rumput laut yang berbeda, pada hampir jarak 17 km satu dengan yang lain. Duyung betina ini menyeberang lima kali antara dua padang-padang rumput laut ini. Dua duyung betina membuat perjalanan-perjalanan ke Haruku Selatan, Saparua dan Nusa Laut, tetapi kembali lagi ke tempat semula ditangkap dekat Haruku. Duyung jantan yang muda menyeberang jarak 65 km kearah terletak dekat Seram dalam waktu empat hari. Tiga binatang betina menggunakan 2-3 tempat pusat yang berada 17 sampai 47 km satu dengan yang lain. Pola dari secara teratur hingga menemukan tempat pusat ini, menguatkan hipotesa dari 'cultivation grazing' oleh kelompok-kelompok kecil duyung-duyung dalam penelitian kami.

Bab 7 menggambarkan tekanan pemberian makanan yang lama maksimal dari duyung dalam hubungan dengan 'biomassa' rumput laut dan 'standing crop'. Untuk ini padang-padang rumput laut di selat Haruku telah dipetakan. Tingkatan lindungan dari jenis-jenis rumput laut dan 'standing crop' tiap kategori dari tingkat lindungan dihitung dengan dasar sekitar monster-monster 'biomassa'. Keseluruhan 'standing crop' dari padang-padang rumput laut yang dimanfaatkan oleh duyung-duyung telah dihitung sebagai 32.295 kg DW. Tekanan pemberian makanan yang lama yang maksimal dari duyung-duyung telah dihitung dengan suatu contoh dari komputer sebagai 9 jejak-jejak rumput tiap-tiap hari dari tiap 900 m 2 padang rumput laut. Didasari dari contoh ini telah ditarik kesimpulan bahwa paling banyak 15 duyung untuk waktu lama dapat mengambil bahan makanan di selat Haruku, sedang untuk keseluruhan daerah penelitian ditaksir jumlah populasi untuk waktu lama paling banyak untuk 125 duyung. Didasari dari data-data penelitian ini telah ditarik kesimpulan bahwa angka kematian karena penangkapan, faktor yang sangat penting nampaknya yang mempengaruhi besarnya populasi di daerah penelitian. Sedang penyebaran dan besarnya kawanan binatang terutama ditentukan oleh pola 'cultivation grazing', oleh kelompok kecil duyung pada tempat-tempat rumput yang tetap.

Bab delapan memberikan suatu analysa kuantitatif dari gejala-gejala 'cultivation grazing' dalam daerah penelitian. Penelitian dalam dua padang rumput yang dikuasai oleh *Halodule uninervis*, dalam daerah pantai dan subdaerah pantai menguatkan pola dari secara teratur mengambil makanen dalam tempat rumput yang terbatas. *In vitro* kemunginan dicernakan, dari rumput laut dalam tempat rumput ternyata punya arti yang lebih tinggi dari di luar tempat luar, tetapi jumlah zat lemas menunjukkan tidak ada arti perbedaan.

Dalam bab 9, berdasar dari bab-bab yang terdahulu telah diadakan analisa, pemaduan, ditarik kesimpulan untuk melindungi dan mengatur populasi-populasi duyung-duyung dalam daerah penelitian. Penelitian sekarang ini menguatkan hipotesa bahwa 'cultivation grazing' adalah merupakan bagian dari suatu strategi makanan, yang diarahkan pada yang maksimal dari energi dan kemungkinan dicernakan sebagai adaptasi pada rumput laut yang merupakan sumber makanan yang inferior dan juga telah diamati kawanan-kawanan binatang kecil di daerah tropis. Kawanan-kawanan binatang ini lebih merupakan kelompok-kelompok mengambil bahan makanan dengan hubungan sosial yang lepas daripada kawanan binatang yang tetap dengan hubungan sosial yang kuat.

Ancaman-ancaman yang terpenting untuk populasi duyung dalam daerah penelitian yakni: (1) kematian oleh jala-jala ikan (seketika) (2) kebinasaan habitat (untuk masa depan) dari duyung karena sedimentasi sebagai akibat dari pertanian dan penggalian bahan tambang. Badan Perancang Pembangunan Daerah (BAPPEDA) dan Badan Perlindungan Alam (PHPA) telah diberikan nasehat sebagai rencana terpadu untuk pemeliharaan dan pengawasan daerah-daerah pantai, suatu Rencana Aktivitas (Aktie Plan) diangkat untuk melindungi sapi-sapi laut. Dalam Rencana-rencana Aktivitas ini diperincih lagi dalam tema-tema berikut ini: kelanjutan penelitian duyung-duyung dan habitat mereka, latihan dan pengajaran, program untuk kesadaran dari masyarakat-masyarakat setempat, mendirikan daerah-daerah terlindung untuk duyung-duyung, pembatasan-pembatasan untuk menggunakan jala angsang oleh nelayan-nelayan dan dengan cermat pemraktekan dari Undang-Undang Nasional dan Internasional yang berlaku terutama yang berhubungan dengan penjualan hasil-hasil duyung-duyung. Demi kepentingan masyarakat-masyarakat setempat yang terlibat dimana cara-cara dari sistem-sistem tradisi dari pengawasan dan pemeliharaan (sasi laut) diberikan banyak penekanan.

Curriculum Vitae

Hans de Iongh was born on 11 May 1951 in The Hague. He attended the Christian HBS (highschool) at Waalwijk during 1962-1969 and started in 1969 with a study Environmental Science at the Agricultural University in Wageningen, completing his MSc with as major subjects Nature Conservation, Environmental Toxicology, Hydrobiology and Fishery and Aquaculture. During 1976 and 1979 he was assigned by the Technical University Eindhoven as extension specialist at a project for the development and diffusion of appropriate technology in West Java, Indonesia. In 1980 he accepted an assignment as associate expert (biologist) in the FAO artisanal fishery project at Lake Kivu, Rwanda, executing a research programme on the freshwater clupeid *Limnothrissa miodon*. After his return to the Netherlands in 1981 and a short intermediary assignment at the Organisation for Inland Fisheries, he joined Haskoning Consultancy B.V. as an ecologist. During 8 years of assignment with Haskoning he gained experience in both project management and consultancy on environmental issues in the Netherlands and abroad. In 1990 he was a senior environmental advisor to the Minister for Development Cooperation and in 1991 he joined his present employer The Centre for Environmental Science of Leiden University. He has been an active participant of the environmental NGO community as a chairman of the IUCN National Committee and as a member of various environmental associations and working groups.

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