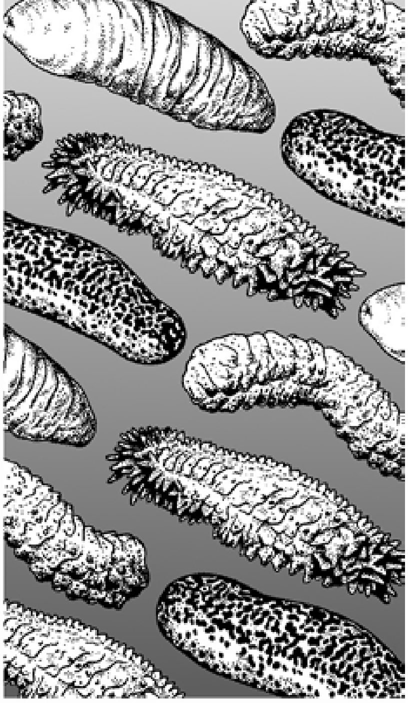

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Inside this issue

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Editorial

This issue of the SPC *Beche-de-mer Information Bulletin* contains 11 papers on sea cucumber research, aquaculture, and stock status. The breadth and depth of the research presented demonstrates the high level of interest on the part of the scientific community in sea cucumbers.

The first paper is from the Darwin Aquaculture Centre. Michelle Simoes and Jens Knauer report on experiments using the fluorochrome OTC to mark dermal spicules of juvenile *Holothuria scabra*.

The second paper is by Fatemah Ghobadyan and colleagues (p. 6), who investigated the macroscopic and microscopic characteristics of gonadal tubules in *Holothuria leucospilota* off the coast of Iran in the Persian Gulf.

Mélanie Demeuldre and Igor Eeckhaut (p. 15) analysed gonadal development in various sizes of *Holothuria scabra* from Madagascar. The authors show that germinal cells are only distinguishable from somatic cells when sea cucumbers are 10 cm long.

Andrew Morgan (p. 24) presents a growth model to estimate size-at-age for the temperate sea cucumber *Australostichopus mollis.*

Kun Xing and colleagues (p. 33) give information about the cage culture of *Apostichopus japonicus* that were transplanted from northern China to the Shengsi Islands in southern China. The co-culture of sea cucumbers with abalone shows great potential for aquaculture.

Hampus Eriksson and colleagues (p. 39) investigated how the size of *Stichopus chloronotus* differs between a back-reef seagrass area and the proximal hard benthic reef flat at a site in Mayotte, and analysed habitat utilization in relation to size (as a proxy for age).

Poh Sze Choo (p. 43) describes the sea cucumber fishery in Semporna, Malaysia and examines the size and sustainability of the fishery. Semporna's sea cucumber fishery appears to be heavily fished and there are no regulations to control the overfishing of sea cucumbers.

Abdul-Reza Dabbagh and Mohammad Reza Sedaghat (p. 49) describe spawning inductions of *Holothuria scabra* that were achieved for the first time in Iran in September 2011. The authors reared individuals and obtained one-year-old juveniles that averaged 22 g in weight.

Mohamed Hamza Hasan and colleagues (p. 53) surveyed sea cucumber populations in the Gulf of Aqaba (Egypt, Red Sea) 10 years after fishing activity ceased, and compared their data with findings from previous samplings carried out in the same area in 1995, 2002 and 2003.

Majid Afkhami and colleagues (p. 60) provide data about sea cucumber fishing methods, processing and distribution at Qeshm Island in the Persian Gulf. The authors determined that sea cucumber stocks at Qeshm Island are actually healthy but advocate that the ban on harvesting them should continue.

Jeff Kinch (p. 62) briefly reports on his observation of juvenile *Stichopus vastus* in Pohnpei Lagoon, Federated States of Micronesia.

Congratulations are due to Shamari Dissanayake who recently completed her PhD dissertation on sea cucumber management. We also wish a happy retirement to Prof Michel Jangoux, who is known worldwide as a brilliant expert in echinoderm biology. A list of his publications on holothurians is presented in this issue (p. 74).

Igor Eeckhaut

PIMRIS is a joint project of five international organisations concerned with fisheries and marine resource development in the Pacific Islands region. The project is executed by the Secretariat of the Pacific Community (SPC), the Pacific Islands Forum Fisheries Agency (FFA), the University of the South Pacific (USP) and the Pacific Regional Environment Programme (SPREP). This bulletin is produced by SPC as part of its commitment to PIMRIS. The aim of PIMRIS is to improve the availability of information on marine resources to users in the region, so as to support their rational development and management. PIMRIS activities include: the active collection, cataloguing and archiving of technical documents, especially ephemera ('grey literature'); evaluation, repackaging and dissemination of information; provision of literature searches, question-and-answer services and bibliographic support; and assistance with the development of in-country reference collections and databases on marine resources.

PIMRIS
Pacific Islands Marine Resources Information System

Marking juvenile sandfish, *Holothuria scabra*, with the fluorochrome oxytetracycline – a preliminary report

Michelle Simoes[1] and Jens Knauer[1]*

Abstract

We conducted a preliminary experiment using the fluorochrome oxytetracycline (OTC) to mark the dermal spicules of juvenile *Holothuria scabra*. The marking efficiency of OTC in this preliminary experiment was much lower than tetracycline (TC) and calcein after 1, 6 and 24 h at the same water temperature (28°C), fluorochrome concentration, and duration of immersion. The highest marking efficiency achieved with OTC (18%) was similar to the 15% marking efficiency achieved with TC after 1 h, and made up only 62% of the 29% marking efficiency found with calcein after 1 h. Moreover, after 24 h, TC was found to have marked 28% of dermal spicules and calcein 39%. Although all treatment groups in this preliminary experiment suffered significant weight loss, none of the treatments resulted in mortalities. Preliminary results indicate that while OTC may be less toxic, it is not as effective as TC and calcein in marking the dermal spicules of juvenile *H. scabra.*

Introduction

Marking the dermal spicules of juvenile sandfish (*Holothuria scabra*) has proven to be a suitable technique to distinguish between hatchery-reared juveniles and natural populations. This is particularly important when evaluating the efficiencies of restocking and sea ranching programmes (Purcell et al. 2006; Purcell and Simutoga 2008; Purcell and Blockmans 2009). The preferred method for marking juveniles is immersion marking, where the fluorochrome is added to a bath solution at the desired concentration. Immersing juvenile *H. scabra* in either the fluorochrome tetracycline (TC) or calcein at a concentration of 100 mg L^{-1} for 24 h at ≥26ºC was found to be the most practical compromise in terms of marking efficiency and survival of *H. scabra* (Purcell and Blockmans 2009). An alternative TC, oxytetracycline hydrochloride (OTC), has been successfully used to mark juvenile fish (Secor et al. 1991; Kayle 1992; Brooks et al. 1994; Bumguardner and King 1996; Jenkins et al. 2002; Butcher et al. 2003; Taylor et al. 2005; Hutchings and Griffiths 2010) and abalone (Day et al. 1995). However, the effectiveness of OTC as a marker for juvenile *H. scabra* has not yet been examined.

We report on a preliminary experiment using the fluorochrome OTC to mark dermal spicules of juvenile *H. scabra*. In particular, we focused on the effect of immersion time in OTC on marking efficiency. We specifically only manipulated this one factor, immersion time, in order to avoid time-consuming manipulation of other factors such as temperature and salinity.

Method and results

Juvenile *H. scabra* were spawned at the Darwin Aquaculture Centre in September 2010 using broodstock owned by Tasmanian Seafoods P/L, following the methods of Agudo (2006). In total, 36 juveniles (weight range 1.5–3.0 g) were randomly selected and transferred to a 600-L pre-conditioning tank. All juveniles were held in the tank for a period of eight days and every second day *Spirulina* sp. (Australian Spirulina,® TAAU Australia P/L, Darwin, Australia) was added at the rate of 5% of the total biomass of *H. scabra.* One day prior to the immersion treatment, no feed was added and the health of all juveniles was inspected according to Purcell and Eeckhaut (2005).

Each of the 36 juveniles was weighed and 3 were randomly placed into each of the 12 containers filled with 1μm-filtered seawater (34 ppt, 28.0–28.5ºC). OTC was added to each container to arrive at a final concentration of 100 mg L^{-1} (Purcell and Blockmans 2009). Groups of three containers were placed in one of four, aerated, polystyrene boxes and left undisturbed for the duration of the respective immersion period (1, 6, 24, 48 h). Each polystyrene box was specific to one immersion period. After the immersion treatment was completed, 3

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juvenile *H. scabra* from each container were placed in one of 12 labelled baskets in the 600-L tank. These individuals remained in the tank for a rest period of 14 days, during which the health of the juveniles was observed daily, *Spirulina* sp. added every second day, and faeces siphoned out twice daily.

Dermal spicule collection and processing followed the methods of Purcell and Blockmans (2009). Following that, spicules were viewed under a Leica DM 4000 Epifluorescence microscope and two sets of photos (using a Leica DFC 320 camera) were taken for each slide. Each set consisted of one photo with fluorescent light and one with natural light. The percentage of marked spicules was then calculated by dividing the number of marked spicules in the fluorescent light picture with those in the natural light picture. The number of spicules counted per photo varied from 10 to 167.

Weight data for juvenile *H. scabra* weighed just prior to immersion and after the 14-day resting period are shown in Table 1. Differences in initial weight of juveniles in all treatment groups were not significant. However, the difference between initial and final weight of juveniles within a treatment was significant for all exposure times. Weight loss ranged from 0.60 ± 0.05 g in juveniles immersed for 6 h, to 0.73 ± 0.15 g in juveniles immersed for 24 h. There was no significant difference in weight loss among treatment groups, and no mortalities were recorded during the duration of the experiment. The observed weight loss may have been caused by subtle, toxic effects of OTC and / or handling stress, which will be examined in future studies.

Juvenile *H. scabra* immersed in 100 mg L^{-1} OTC for 24 h had a significantly higher percentage of marked spicules (18.0 ± 2.2%) compared with other treatments (Fig. 1). Hence, percentage marking with OTC increased with time up to 24 h as was shown for TC and calcein (Purcell and Blockmans 2009). Immersing juvenile *H. scabra* in OTC for 48 h resulted in a significantly lower percent marking as compared with 24 h (Fig. 1). Although all treatment groups suffered a significant loss of weight after the 14-day resting period (Table 1), percentage marking was only affected after 24 h. In contrast, immersion in 100 mg L^{-1} TC or calcein had no effect on the growth of juvenile *H. scabra* as compared with an unmarked control group (Purcell and Blockmans 2009). However, while none of the 36 juveniles used in the present study died, immersion in either TC or calcein (concentrations not stated) resulted in the death of 6 (from TC) and 1 (calcein) juveniles out of 108 (Purcell and Blockmans 2009). Percentage marking in *H. scabra* immersed in OTC for 1 h was significantly lower than in all other treatments (2.3 ± 0.4%). There was no significant difference between percentage marking in juveniles immersed for either 6 h (10.3 ± 1.4%) or 48 h (12.5 ± 3.2%).

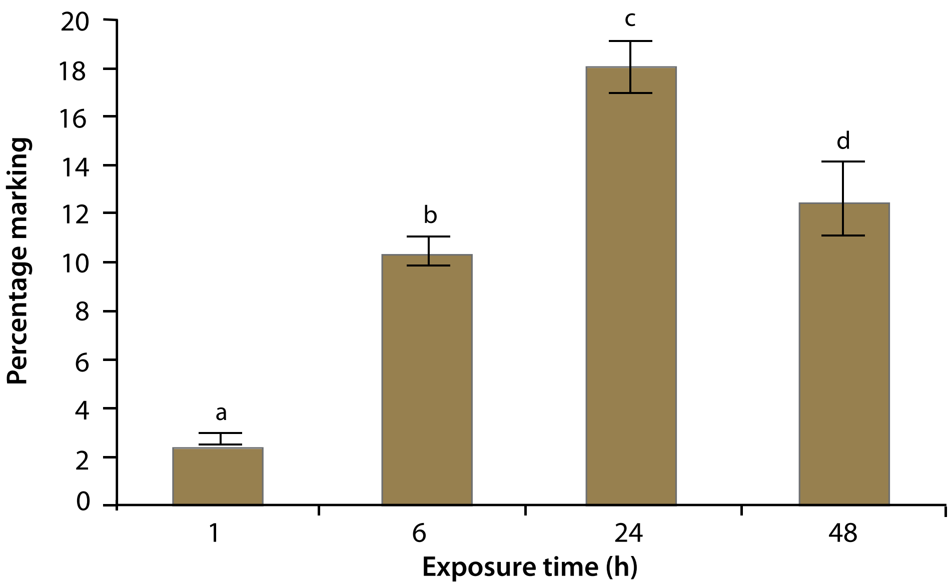

Figure 1. Percentage marking of spicules of juvenile *Holothuria scabra* immersed in the fluorochrome oxytetracycline for up to 48 h. Values are the mean ± SE (n = 3). Significant differences are indicated by different letters ($p \leq 0.05$).

Table 1. Initial and final weights of juvenile sandfish, *Holothuria scabra*, marked with the fluorochrome oxytetracycline for up to 48 h. Values are the mean ± SE (n = 3). Significant differences within rows are shown by * ($p \leq 0.05$).

Exposure time (h)	Initial weight (g)	Final weight (g)
1	2.30 ± 0.06	1.63 ± 0.14*
6	2.23 ± 0.09	1.61 ± 0.03*
24	2.23 ± 0.03	1.53 ± 0.14*
48	2.00 ± 0.10	1.36 ± 0.07*

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An investigation of the macroscopic and microscopic characteristics of gonadal tubules in the sea cucumber *Holothuria leucospilota* (Persian Gulf, Iran)

Fatemah Ghobadyan,[1] Hossein Morovvati,[2] Leila Ghazvineh,[1] Ehsan Tavassolpour[1]*

Abstract

In this study, we present data obtained from monthly samplings of *Holothuria leucospilota* done between July 2007 and June 2008 (except December and January) along Iran's Bustaneh Coast in the Persian Gulf. In total, 124 females and 108 males were collected. Macroscopic and microscopic features of the gonads were used as the main criteria for determining maturity stages. Observed macroscopic features included gonad colour, weight, length, diameter and number of tubules, while microscopic examinations consisted of histological studies of stained slides with haemotoxylin and eosin. Based on these studies, five stages of maturity were determined for both sexes: early growth (I), growth (II), advanced growth (III), mature (IV) and post-spawning (V). The tubules were found to be much longer and narrower in males than in females. Gonadal tubules developed from stage I to stage IV, declining in stage V. The possible relationship between tubule numbers and gonad weight was evaluated, and was found to be 0.73 for males and 0.80 for females.

Introduction

Holothuroidea (sea cucumbers) is a diverse class of worm-like and usually soft-bodied echinoderms. They are found in nearly every marine environment, but are particularly diverse in tropical shallow-water coral reef ecosystems. They range from the intertidal, where they may be exposed briefly at low tide, to the floor of the deepest oceanic trenches. Sea cucumbers are a group of marine invertebrates that are harvested worldwide, mostly for human consumption in Asian countries. Over the past several decades, a significant increase in the demand for sea cucumbers has led to an explosion in exploitation, which often results in population declines in many producing nations. Because of their critical importance as a source of livelihood for many artisanal fishers from developing countries, and as a globally traded product, there is considerable interest in the biology, ecology and fisheries management of sea cucumbers (Conand and Muthiga 2007). There have been few ecological studies conducted on sea cucumbers in the Persian Gulf. The importance of detailed studies on holothuroids is necessary due to their key role in the conservation of the marine environment. They are essential economically and used as food, are important members of benthic communities, and are responsible for causing significant changes in the composition of the sea floor. They also have medical significance such as treating weakness, impotence, senility, constipation due to intestinal dryness, and frequent urination. The worldwide decline of wild stocks of sea cucumbers has generated a great deal of interest in their reproduction and biology. Such information could lead to the development of better management programmes as well as aquaculture of this valuable resource.

The goals of the present study are to describe the macroscopic and microscopic characteristics of gonadal tubules and determine the gonadal development stages in *H. leucospilota* on the Bustaneh coast of Iran's Hormozgan Province in the Persian Gulf.

Materials and methods

Sea cucumbers were collected from the intertidal area at Bustaneh in the Persian Gulf of Iran (26°31'N and 54°39'E) (Fig. 1). From July 2007 to June 2008, 25–30 animals were collected each month. Sex was determined by dissecting the animals. Male tubules were always creamy white in colour. Female tubules were more transparent, with the interior having a granulated appearance. Female tubules became reddish-orange with the development of fecund ovaries. The gonads were preserved in buffered formalin (10% dilution). In a holothurian population

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with simultaneous gonadal development, spent tubules are absorbed after the reproductive season; therefore, gonads may not be visible for a certain period (Purwati and Luong-van 2003).

Identification of maturity stages in this study was done using several methods. Macroscopic features were assessed and then a microscopic observation of a fragment of gonad was made (Conand 1981). We then confirmed our results with histological examinations. The macroscopic and microscopic features were used to assess maturity stages of gonads, as described by previous studies (Drumm and Lonergan 2005; Ong-Che 1990; Purwati and Luong-van 2003). Gonadal macroscopic features, including gonad colour, total number of tubules in a gonad, length of tubules,[3] diameter of tubules,[4] and presence of gametes in squash preparations were studied. The amounts of all these features depend on the stage of maturity. The relationship between gonad weight and the number of tubules was calculated for both sexes. The microscopic study consisted of histological examinations. A subsample of 10 animals (representing the available size range) was taken from each monthly sample for histology. Small sections of gonad tubules were dehydrated, embedded in paraffin, sectioned (5-μm thick) and stained with haemotoxylin and eosin (H/E). The histological stages of gametogenesis were based on those used in previous studies of sea cucumber gonads (Drumm and Lonergan 2005; Purwati and Luong-van 2003; Rasolofonirina et al 2005; Shiell and Uthicke 2006). Based on these criteria, a five-stage maturity scale was determined: early growth (Stage I), growth (Stage II); advanced growth (Stage III); mature (Stage: IV); and post-spawning (Stage: V). Each gonad was examined and assigned in order to determine its sexual stage. These five maturity stages were verified by histological examination and macroscopic features.

Results

Sexes were separate in *Holothuria leucospilota* but there was no sexual dimorphism. Therefore, it was not possible to differentiate males from females externally. The gonads of females and males are different colours so could be sexed by dissection. The gonad was a single tuft in *H. leucospilota* and consisted of tubules hanging freely in the coelom from a transparent, saddle-like gonadal base located at the side of the anterior part of the intestine. Each tubule formed two or more branches. When mature (Stage IV), female tubules were pink to reddish-orange, and the oocytes were visible as small as white spots in the fecund ovary. After spawning (Stage V), the tubules deteriorated and turned brown; unspawned gametes were likely reabsorbed. Male gonadal tubules in advanced stages of maturity were long and creamy-white to beige in colour. The length, diameter, colour and number of tubules in both sexes were related to the stages of development.

Figure 1. Study site: Bustaneh, Persian Gulf, Iran

[3] This was done by measuring the lengths of 20% of the total number of tubules for each gonad, to the nearest 0.02 mm measured from tip to end by means of colis in order to determine the average length of gonad).

[4] This was done by measuring the diameter of 20% of the total number of tubules for each gonad, by means of an ocular micrometer, in order to determine the average diameter of gonad).

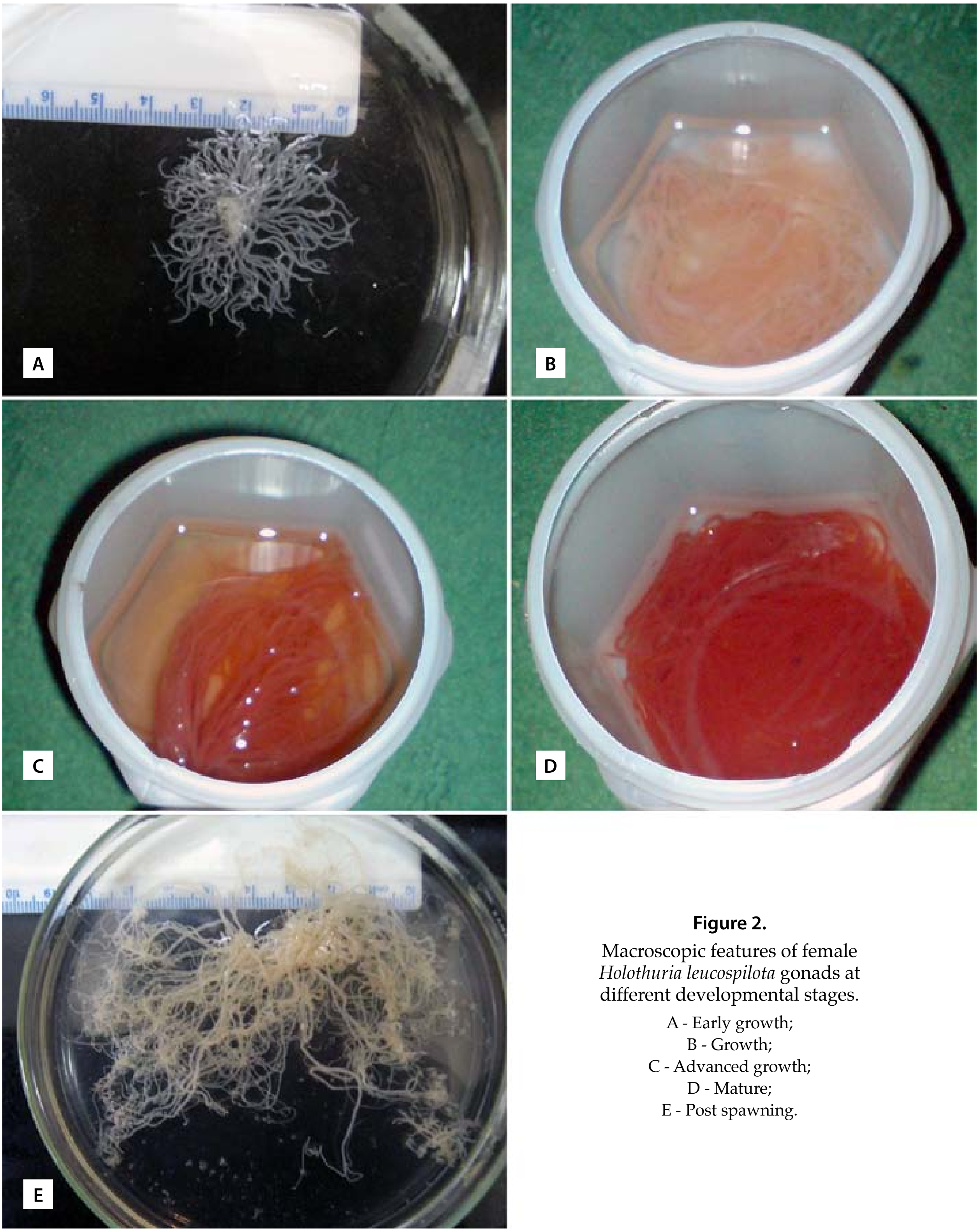

Figure 2.

Macroscopic features of female *Holothuria leucospilota* gonads at different developmental stages.

A - Early growth;
B - Growth;
C - Advanced growth;
D - Mature;
E - Post spawning.

Macroscopic features of gonadal maturity stages

Stage I – Early growth

Gonads at this stage could not be sexed by microscopic examination. And sex could only be identified by histological examination. The tubules in both sexes were thin, white to transparent, slightly branched, and were small and numerous (Fig. 2A, 3A).

Stage II – Growth

The tubules' dimensions, numbers and branches increased in both sexes. Female gonads were white to very light-pink. Sex could be determined microscopically by the presence of developing oocytes (Fig. 2B) and male gonads were pale-white (Fig. 3B).

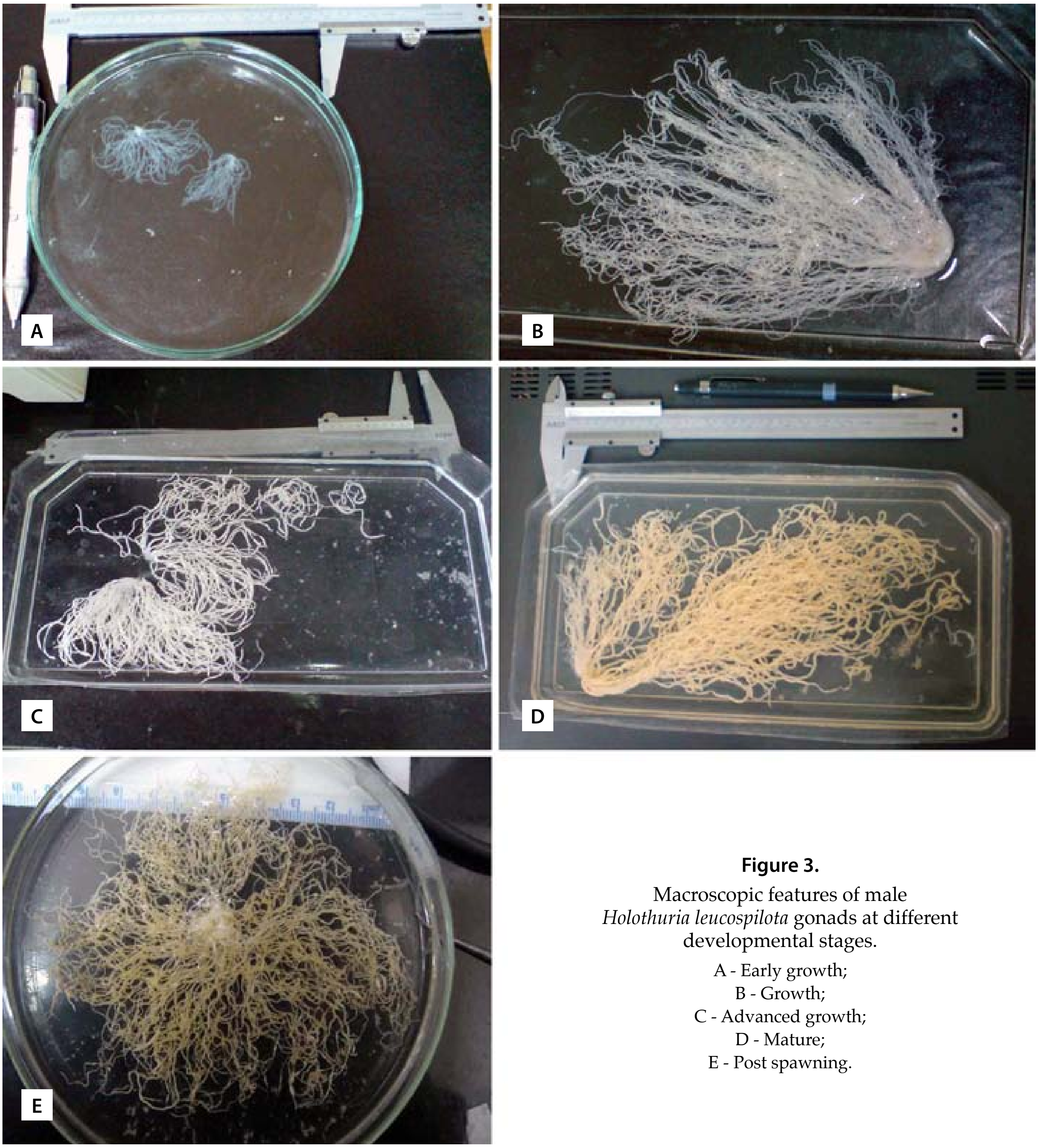

Figure 3.

Macroscopic features of male *Holothuria leucospilota* gonads at different developmental stages.

A - Early growth;
B - Growth;
C - Advanced growth;
D - Mature;
E - Post spawning.

Stage III – Advanced growth

Tubules were longer, thicker, more branched and more numerous in both sexes. Female gonads were dark pink (Fig. 2C) and male gonads were a slightly dark-cream colour (Fig. 3C).

Stage IV – Mature

Tubules were bulging, long and thick in both sexes. Female gonads changed colour from pink to red-orange (Fig. 2D) and male gonads turned to beige (Fig. 3D).

Stage V – Post-spawning

After spawning, the tubules in both sexes deteriorated and turned brown (Fig. 2E, 3E). Tubules were flaccid and more or less empty, but some parts of the tubule volume were still occupied by undischarged gametes. Undischarged oocytes at various stages of deterioration were noted in females and were likely reabsorbed.

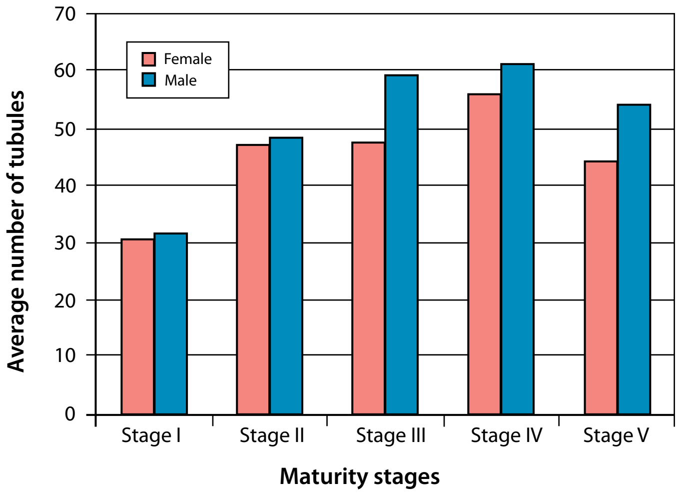

Figure 4. Average number of tubules at different stages of maturity for female and male *Holothuria leucospilota*.

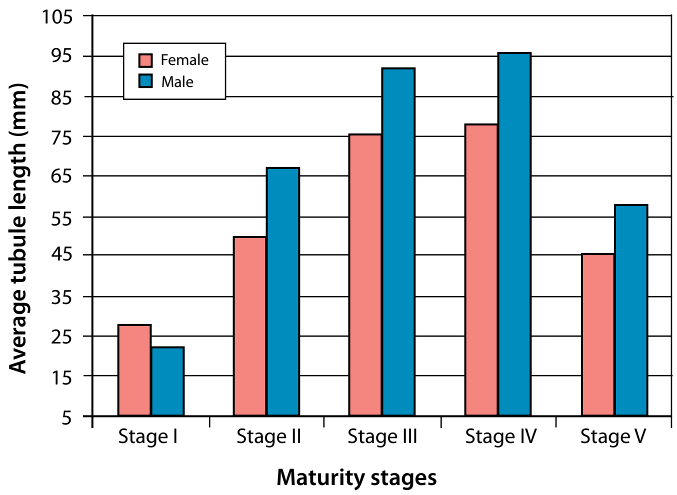

Figure 5. Average tubule length at different stages of maturity for female and male *Holothuria leucospilota*.

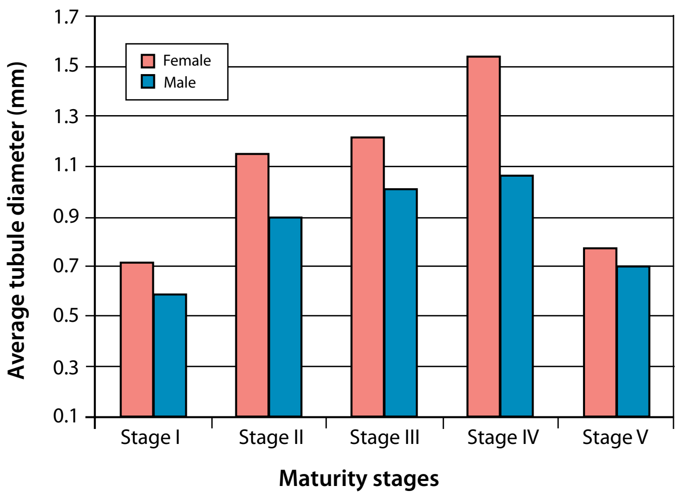

Figure 6. Average tubule diameter at different stages of maturity for female and male *Holothuria leucospilota*.

Biometry

Variations in gonad biometrical parameters, including number, length and diameter of tubules in different stages of maturity, are presented in Figures 4, 5 and 6 for both sexes. Biometrical parameters clearly show the increasing number of tubules per individual with developing maturity. The value of tubules' length and number were greater in males but the diameter was higher in females than males (t-test, $p > 0.05$).

The relationship between gonad weight ($GW_{(f=female)}$, $GW_{(m=male)}$) and number of tubules ($y_{(f)}$, $y_{(m)}$) gives a high correlation coefficient (R^2) for both sexes and is expressed by the following equations (Table 1).

Table 1. Relationship between gonad weight (GW) and number of tubules (y)

Female	Male
$y_{(f)} = 34.081\ GW^{0.2121}_{(f)}$	$y_{(m)} = 37.045\ GW^{0.2467}_{(m)}$
$R^2 = 0.803$	$R^2 = 0.737$

Microscopic features of female gonad maturity stages

Stage I – Early growth

The tubule lumen area was empty of gametic cells, and some pre-vitellogenic oocytes lined the germinal epithelium of the ovary (Fig. 7A).

Stage II – Growth

Active vitellogenesis, with oocytes growing from early to later stages of vitellogenesis, was observed. Many small oocytes and pre-vitellogenic oocytes along germinal epithelium were observed (Fig. 7B).

Stage III – Advanced growth

Small oocytes were observed along the germinal epithelium and lumen, mostly occupied by large mature oocytes (Fig. 7C).

Stage IV – Mature

Lumen were packed with mature oocytes and no small oocytes were present along the germinal epithelium. Each oocyte has a well determined germinal vesicle (Fig. 7D).

Stage V – Post-spawnimg

Residual oocytes at various stages of deterioration were observed in lumen. Some nutritive phagocytes begin to appear. Elongated empty areas were seen in tubules, suggesting the passage of oocytes along the tubule during spawning (Fig. 7E).

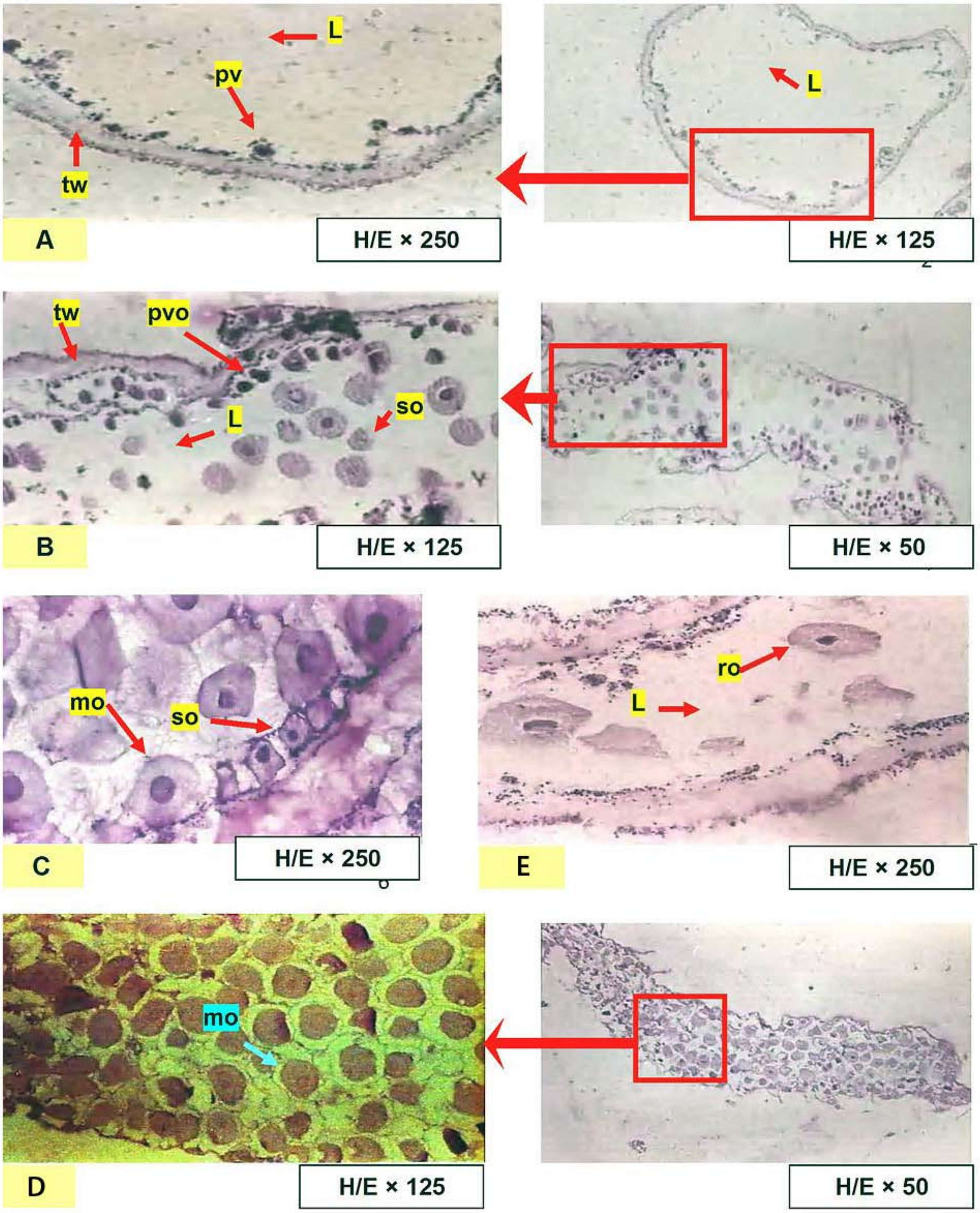

Figure 7.

Microscopic features of female *Holothuria leucospilota* gonads at different developmental stages.
L: lumen area; **mo:** mature oocyte; **pvo:** previtelogenic oocyt; **ro:** residual oocyte; **so:** small oocyte; **tw:** tubule wall.
A - early growth; B - growth; C - advanced growth; D - mature; E – post-spawning.

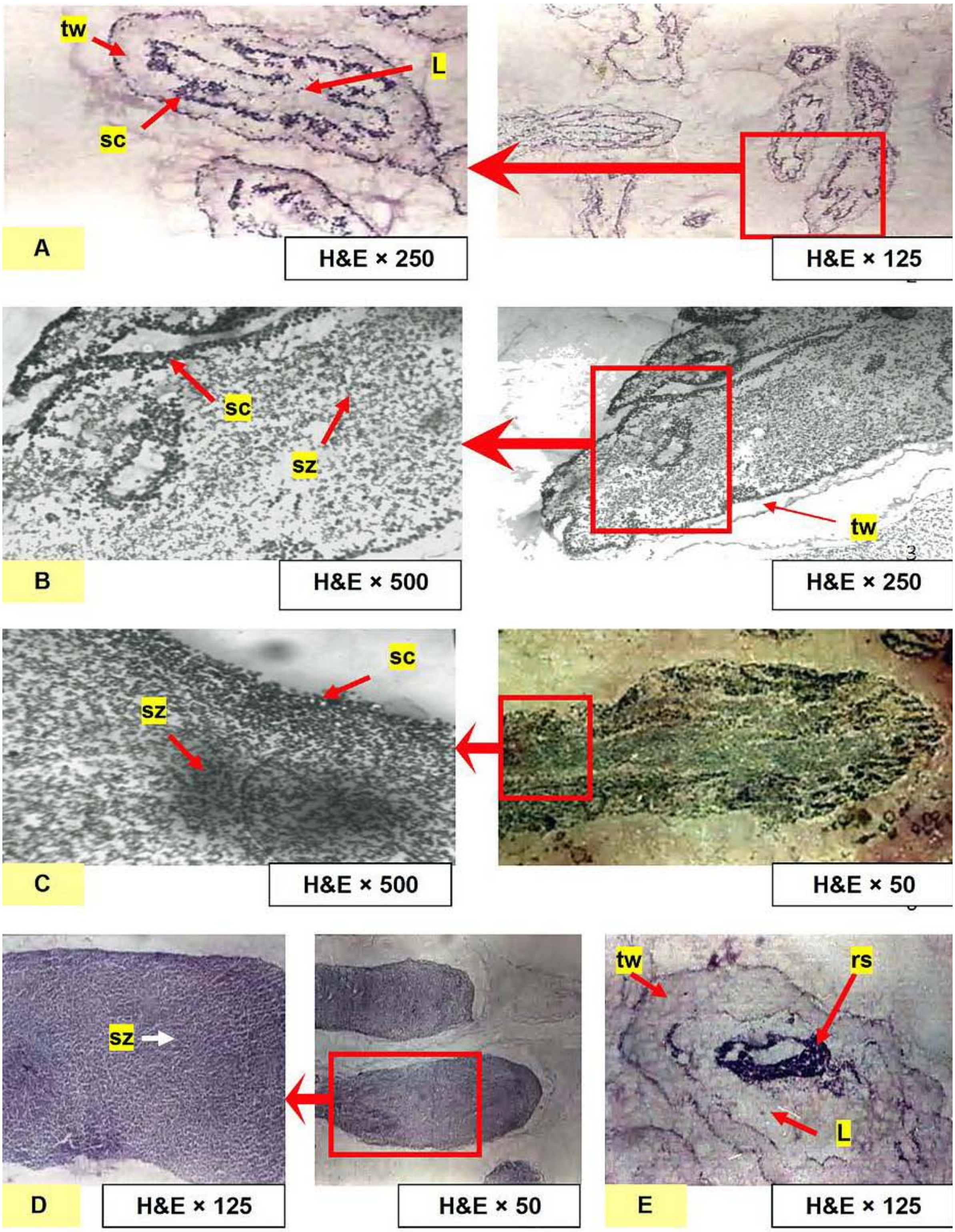

Figure 8.

Microscopic features of male *Holothuria leucospilota* gonads at different developmental stages.
L: lumen area; **rs:** residual spermatozoa; **sc:** spermatocyte; **sz:** spermatozoa; **tw:** tubule wall.

A - early growth; B - growth; C - advanced growth; D - mature; E – post-spawning.

Microscopic features of male gonad maturity stages

Stage I – Early growth

The tubules in this stage were characterised by the empty lumen area and presence of spermatocytes along the germinal epithelium (Fig. 8A).

Stage II – Growth

In this stage, tubules were seen with numerous infolds of the germinal epithelium with columns of spermatocytes along it and some spermatozoa in lumen area (Fig. 8B).

Stage III – Advanced growth

Tubules with a smooth wall were observed. Spermatocytes were very reduced and lumen were filled with spermatozoa (Fig. 8C).

Stage IV – Mature

Tubules' lumina were fully packed with spermatozoa and had very thin and smooth tubule walls. No proliferating zone with earlier stages along the germinal epithelium were seen (Fig. 8D).

Stage V – Post-spawning

Tubules in this stage showed elongated empty passages in the lumen following spawning, and a few residual spermatozoa. No proliferating zone along the germinal epithelium containing spermatocytes was seen (Fig. E)

Discussion

Development of gonadal tubules

Individuals of *Holothuria leucospilota* on the Bustaneh coast of the Persian Gulf in Iran, possess a single tuft of gonadal tubules. A large number of keys for sea cucumber maturity stages have been recommended by Chao et al. (1994), Conand (1993), Drumm and Lonergan (2005), Howaida et al. (2004), Lee et al (2008), Purwati and Luong-van (2003), Rasolofonirina et al. (2005), Shiell and Uthicke (2006), Thierry and Conand (2001). The present study shows that the ovarian tubules were shorter and wider, but the number of tubules in testes was higher than that of the ovaries. Similar results were obtained on *Actinopyga echinites* in New Caledonia where it was explained that testicular tubules were slightly longer and narrower than ovarian ones (Conand 1982). Yet, in *Stichopus herrmanni* from Kish Island, Iran, it has been reported that the number of gonadal tubules in males is higher than that of females (Tehranifard et al. 2006). In another study in New Caledonia, three species of sea cucumbers, Conand (1981) reported that: 1) in the post-spawning stage, the gonads of *Thelenota ananas* are deflated and more limp, and residual ripe oocytes or spermatozoa may be observed as well as signs of atresia and reabsorption of germinal cells by phagocytic cells; 2) *Holothuria nobilis* gonads are sexually dimorphic: in females the tubules are shorter and wider; 3) *H. fuscogilva* gonads are not sexually dimorphic.

In the present study, with the continuation of maturity in both sexes, from the early to fecund stage, the value of the biometric parameters increased. In the last stage of maturity (post-spawning), the measured parameters of gonad decreased in male and female individuals. Most likely, this situation is due to the gonad regression after spawning. Purwati and Luong-van (2003), in their study on *Holothuria leucospilota* in Darwin, Australia, explained that this species has the capability of "reabsorbing" its gonads after spawning. In a study on *H. leucospilota* in Hong Kong (Ong-Che 1990), the same results with regard to tubule dimension in males and females were reported. The presence of individuals without gonads in the resting phase was explained by Conand (1981) in research conducted in New Caledonia with three species of sea cucumbers, which showed that the gonad of those species increased in dimension from the early to fecund stage, and decreased after spawning, in the post-spawning stage.

In this study, the relationship between gonad weight and number of tubules gave a high correlation coefficient (R^2) for both sexes. Rasolofonirina et al. (2005) made the same observation for *Holothuria scabra* in the southwestern Indian Ocean.

Acknowledgements

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Gonad development in the sea cucumber *Holothuria scabra* Jaeger, 1833

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Abstract

The purpose of this study is to describe the gonads of small *Holothuria scabra*. The same three tissue layers occurring in adults are also found in juveniles, even in very small specimens. The only difference between adults and juveniles less than 10 cm in length is that, in the latter, it is impossible to distinguish the germ cells in the inner epithelial layer, where they are probably structurally confused with somatic cells. In specimens over 10 cm in length, germ cells are found in the longer tubules (> 0.6 cm) but not in the shorter tubules (< 0.7 cm). The first recognisable germ cells appear eight to nine months after fertilisation (including larval development) in *H. scabra*.

Introduction

In adult sea cucumbers, in particular *Holothuria scabra*, the gonad is situated in the anterior and dorsal part of the animal. It is attached by a mesentery in the interambulacrum CD (Hyman 1955). Sea cucumbers may have a gonad on both sides of the mesentery, but in *H. scabra* and in the family Holothuridae in general, it occurs only on the animal's left side. The gonad extends into a gonoduct, which emerges from the base of the gonad, runs along the dorsal mesentery and terminates outside the body through the gonopore situated near the mouth (Smiley 1994; Rasolofonirina et al. 2005). Testes and ovaries show major similarities in structure (Chia and Bickell 1983). Gonad tubules are formed from three concentric layers comprising a central lumen where germ cells are found (Atwood 1973). The terminology used to characterise these tissues is variable, with Smiley and Cloney's usage (1985) being the most recent: from the outside to the inside, the three layers are the outer peritoneal tissue, the connective tissue compartment, and the inner epithelium.

In adult sea cucumbers, the outer peritoneal tissue is composed of three cell types: peritoneal epithelial cells, myoepithelial cells and neurons. Epithelial cells — which have a cilium surrounded by a collar of microvilli (Atwood 1973) — are the most prevalent cell type, and their role is to absorb the nutrients in the coelomic fluid (Atwood 1973; Smiley 1988b; Smiley and Cloney 1985). Myoepithelial cells are typically divided into two layers: an outer circular one and an inner longitudinal one (Smiley et al. 1991). Some species, such as *Stichopus californicus*, only have a circular layer (Smiley and Cloney 1985). The connective tissue is separated from the outer and inner epithelia by a basal lamina. The inner epithelium of the ovary tubules comprises three cell types: somatic parietal cells, follicular cells and germ cells. The first two cell types, which are ciliated cells, appear to be morphologically identical. The only difference is that the follicular cells surround the oocytes and are thought to have an endocrine function (Kanatani 1979). In the male's inner epithelium, there is no follicular cell and Atwood (1973) uses the general term "epithelial cells". Germ cells range in size from 100 μm to 5 mm (Hansen 1968) and fill the whole tubule, leaving little free space when the animal is ready to spawn (Smiley 1988b).

Only gonads from adults have been histologically characterised in sea cucumbers. The purpose of this study is to describe the gonads of young *H. scabra* in order to better understand the ontogenesis of this organ at the beginning of the post-metamorphic phase.

Materials and methods

Specimen collection and storage

Holothuria scabra Jaeger, 1833 specimens used in this study came from the Madagascar Holothurie company. Those measuring between 3 cm and 9 cm in length came from the sea cucumber farm at Belaza (south of Toliara), while larger animals came from enclosures in the natural environment at Sarodrano village.

Living animals were transferred to aquaria at the Institut Halieutique et des Sciences Marines. Gonads from 43 specimens from 3 cm to 13 cm in size were fixed partly in Bouin's fluid and partly in a 3% glutaraldehyde solution for at least four hours. They were first observed with an Axioscope A1 (Zein) microscope or a binocular microscope (depending

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on the size of the gonad) and photographed, before any other form of treatment.

Scanning electron microscopy

Entire gonads from sea cucumbers 3–7 cm long, and fractions of gonads from sea cucumbers 10–13 cm long were prepared for observation under a scanning electron microscope. Samples fixed in Bouin's fluid were stored in 70% ethanol. After being dehydrated in graded alcohol baths (70%, 90% and 100% ethanol), they were dried using a Polaron critical point dryer. They were then placed on aluminium stubs to be coated with gold in a JEOL JFC-1100E sputter-coater for five minutes. After these steps, samples were observed with a JEOL JSM-6100 scanning electron microscope.

Samples placed in glutaraldehyde were rinsed three times for 10 minutes in a rinsing solution of 0.2 M sodium cacodylate. They were then post-fixed for one hour in a 1% osmium tetroxide solution. After three rinses, samples were dehydrated in a series of graded ethanol baths (25%, 50%, 70%, 90% and 100% ethanol). Drying and metallisation steps were identical to those used for samples placed in Bouin's fluid.

Semi-thin sections

Some samples placed in the glutaraldehyde were rinsed, post-fixed and dehydrated in the same way as for the scanning electron microscope examination, but embedded in Spurr resin. They were then placed for 24 hours at 70°C. Semi-thin sections (1 µm thick) were performed by using a Reichert Austria U2 microtome with a glass knife. These sections were hot-stained using a mixture of equivalent volumes of 1% methylene blue and 1% Azur II for 30 seconds and then observed using the Axioscope A1 (Zein) microscope.

Results

The gonad, whether male or female, has a base from which gonad tubules run, and from which emerges the gonoduct, running along the anterior part of the digestive tube, to which it is attached by a mesentery. Each gonad tubule is formed from a primary branch and a number of subsidiary branches of various types called secondary, tertiary branches, etc., up to the apex of the gonad tubule. Dichotomisations are referred to as being primary, secondary or tertiary if they give origin to secondary, tertiary and quaternary branches, respectively. The branch situated above the gonad apex is also called the terminal branch.

Gonad tubules may show either of two types of dichotomisation (Figs. 1 and 2). Symmetrical dichotomisation (Figs. 1 and 2 A, B) involves the parent branch dividing into two offshoots, each having an identical diameter. Asymmetrical dichotomisation (Figs. 1 and 2 C, D) occurs when a parent branch gives birth to two offshoots of varying diameters, one of which has a diameter almost equivalent to that of the parent branch. Infrequently, tubules form trichotomies and not dichotomies (Fig. 1 C).

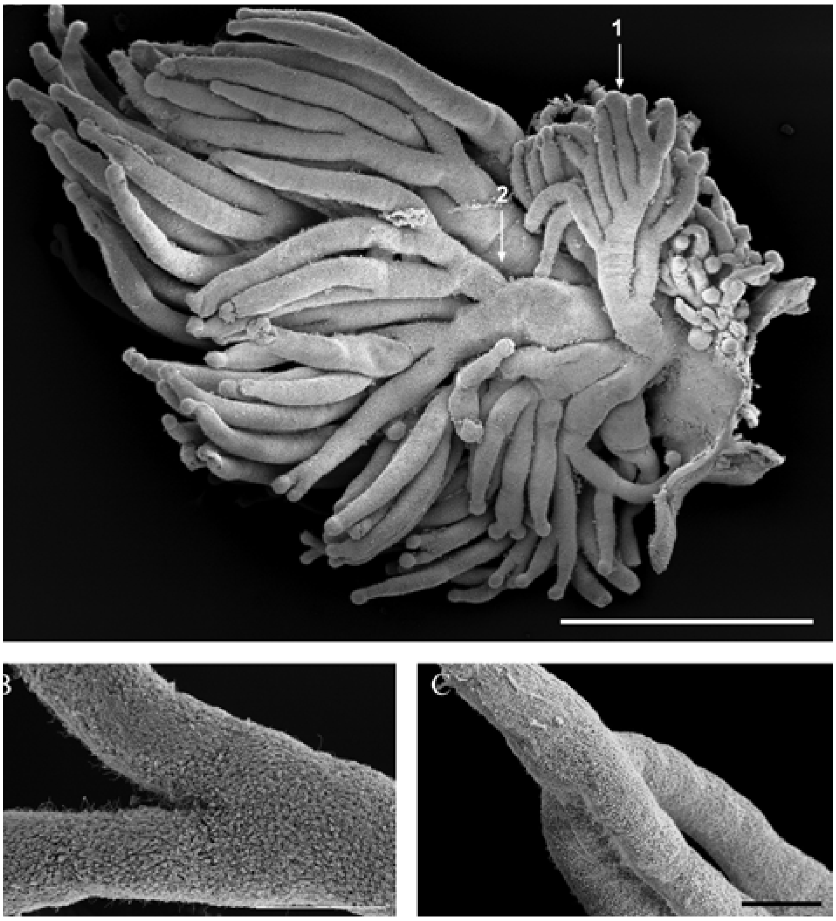

Figure 1. Photos by scanning electron microscopy (SEM) of *Holothuria scabra* gonads. Plate showing the dichotomisation of gonad tubules.

A: Portion of the gonad of a specimen 11 cm long showing the two possible types of dichotomisation: symmetrical (2) and asymmetrical (1) (Scale: 1 mm)
B: Gonad tubule showing a dichotomy (Scale: 100 µm)
C: Gonad tubule showing a trichotomy (Scale: 100 µm)

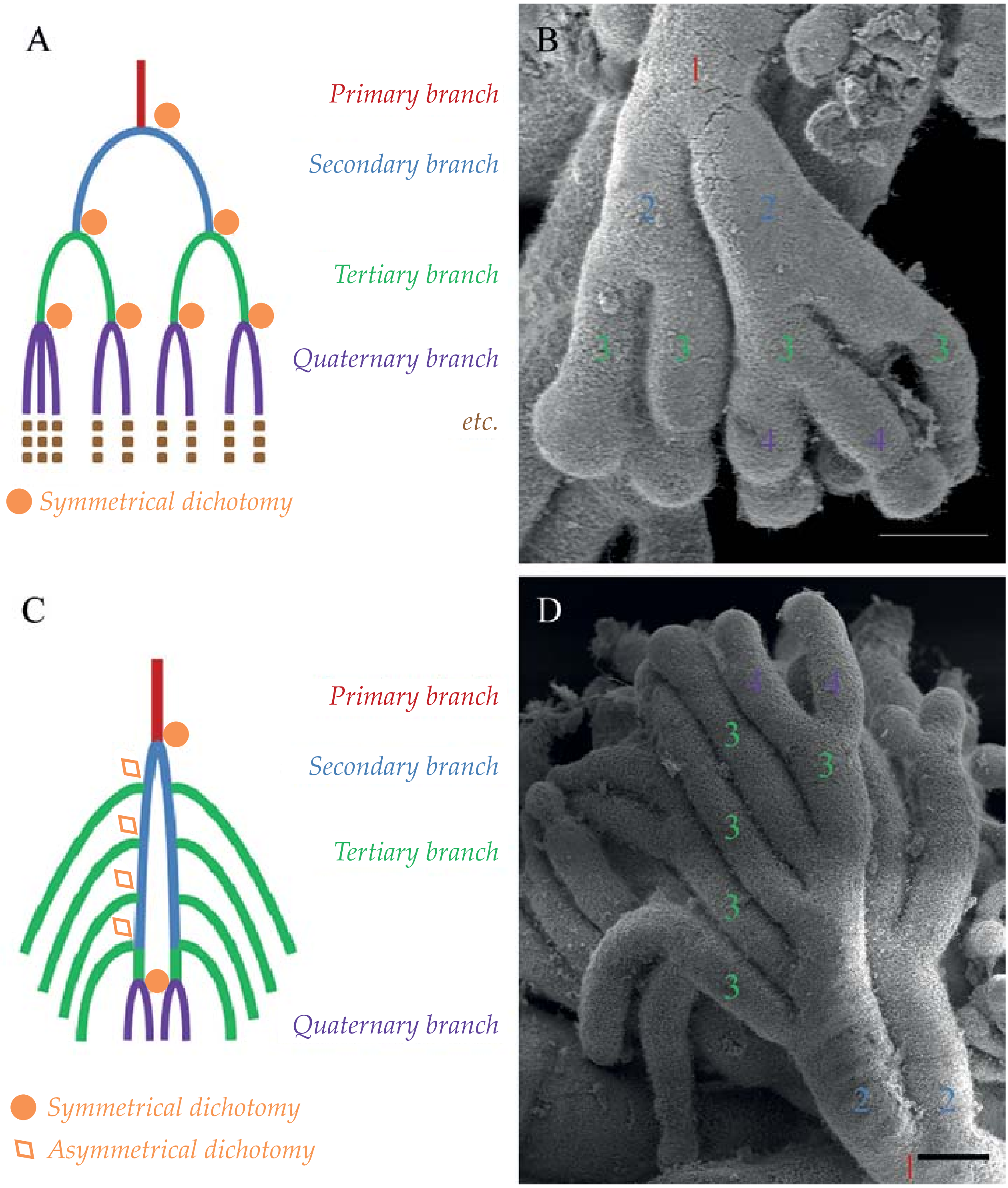

Figure 2.

Plate showing the two types of dichotomy found in gonad tubules.
1: Primary branch; 2: Secondary branch; 3: Tertiary banch; 4 : Quaternary branch.

A: Diagram representing symmetrical dichotomy
B: Photo representing symmetrical dichotomy (Scale: 200 µm)
C: Diagram representing asymmetrical dichotomy (represented by ◇) — the first and last dichotomy (represented by ●) are symmetrical dichotomies
D: Photo representing asymmetrical dichotomy — the first and last dichotomies are symmetrical (Scale: 200 µm)

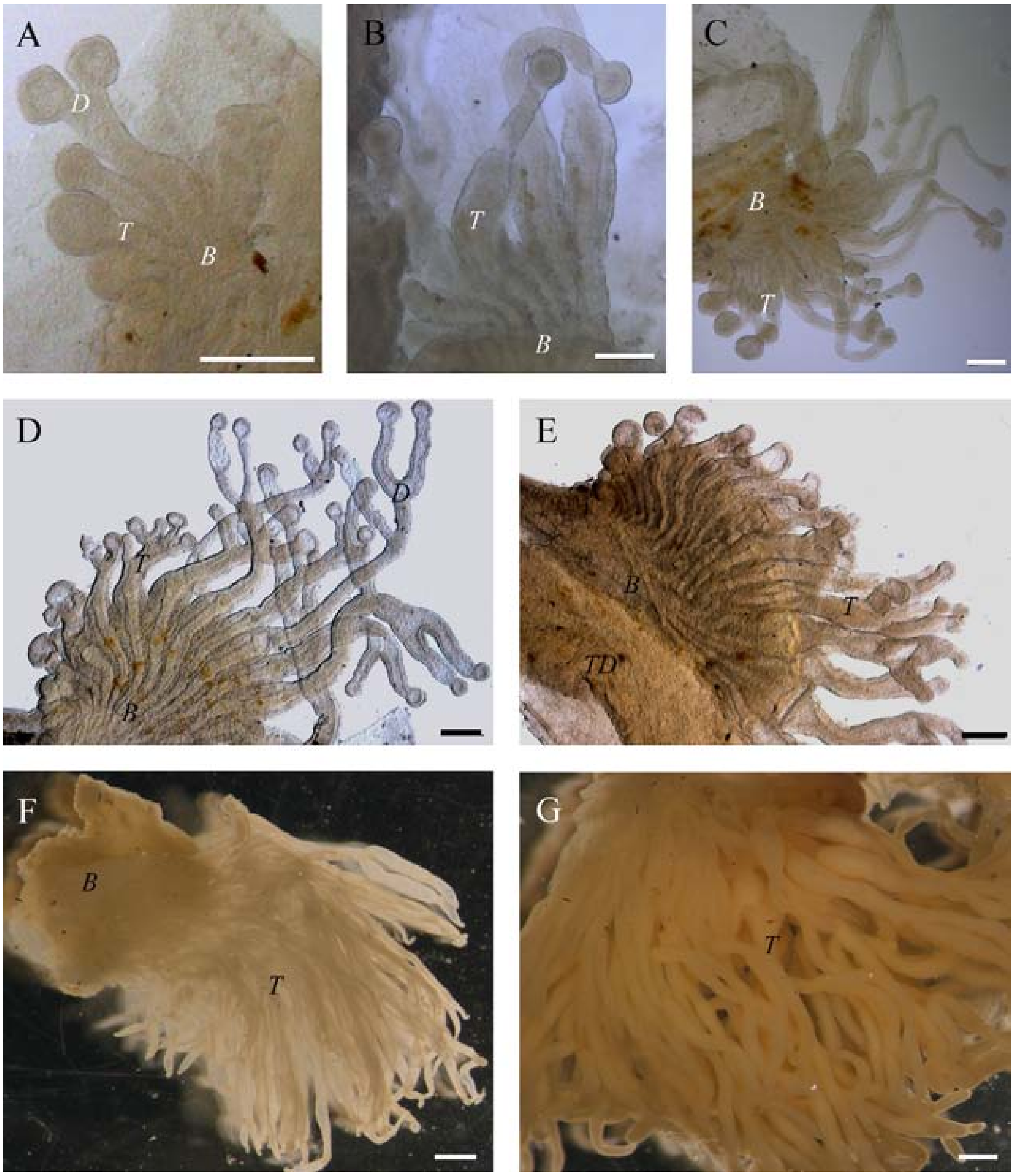

Figure 3. Plate representing gonads of specimens of species *H. scabra* of varying lengths from 3 cm in Photo A to 12 cm in Photo F.
B: base of the gonad; *D*: dichotomisation; *T*: gonad tubule. Scale: 200 µm (A–E) and 0.3 cm (F–G).

Photos taken by an optical microscope of the gonad of a specimen: A: 3.3 cm in length; B: 4 cm in length; C: 5.5 cm in length; D: 7 cm in length; and E: 8.8 cm in length

The gonad in specimens 3 cm long (Fig. 3 A) comprises less than five tubules, some of which are dichotomised but are formed only from primary and secondary tubules. Figure 3 A portrays a gonad with a gonad tubule (the longest) showing symmetrical dichotomy. The primary branch of this gonad tubule is 60 µm in diameter and 250 µm long, while the secondary branch, which is 5 µm long, leads into a tubule apex resembling a sphere with a diameter of 100 µm. The gonad of specimens 4 cm long (Fig 3 B) has 5–10 gonad tubules; 7 of which are present on the specimen shown in Figure 3 B. Most gonad tubules are not dichotomised but when they are, the dichotomy only gives birth to secondary branches. The longest measured tubule was 900 µm and the shortest was 100 µm. The diameter was 70 µm. Each tubule terminates in a tubule apex 100 µm in diameter.

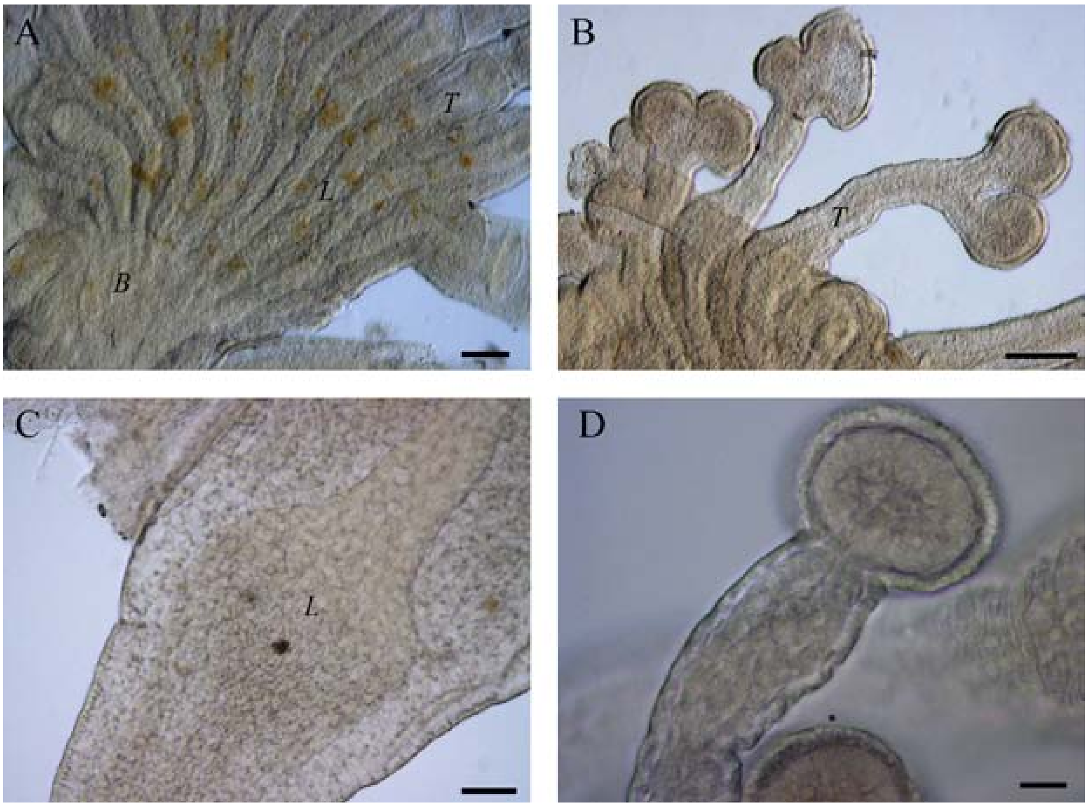

Figure 4. Details of gonads of *Holothuria scabra*.
B: base of the gonad; *L*: lumen of the gonad tubule; *T*: gonad tubule.

A: Base of the gonad in a specimen 7 cm long (Scale: 100 μm)
B: Small tubules already showing dichotomy (Specimen 7 cm long) (Scale: 100 μm)
C: Base of a gonad tubule in a specimen 7 cm long (Scale: 50 μm)
D: Apex of the tubule of a gonad in a specimen 4 cm long (Scale: 20 μm)

The gonad in specimens 5 to 9 cm long (Fig 3 C) has 10–20 tubules. The specimen shown in Figure 3 C is 5.5 cm long and has 17 tubules. The longest tubule measures 1.6 mm. A number of tubules show primary dichotomisation. The primary branch forms 90% of the total length of gonad tubule. The terminal branch, 70 μm in diameter, is short and directly followed by the tubule apex (100 μm in diameter).

The gonads represented in Figures 3 D and E come from specimens between 7 cm and 8 cm in length. The number of gonad tubules connected to the base of the gonad was about 15. The length of primary branches (45%) exceeds that of secondary (11–34%) and tertiary (30%) branches. The tubule apex always measures some 100 μm in diameter while the tubule is 70 μm in diameter. Specimens measuring 7 cm have, at this length, a gonad where the tubules increase in length from one side of the gonad to the other.

The gonad in specimens 9–11 cm long (Fig 3 F) comprises 20–60 tubules with a diameter of 1.2 mm. The gonad of the specimen illustrated in Figure 3 F measures 9.5 cm long and has 29 gonad tubules with a diameter of 2.0 mm. A larger proportion of tubules with tertiary branches are observed (52%). The diameter of a tubule is 150 μm at its extremity. The gonad of a dissected specimen 10.3 cm long (Fig 3 G) is formed from 55 tubules, some of which have quaternary branches. The highest proportion of tubules (42%) has tertiary branches.

In Figure 4, some details of a gonad can be observed. Photo A focuses on the base of the gonad. The lumen of each tubule terminates in a common zone leading to the gonoduct. Photo B shows the dichotomisation of shorter tubules: even a 250 μm tubule shows dichotomisation. Photo C shows the tubule lumen at its base, which shows a slight swelling. Photo D is of the end of a tubule, and the tubule apex is visible. It has a diameter of 100 μm.

In brief, when a gonad develops, the number and length of tubules increases, but the diameter does also. The tubule apex keeps its diameter even in gonads of larger specimens. Primary dichotomisations are found in juveniles more than 3 cm long. Tubule growth not only occurs at its extremity: primary and secondary branches of larger specimens are longer than those in smaller specimens.

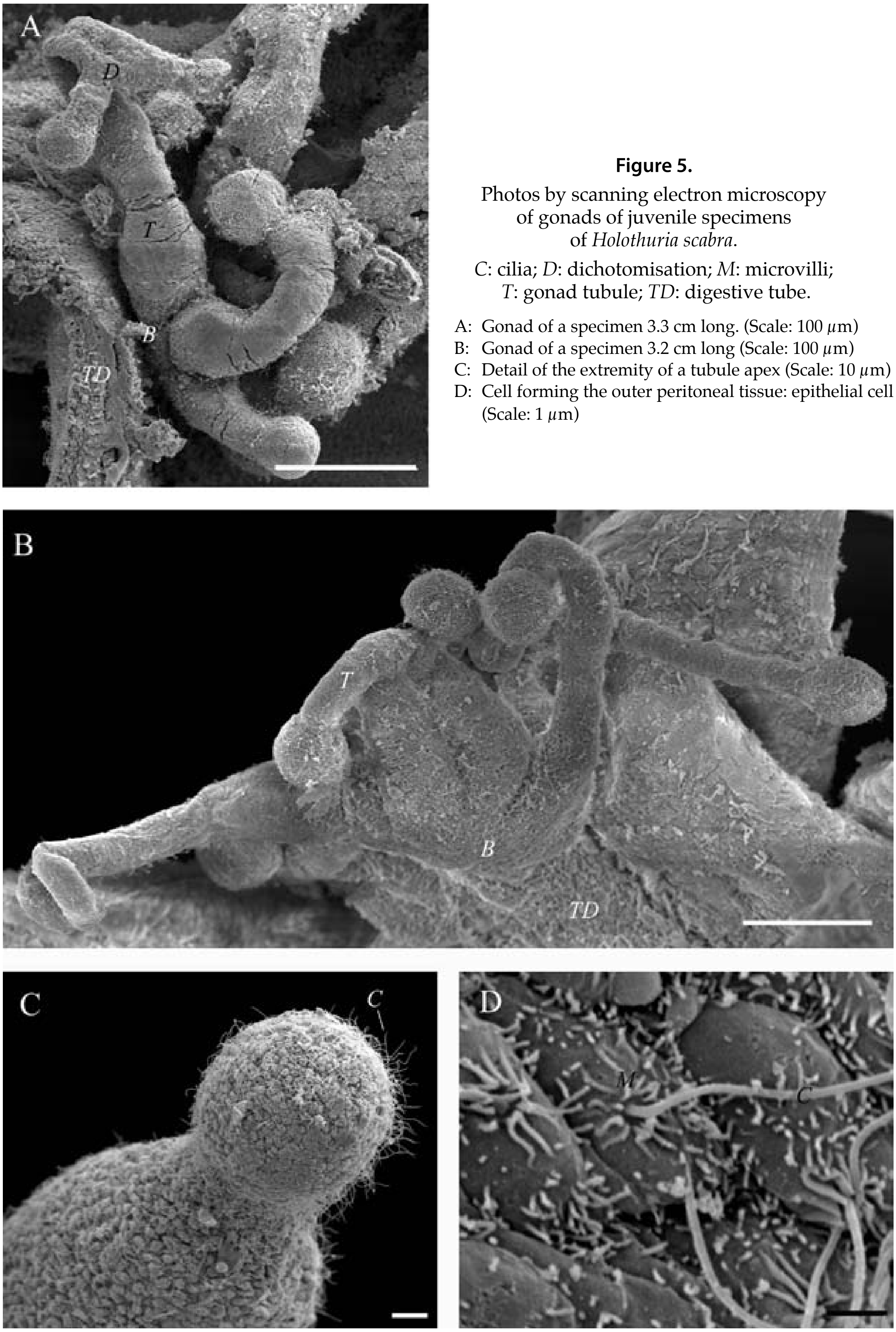

Figure 5.

Photos by scanning electron microscopy of gonads of juvenile specimens of *Holothuria scabra*.

C: cilia; *D*: dichotomisation; *M*: microvilli; *T*: gonad tubule; *TD*: digestive tube.

A: Gonad of a specimen 3.3 cm long. (Scale: 100 μm)
B: Gonad of a specimen 3.2 cm long (Scale: 100 μm)
C: Detail of the extremity of a tubule apex (Scale: 10 μm)
D: Cell forming the outer peritoneal tissue: epithelial cell (Scale: 1 μm)

Gonads were also observed by scanning electron microscopy. Figure 5 A illustrates a gonad from a specimen 3 cm long. The gonad tubules (of which one is dichotomised) converge towards the base attached to the mesentery of the digestive tube. The tubule apex has a diameter of 60 μm. Another gonad from a specimen 4 cm long is illustrated in Figure 5 B. It is formed of 7 gonad tubules, with each tubule terminating in a tubule apex that is 60 μm in diameter (Fig. 5 C). The surface of gonads is uniformly ciliated. A cilium measures 11 μm in length and is encircled by a collar of microvilli that is 0.1 μm long. Each cilium is 2.2 μm distant from the next (Fig. 5 D).

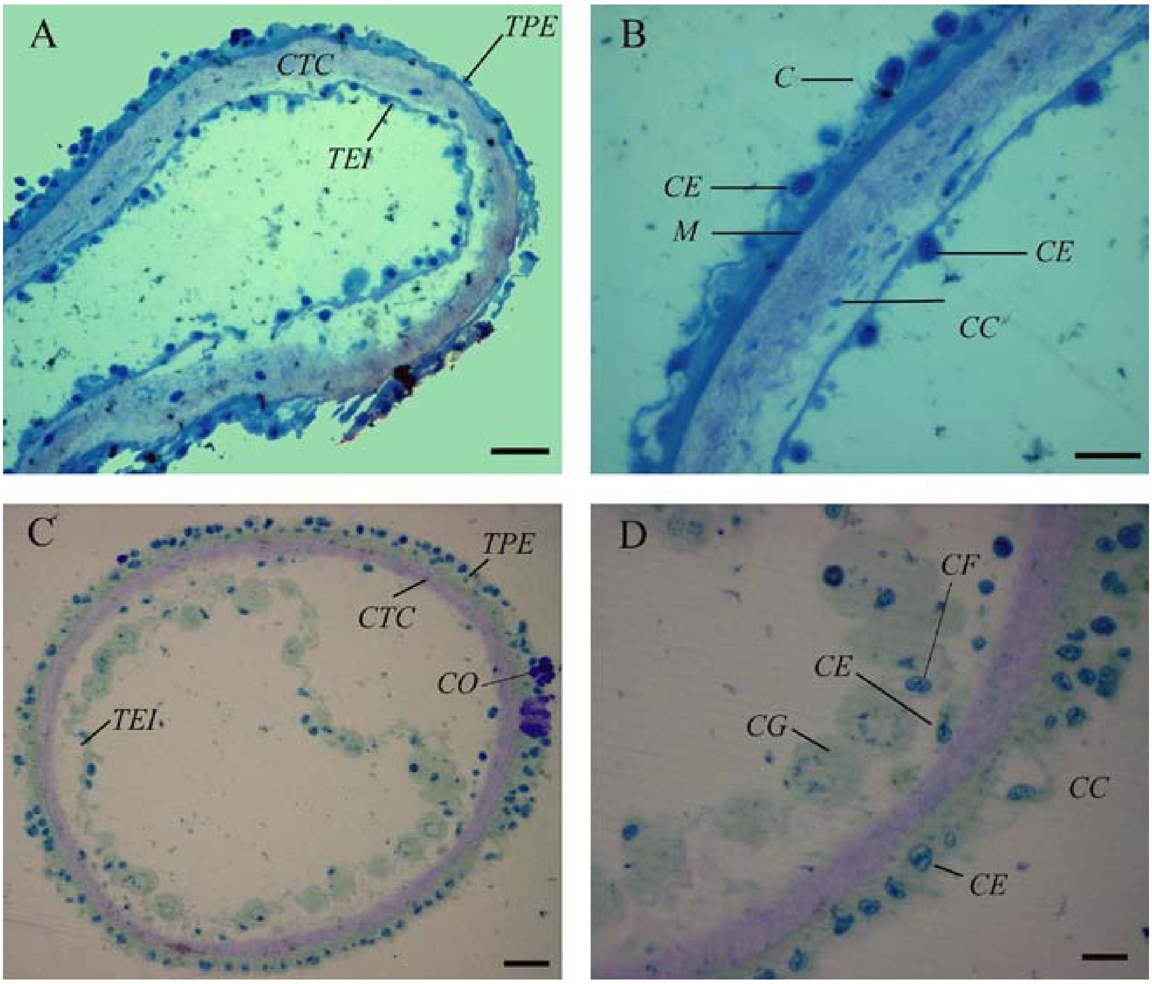

Figure 6. Semi-thin sections in a gonad from a specimen 10 cm long.
C: Cilia; CC: Connective cell; *CE*: Epithelial cells; *CF*: Follicle cell;
CG: Germ cell; CO: Coelomocytes; *CTC*: compartment of connective tissue;
M: muscle; *TEI*: Inner epithelial tissue; *TPE*: outer peritoneal tissue.

A: General view of a circular section in a small-sized gonad tubule (Scale: 20 μm)
B: Detail of the wall of a small-sized gonad tubule (Scale: 10 μm)
C: General view of a circular section in a big-sized gonad tubule (Scale: 10 μm)
D: Detail of the wall of a big-sized gonad tubule (Scale: 5 μm)

Semi-thin sections enable comparison of small tubules (length < 0.6 cm; Figs. 6 A and B, and Fig. 7) with longer ones (length > 0.7 cm; Figs. 6 C and D, and Fig. 8) in the same specimen. This also makes it possible to conduct research on the histology of gonad tubules in small specimens (< 10 cm long). Germ cells (oocytes here) are only detected in large tubules, not in small ones. In the outer peritoneal tissue, ciliated epithelial cells are the most prevalent and, therefore, form the most common cell type. These cells measure 15 μm wide and 2.5 μm thick at their thinnest point. They have a cilium and a collar of microvilli. The nucleus is at the base of the cell. Some cells of the "cœlomocyte" type are shown in Figures 6 B and D. Their cytoplasm is filled with vesicles 2 μm in diameter. A circular muscular layer is also present (Fig 6 B). Nerves were not detected because of inadequate resolution. A basal lamina separates the outer epithelium from the connective tissue. In the connective tissue compartment there are some connective cells (Figs. 6 B and D) and the fibrous matrix. The innermost layer (inner epithelium), also delimited by a basal lamina, is the one that differs depending on the size of the tubules studied. In small gonad tubules of large specimens and in gonad tubules of small specimens (< 10 cm) (Fig. 6 B), only one cell type is identifiable — the inner epithelial cells — while for larger gonad tubules, germ cells and their follicular cells are also present (Fig 6 D). Epithelial cells are, in both cases, flat-shaped cells 15 μm wide and 0.5 μm thick. At this resolution, only apical microvilli have been observed. Follicular cells have the same structure and may enter into contact with epithelial cells. They wholly or partly cover the oocytes.

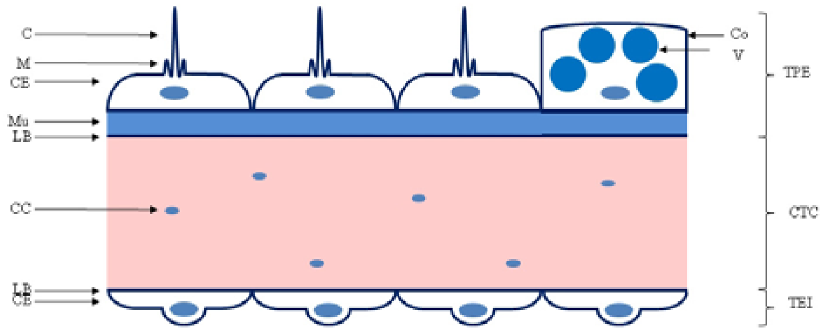

Figure 7. Diagram representing the wall of a small-sized tubule (< 0.6 cm long).
C: Cilia; CC: Connective cells; CE: Epithelial cells;
CTC: compartment of connective tissue; LB: Basal lamina; M: Microvilli;
Mu: Muscle; TEI: Inner epithelial tissue; TPE: outer peritoneal tissue.

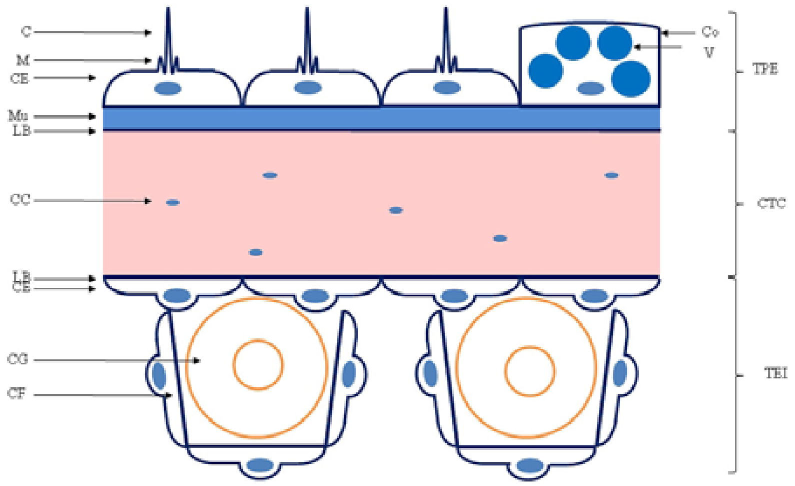

Figure 8. Diagram representing the wall of a large-sized tubule (> 0.7 cm long).
C: Cilia; CC: Connective cells; CE: Epithelial cells; CF: Follicle cells; CG: germ cells;
CTC: compartment of connective tissue; LB: Basal lamina; M: Microvilli;
Mu: Muscle; TEI: Inner epithelial tissue; TPE: outer peritoneal tissue.

Discussion and conclusion

The annual development of adult sea cucumbers gonads has been described by Smiley (1988a), who suggested that there is an annual tubule recruitment event. In this model, gonad tubules are grouped into three cohorts: primary tubules (the smallest and most anterior of the tubules), secondary tubules (intermediate in position and size) and fertile tubules (the most posterior). Within each separate cohort, development is synchronous. If in year N, tubules are at the stage of primary tubules, in year N+1, these tubules will become secondary tubules and then, the following year, they will be fertile tubules. When tubules are empty after spawning, they shrink. Smiley's model assumes that tubules of the same cohort are at the same stage and that fertile tubules shrink after spawning. Since the initial publication of this model by Smiley, a number of exceptions have been discovered and its applicability seems limited. This is thought to be the case with the sea cucumber *H. scabra* (Sewell et al. 1997). The gonad of *H. scabra* is not divided into several cohorts of tubules. Apart from the still immature smallest tubules, all tubules forming the specimen's gonad are at the same stage of development. Within a given population, however, specimens are not all at the same stage (Ramofafia and Byrne 2001). For Ramofafia and Byrne (2001), the annual growth of a gonad is characterised by tubule growth (in size and number) but also by an increase in the number of ramifications. This increases the total volume of the gonad and, therefore, fertility. Large tubules can dichotomise up to two or three times, whereas smaller ones do not do so at all (Rasolofonirina et al. 2005).

The structure of gonad tubules of various species of adult sea cucumbers is well known through works by Davis (1971), Atwood (1973) and Smiley and Cloney (1985). Their research results show the presence of three concentric layers delimiting a central lumen where germ cells are situated: an outer peritoneal layer, a connective tissue compartment, and an inner epithelium containing germ cells. In juveniles, on the other hand, the anatomy of gonads is still not well known. The same three tissue layers that are present in adults are found even in very small juveniles, and their histological structures also seem identical. The only difference between adult specimens and juveniles less than 10 cm long is the impossibility of distinguishing germ cells in the inner epithelial layer, which is probably confused in structure with somatic cells. In specimens longer than 10 cm, germ cells are found in long tubules (> 0.7 cm) but not in short tubules (Figs 7 and 8). There would, therefore, seem to be at least two groups of tubules in each gonad: immature tubules and mature tubules. These results confirm Ramofafia and Byrne's theory (2001) that all gonad tubules are at the same stage of development except for small tubules, which remain immature during the year of observation and will certainly become mature subsequently. From our observations, the first recognisable germ cells appear eight to nine months after fertilisation (including larval development) in *H. scabra*. The cells of the outer peritoneal wall have a very similar morphology to those of choanocyte-type cells, which can be found in the gonoduct wall of sea cucumbers. These cells have a collar of microvilli surrounded by a cilium. This morphological similarity may reflect a similarity in function because both choanocytes and cells of the outer peritoneal wall play the role of securing nutrients in their surrounding environment.

During ontogenesis, juveniles develop their gonads until they become mature specimens capable of reproduction. The gonads, therefore, increase in size. Dichotomy, number of tubules, and length and diameter also increase. Finally, the total volume of the gonad increases and, consequently, its reproductive potential does also (Ramofafia and Byrne 2001). The development of gonads is essential to ensure the reproductive success of sea cucumbers. Two categories of dichotomy have been observed in gonad tubules: symmetrical dichotomisation and asymmetrical dichotomisation. In the case of symmetrical dichotomisation, the division of a parent branch gives birth to two "offspring" of identical diameter. In asymmetrical dichotomisation, two offshoots of different diameters are obtained, with one such branch having a diameter very similar to that of the parent branch. Gonad dichotomisation is an adequate way of increasing the volume of the gonad without excessively increasing the size at the base where all gonad tubules converge and from where the gonoduct connects the gonad to the outside environment.

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Use of a growth model to estimate size at age in the temperate sea cucumber *Australostichopus mollis*

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Abstract

Exposure to unstable and dynamic habitats influences sea cucumber life history characteristics such as growth and survival. Consequently, size is affected by the habitat a species has adapted to over time. Size and seasonal trends in growth and mortality of a population of *Australostichopus mollis* reflect this. Typically, *A. mollis* population growth halted in the winter months of May, June, July, and resumed through late spring, summer and early autumn. A growth model can be used to estimate size at age, provided cohorts through time are identified and the sample is representative of the population. Although the population appeared unimodal due to the inability to identify juvenile cohorts, the Pauly seasonal modification of the von Bertalanffy growth equation was applied and calculated asymptotic population weight at 130 g after three years. K, the rate at which asymptotic weight was approached, was 1.37 yr^{-1}. Age slicing identified two age groups in the population, year 0 and year 1. Weight at the start of year 0 was 17 g, increasing to 100 g in the second year of growth (year 1). In addition, mortality had a strong influence on population dynamics, with instantaneous natural population mortality (M) of 0.58 and a maximum total population mortality rate (Z) of 1.5 yr^{-1}. For sea cucumbers such as *A. mollis* that exist in ruderal, unstable, and dynamic environments, growth rate is high but mean adult size is reduced while mortality is usually high but variable. Parameter estimates reflected those for other sea cucumber species with similar life history traits. Provided juvenile cohorts can be identified, in the future the growth model would be useful in determining further the population parameters of *A. mollis*.

Introduction

Traditionally, changes in weight and associated reproductive indices, variation in mean population weight and maximum adult weight, and in particular the determination of size at first reproduction or sexual maturity, have been used to describe growth characteristics of sea cucumbers (Cameron and Fankboner 1985, 1989; Conand 1988, 1989, 1993; Conand et al. 1998; Raj 1998; Ramofafia et al. 2000; Sewell 1990, 1992; Sewell and Bergquist 1990; Toral-Granda and Martinez 2008; Uthicke 1997). These growth characteristics are used to understand in an ecological context the expression of life history traits in both juveniles and adults of a population. For example, the growth of caged juveniles of *Australostichopus mollis* has been followed over a nine-month period at various locations and growth compared with sediment characteristics, food availability and habitat (Slater and Jeffs 2010). Such growth characteristics can be compared within and between species and related to ecological observations on habitat adaptation. In particular, how low stress and high disturbance habitats impact on population growth and survival (Carlow 1984; Lawrence and Bazhin 1998; Lawrence and Herrera 2000). Such habitat adaptation is related to the tradeoff between growth and survival.

Previously, the von Bertalanffy growth equation and its variants (Basson et al. 1988; Pauly 1987; Hoenig and Hanumara 1982) have also been used to determine population growth and mortality parameters and to describe growth characteristics for some species of sea cucumbers. These population parameters can be used to further evaluate population dynamics. Asymptotic population weight (L_∞) and the Shephard method (Shephard 1987a) for estimation of the growth coefficient (K), the rate at which the population approaches asymptotic population weight, are estimated. The parameter t_0 is also computed, representing a point in time at which animals are essentially "born". The Pauly model for seasonal growth is also used where strong seasonal growth is suspected (Pauly 1987). The von Bertalanffy constants are then used to determine instantaneous natural mortality (M) along with total mortality rate (Z), which is estimated from a regression capture curve. Such estimates of population growth and mortality have been quantified for the sea cucumbers *Thelenota ananas*, *Stichopus chloronotus* and *Isostichopus fuscus* and *Holothuria floridana* (Conand 1988; Ebert 1978; Fuente-Betancourt et al. 2001; Hearn et al. 2005; Reyes-Bonilla and Herrera-Perezrul 2003).

The rate at which growth (K) approaches asymptotic population weight has been determined for

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H. floridana (Fuente-Betancourt et al. 2001) and for *T. ananas* and *S. chloronotus* (Conand 1988). High values of K are associated with rates of growth that approach asymptotic population weight quickly, usually greater than 1.0 yr^{-1} (Sparre et al. 1989). Typically, in populations of sea cucumbers with high values of K, total mortality rates are often greater than 0.5 yr^{-1} but may vary. Total mortality rate (Z) and natural instantaneous mortality (M), have been estimated for populations of *I. fuscus* (Hearn et al. 2005; Herrera-Perezrul and Reyes-Bonilla 2008; Herrera-Perezrul et al. 1999; Toral-Granda and Martinez 2007; Reyes-Bonilla and Herrera-Perezrul 2003). The mortality rate has also been determined for *H. floridana* (Fuente-Bentancourt et al. 2001). These population parameters can be used to further understand exogenous influences on growth characteristics such as size at 1 year, size at first reproduction, adult size and life history characteristics.

The sea cucumber *Australostichopus mollis* is distributed widely around New Zealand, and occupies a range of habitats (Mladenov and Campbell 1996; Shears and Babcock 2007). It is also found in Australia on the southern coast of New South Wales, Victoria and Western Australia (Sewell 1990). It can be found in a wide range of habitats and depths, from shallow inshore waters on rocky and sandy substrates to mud seafloors at depths exceeding 100 m (Dawbin 1949). The basic ecology, reproduction and larval development and juvenile and adult nutrition of *A. mollis* have been described (Archer 1996 Morgan 2008a, 2008b, 2009a, 2009b; Raj 1998; Sewell 1990, 1992; Sewell and Bergquist 1990; Slater and Carton 2007; Slater and Jeffs 2010). *A. mollis* is typically 13–25 cm in length and has a unimodal, size-frequency distribution and the viscera index maintains an approximate uniform value throughout the year (Sewell 1990). The contribution of gonad-to-weight fluctuation is minimal (Archer 1998; Sewell 1990) but seasonal diapause and food availability may contribute to some variation in body-wall weight over time (Sewell 1990; Slater and Jeffs 2010). This has also been found for *Parastichopus californicus*, which remains in diapause until conditions improve (Silva et al. 1986) and for *Holothuria theeli* (Sonnenholzer 2003).

The objective of the present study was to record changes in the distribution of weight of *A. mollis* over a year for an *in situ* population and model growth to determine size at age. Model parameters are then discussed and compared in terms of sea cucumber growth, life history characteristics and habitat adaptation. The present study is constrained by a number of factors, including the unimodal, size-frequency distribution of *A. mollis*. The study is conducted at one site and precludes following a cohort of juveniles through time due to not finding them in any significant numbers. Growth and mortality parameters were determined based on the "adult" population.

Materials and methods

Collection and sampling

A population of *A. mollis* was sampled once every two months on a subtidal rocky reef on the northeast coast of New Zealand at Ti Point for one year. Ti Point Peninsula (36º 19'24 S 174º 48'04 E) is 90 km north of Auckland and 5 km south of Leigh Marine Reserve in northeastern New Zealand (Sewell 1990). Sampling was carried out once every two months because a pilot study where *A. mollis* was collected once a month for seven months indicated that sampling frequency at short intervals confounded results. The headland of Ti Point is adjacent to the entrance to Whangateau Harbour. Its benthic habitat consists of a rocky subtidal reef made up of rocks and boulders, including large stands of *Ecklonia radiata* kelp, leveling out to a sand bottom at approximately 10 m. It is a site at the northern end of the Hauraki Gulf. Winds are generally from the southwest although occasional strong winds are experienced from the north and southeast.

Animals were always collected from the same location and within a 50 × 50 m^2 area using large catch bags. The sampled weight-frequency distributions were also representative of the population at Ti Point (Archer 1998; Morgan 2009a; Sewell 1990). A small vessel was used to access the survey site. Sampling was carried out on days with relatively calm sea conditions. Sea cucumbers were collected using scuba, and were placed in catch bags, taken to the surface, and placed in 20-L tubs of seawater on the vessel. The vessel was relocated to a sheltered area inside the adjacent Whangateau Harbour entrance, and while at anchor the sea cucumbers were weighed to the nearest 5 g. Weight was recorded for each individual collected and the animals were returned (by scuba) together to the site they were gathered from and placed back on the sea bed.

Growth

Data were formatted for modeling, and dates converted to proportions of a 365 day year. Starting with the first sampling date of 14 October, this was divided by 365. For each subsequent sampling date the previous number of days were added and the total divided by 365. For each sampling date, sea cucumbers counts were grouped in 20-g size intervals and Length Frequency Distribution Analysis (LFDA) Version 5 — see www.fmsp.org.uk — was used to analyse the dataset.

The von Bertalanffy model is the simplest of the LFDA growth models and requires three parameters to be estimated. Alternative methods when using it are the Shepherd's Length Composition Analysis (Shepherd 1987a) Projection Matrix (Basson et al. 1988), or Length/Weight Frequency Analysis (ELEFAN) (Pauly 1987). The Hoenig (Hoenig and Hanumara 1982) and Pauly (Pauly 1987) functions are variations of the von Bertalanffy model and take into account seasonal growth. A score function (goodness of fit) is used in LFDA to derive a number that shows how likely it is that the data come from a stock with that growth function. The higher the function (approaching 1) the more likely it is the data come from a stock with that growth function.

The Pauly model was used in the present study because it is geared towards populations that stop growing completely at certain times of the year. This was determined for the present study from observations of changes in size classes and mean population weight over the year. For seasonal growth, C and t_s (the start of convex segment of oscillation) were estimated from the data as well as K, the rate at which weight approaches infinity (W_∞) and actual W_∞. In the present study, the model was run several times, altering K and W_∞ to cross-check score maximisation (Table 1). This process was performed for the non-seasonal ELEFAN to give a baseline comparison of model parameter maximisation for the Hoenig and Pauly seasonal model. The Pauly seasonal model was then used in subsequent steps and model maximisation of parameters compared with non-seasonal parameter estimates.

The catch curve total mortality rate was also estimated for each distribution by fitting a regression line through the von Bertalanffy catch curve. Z was estimated for each sample and the mean and standard error given.

Table 1. Model output of growth parameters for *Australostichopus mollis* and model maximisation for goodness of fit. Where, K = growth rate, W_∞ = asymptotic weight, t_0 = time at which weight = 0, t′ = real age (t) less total no growth time to age t, NGT = duration of non growth within a year, T_s = start of convex segment of oscillation with respect to t = 0.

	Step 1 K vs W_∞	Step 2 C vs t_s	Step 3 NGT vs t_s	Step 4 K vs W_∞
K	1.12	1.38	1.0	1.22
W_∞	133	125	140	133
C	0.46	0.44	NA	NA
t_0	-0.96	0.91	-0.39	-0.31
T_s	0.27	0.06	0.17	0.19
NGT	NA	NA	0.29	0.30
Maximised at:				
Fit	0.89	0.89	0.95	0.96
K	1.33	NA	NA	1.37
W_∞	125.90	NA	NA	129
C	NA	0.46	NA	NA
t_0	-0.93	-0.92	-0.40	-0.94
t_s	NA	0.27	0.19	NA
NGT	NA	NA	0.30	NA

Growth function

Calculated growth parameters were used to estimate weight at time t (W_t) and construct the growth curve. The general growth equation is:

$$W_t = W_\infty \times (1-e^{-q})$$

In the Pauly seasonal growth equation q is:

$$q = K(t'-t_0) + K/Q[\mathrm{Sin}Q(t'-t_0) - \mathrm{Sin}Q(t_o-t_s)]$$

Where $Q = 2\pi(1-NGT)$
K = growth rate
W_∞ = asymptotic weight
t_0 = time zero (born)
t′ = real age (t) less total no growth time to age t
NGT = duration of non-growth within a year
t_s = start of convex segment of oscillation with respect to t = 0

Results

The majority of *A. mollis* within the population were in the 100–119-g size class (Fig. 1). The next prevalent size class was 120–139 g. Mean population weight declined to April, reaching 107 ± 3.3 (CI) g and then increased to 127 ± 4 (CI) g in October, the final sampling date (Fig. 2). Over the year, 1,654 individuals were sampled, consisting of 297 in sample 1 October, and 221, 218, 172, 203, 292, and 251 for

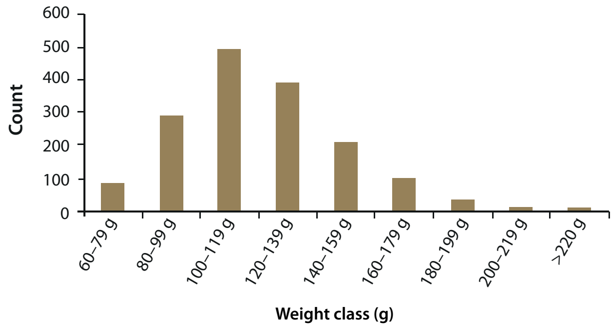

Figure 1. Total numbers of *Australostichopus mollis* from each 20-g size class recorded over all seven days of surveying (n = 1654).

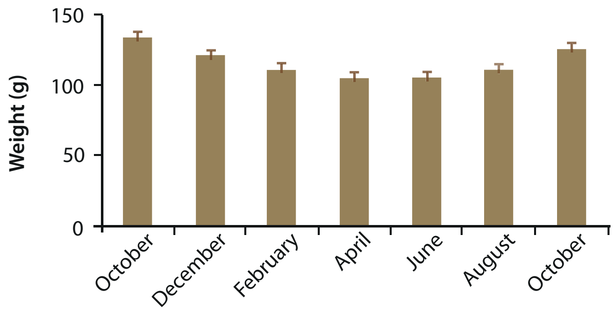

Figure 2. Mean weight (g) of *Australstichopus mollis* for each sampling date (±SE).

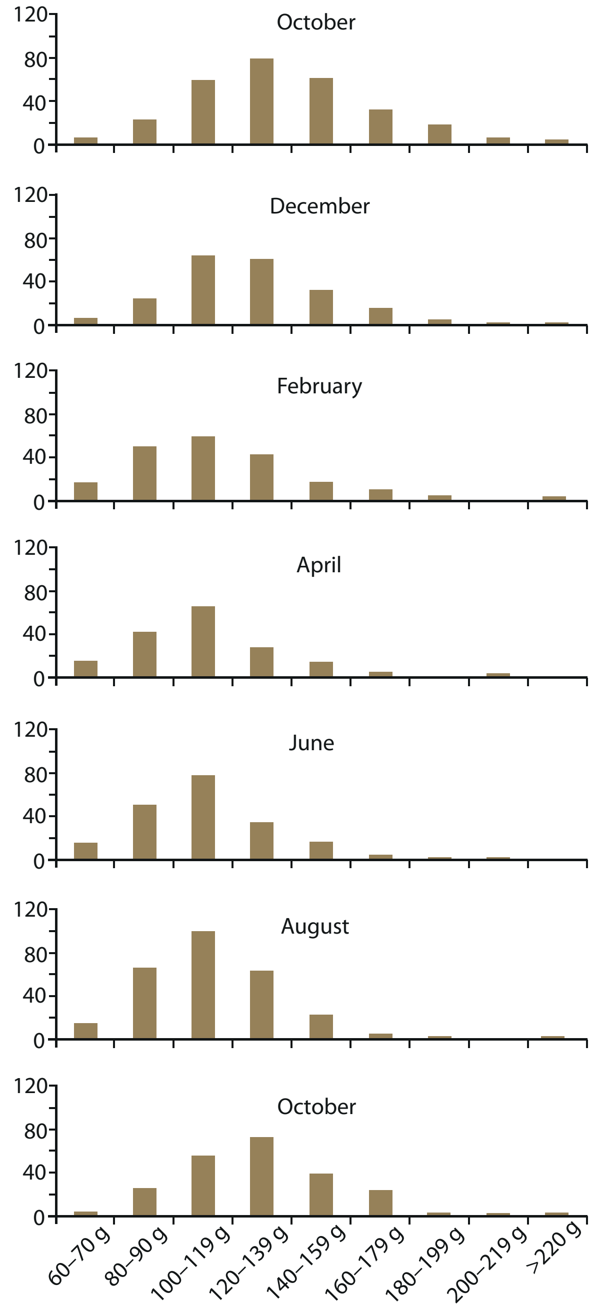

Figure 3. Changes in numbers of *Australstichopus mollis* for each size-frequency distribution over the year of sampling.

December, February, April, June, August and October, respectively.

In general, an overall increase in population numbers was observed, moving through adult cohorts for the 80–99, 100–119, and 120–139-g size classes (Fig. 3). Numbers over the 120–139-g size class were less for April, June and August. Numbers in the 100-119 g size class were consistently high. Numbers in the size classes between 120–139 g and 160–179 g decreased from December through to April of the following year, followed by an overall increase on subsequent sampling dates.

Estimated parameters were inserted into the von Bertalanffy growth equation with the Pauly seasonal modification and weight-at-age calculated for proportions of the year across years (Fig. 4). Weight at year zero was 17 g but t_0 was calculated at - 0.97 for model maximisation. This assumed that at some prior time they were eggs, larvae and subsequently settled, adopting the early juvenile stage prior to being a juvenile. This period of time is not known but can be approximated from knowledge of the larval cycle and early juvenile period, and may take anywhere between four months to one year (Morgan 2009b; Slater and Jeffs 2010; Stenton-Dozy and

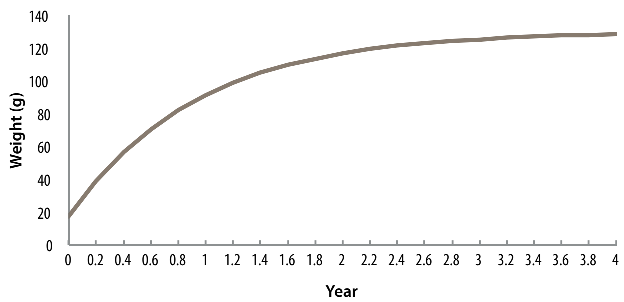

Figure 4. von Bertalanffy population model estimates of size-at-age for *Australostichopus mollis* from parameters calculated for the Pauly seasonal growth function.

Heath 2009). Growth of *A. mollis* after one year was estimated at 100 g, reaching 120 g after two years. Subsequently, asymptotic weight tended towards 130 g at three years.

The age composition of weight frequencies was calculated by using the fitted growth curve to delineate boundaries between weights-at-age and then slicing the weight-frequencies at those boundaries (Fig. 5). t_0 was constrained to lie between -1.0 and 0.0, meaning that nominal ages were not the same as true ages. Both the Hoenig and von Bertalanffy models estimated similar weights at years 0 and 1. Weights for year 0 ranged between 20 g and 50 g. This was indicative of the proportion of the population in its first year of growth. Weights for year 1 ranged between 70 g and 140 g. This was indicative of the proportion of the population in its second year of growth.

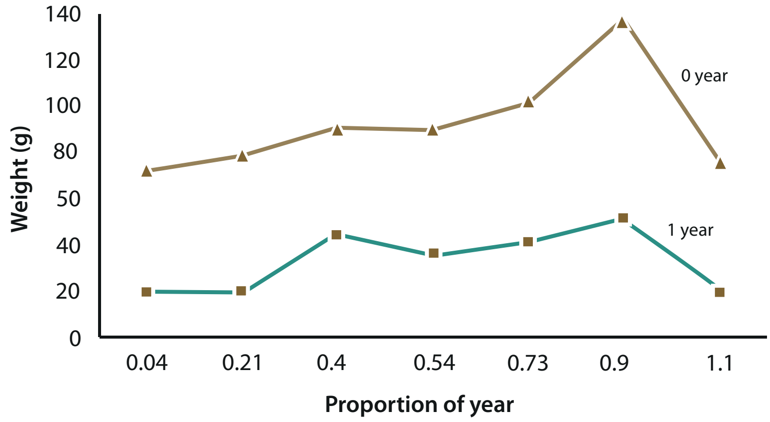

Figure 5. Population age composition of weight frequencies for *Australostichopus mollis* calculated from the fitted growth curve to delineate boundaries between weights at age and then slicing the weight frequencies at those boundaries. t0 was constrained to lie between -1.0 and 0.0, meaning that nominal ages might not be the same as true ages.

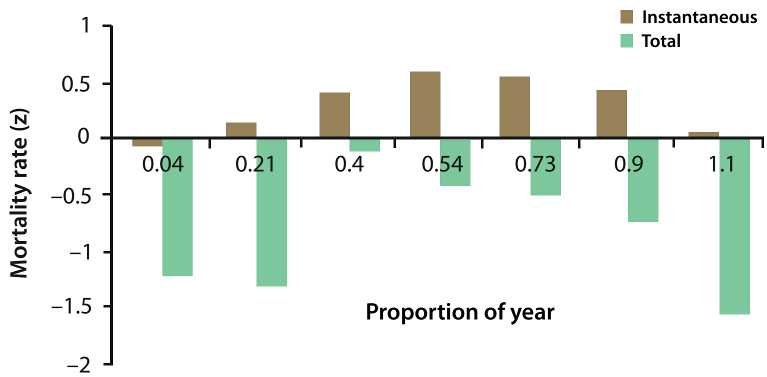

Figure 6. Instantaneous (natural) and total population mortality rates of *Australostichopus mollis* at each sampling date (Bev Holt K = 1.22; W_∞ = 133; Lc = 60; mean = 0.30; std err = 0.10; catch curve K = 1.22; W_∞ = 133; mean = -0.84; std err = 0.08).

The total mortality rate Z was based on non-seasonal growth. This is not usually a problem because most stocks growth, although not maximised, can be reasonably described by the non-seasonal von Bertalanffy model. The Beverton Holt instantaneous mortality rate (Beverton and Holt 1956) describes the relationship between weight, weight at first full exploitation, the von Bertalanffy parameters and the total mortality rate Z. Lc is the first weight class fully exploited and can be interpreted from the data. For *A. mollis*, instantaneous mortality (natural mortality M) was 0.58 (Fig. 6). Maximum total population mortality rate was -1.5 yr^{-1} in October. Because it was likely there were only two age classes in the data, mortality rates should be interpreted with caution and may be influenced by seasonal growth limitation.

Discussion

Size is a tradeoff between growth and survival, which is impacted on by the environment a species has adapted to over time. This has been explained previously for sea urchins relative to the amount of stress and disturbance they are exposed to in the environment they have adapted to (Lawrence and Bazhin 1998). For instance, ruderal species in environments where they are exposed to low stress and high disturbance (Carlow 1984; Lawrence and Bazhin 1998; Lawrence and Herrera 2000) will exhibit faster growth rates but decreased survival, and will put more resources towards reproduction but maintain low assimilation efficiency (Table 2). Similarly, for sea cucumbers in temperate coastal regions where food may be seasonally abundant (Hammond 1982; Sonnenholzer 2003) and the area exposed to high disturbance, mortality may be high. In this environment the proportion of weight reached at first reproduction relative to weight at one year may also be high (i.e. sexual maturity is reached before or near one year). This is typical of a species such as *A. mollis* where in the present study size in the second year of growth was modeled at 100 g. For this species in this location, size at sexual maturity was greater than 75 g (Sewell 1987). This relationship between size and sexual maturity may differ in more stress-tolerant sea cucumbers in an environment with low disturbance (i.e. some deep-water species in sheltered environments that are food limited). Survival may be high but growth rates are slow and time to reproductive maturity as a proportion of size at one year is extended.

Once reproductive maturity is reached, sea cucumber weight can fluctuate seasonally relative to the allocation of resources to reproduction and/or growth and metabolism (Rutherford 1973), as was found for *I. fuscus* (Herrero-Perezrul and Reyes-Bonilla 2008). This relationship between population weight and reproductive maturity has been determined for sea cucumbers such as *Holothuria scabra*, *H. nobilis*, *Actinopyga echinites* and *Thelenota ananas* (Table 3). In the present study for *A. mollis*, mean population weight also varied seasonally between 107 g and 135 g, depending on the time of the year. Furthermore, in another study a marked growth limitation for *A. mollis* juveniles was found to occur between six and nine months after caging either due to an increase in biomass or seasonal growth limitation (Slater and Jeffs 2010). In both studies, this seasonal weight loss in *A. mollis* occurred during the winter months of May, June and July. In another study, the mean population weight of *I. fuscus* was 386 g with a maximum adult weight of 815 g but this varied significantly between months, depending on reproductive condition (Herrero-Perezrul and Reyes-Bonilla 2008). Toral-Granda

Table 2. Life history characteristics of *Australostichopus mollis* affected by the environment a species has adapted to and whether they increase or decrease (summarised from: Carlow 1984; Lawrence and Bazhin 1998; Lawrence and Herrera 2000).

	Ruderal Low stress High disturbance	Competitive Low stress Low disturbance	Stress-tolerant High stress Low disturbance
Growth	+		–
Survival	–		+
Reproductive effort	+		–
Assimilation efficiency	–		+
Proportion of maximum weight at first reproduction	<		>
Proportion of reproductive weight at one year	>		<

Table 3. Sea cucumber species and the ratio of drained weight at first reproduction (DW 1st Repro) to population drained weight (Pop DW) converted to a percentage (%).

Species	DW 1st Repro	Pop DW	%	Authors
Holothuria scabra	130	350	37	Conand 1989
H. scabra versicolor	320	970	33	Conand 1989, 1993
H. fuscogilva	900	1460	62	Ramofafia et al. 2000
H. nobilis	580	1240	47	Conand 1989, 1993
Actinopyga echinites	130	300	43	Conand 1989
Thelenota ananas	1150	1980	58	Conand 1989. 1993
Parastichopus californicus	50	313	16	Cameron and Fankboner 1985, 1989
Australostichopus mollis	91	140	65	Raj 1998 (South Island)
A. mollis	75	130 (W)	58	Sewell 1990, 1992, present study (North Island)
Stichopus japonicus	50	120	41	Ito 1995; Ito and Kitamura 1998
S. chloronotus	52	110	47	Conand 1988; Uthicke 1997; Conand et al. 1998
Isostichopus fuscus	367	500	73	Herrero-Perezrul et al. 1999

W = wet weight of whole animal (green weight) and Martinez (2007) also found that *I. fuscus* was sexually active throughout the year and that where condition indices relative to size were highest, this reflected a peak in reproductive condition. However, apart from work by Conand (1988) and more recent studies (Herrero-Perezrul and Reyes-Bonilla 2008; Toral-Granda and Martinez 2007) little is known about how size-at-age or the rate at which a particular size is approached interacts with any variation in reproductive condition or weight fluctuations across seasons for sea cucumbers.

Size at age can vary between and within years. In the present study, *A. mollis* consisted of two age classes, year 0 and year 1, with a size at the start of year 0 of 17 g. It is also assumed that at some time prior, as estimated by the parameter t_0, individuals in the population of *A. mollis* were eggs, larvae and early juveniles. Previously, for both *T. ananas* and *S. chloronotus*, t_0 was -0.672 and -0.251, respectively (Conand, 1988) so estimates of t_0 for *A. mollis* in the present study are not uncommon. Estimates of t_0 from -0.4 to -0.97 put this period anywhere from about four months to one year. *A. mollis* growth after six months in cages ranged from 32 g to 100 g after starting at an initial size of 23 g (Slater and Jeffs 2010).

A. mollis hatchery bred juveniles have been found to reach 50 mm in six months from initial spawning, weighing approximately 4 g (Stenton-Dozey and Heath 2009). In another study, the sea cucumber *Cucumaria pseudocurata* was found to have a large increase in growth rate during the first year subsequent to recruitment (Rutherford 1973), which is also not uncommon in ruderal unstable environments. Similar to *A. mollis*, a decrease in growth rate was observed after this initial year. In the present study, very few individuals were found weighing less 60 g, so it was assumed they recruited into the population near or around this size (Sewell 1990). In addition, for *A. mollis* in year 1, a large proportion of total growth occurred as was found for *A. mollis* juveniles in caging experiments (Slater and Jeffs 2010). Evidence suggests that variation in size-at-age may be a consequence of the timing of spawning and variable growth rates of individuals within the population prior to recruitment. This may account for the variability in size range within year 0 and year 1 for age slicing and the estimate of t_0 in the von Bertalanffy model.

In addition, within a species, geographic distribution size-at-age is not always consistent. For example, in *I. fuscus* size at sexual maturity was 367 g and this was reached after five years, with asymptotic population weight being 575 g (Herreo-Perezrul et al. 1999; Reyes-Bonilla and Herrero-Perezrul 2003). Conversely, Toral-Granda and Martinez (2007) found size-at-maturity in a different location to be 165 g drained weight but age was not known. For *A. mollis* on the South Island of New Zealand, size at sexual maturity was greater than 90 g drained weight, or approximately 100 g wet weight, with a mean population weight of 140–150 g drained weight (Raj 1998). However, size-at-age and the rate this was approached was not known. On the North Island of New Zealand, size at sexual maturity of *A. mollis* was greater than 75 g (Sewell 1987) and occurred at less than one year. This size range is smaller than those from the South Island. Despite this, for both North and South Island populations, size at reproductive maturity of *A. mollis* accounted for approximately 60% of mean population weight (Table 3). However, for a species over a broad geographic scale, without knowledge of both growth rate and size at age within a habitat it is difficult to determine life span.

The rate (K) at which asymptotic population weight was reached in *A. mollis* was estimated to be as high as 1.37 yr^{-1} in the maximised model but was as low as 1.0 yr^{-1} in model iterations. In a previous study for *H. floridana* the rate of K was 0.21 yr^{-1} (Fuente-Betancourt et al. 2001) while for *T. ananas* and *S. chloronotus* it was 0.199 yr^{-1} and 0.449 yr^{-1}, respectively (Conand 1988). Although *A. mollis* is temperate and *S. chloronotus* is sub-tropical, they appear to have similar size characteristics although *A. mollis* has a higher value for K. Typically, short-lived species such as *A. mollis* that exist in distinctly ruderal environments have a high value of K (> 1.0 yr^{-1}) and approach asymptotic population weight quickly (Sparre et al. 1989). For *A. mollis*, asymptotic population weight occurred at three years while for *S. chloronotus* this took six years. Consequently, it is expected that K for *A. mollis* would be approximately double that of *S. chloronotus*. However, much larger species such as *T. ananas* are long lived and usually have relatively low values for K. In such cases it could be expected that life span is extended considerably. For *T. ananas*, age at asymptotic population weight was 14 years while K was as low as 0.199 yr^{-1} (Conand 1988). However, in ruderal environments such as the present study, an increase in the rate at which asymptotic population weight is approached has significant consequences for survival. In these environments as life span is extended individuals are increasingly exposed to the risk of mortality.

A high rate of mortality is due to the tradeoff between achieving fast growth and reduced survival in unstable ruderal environments (Carlow 1984; Lawrence and Bazhin 1998; Lawrence and Herrera 2000). Both *H. atra* and *I. fuscus* live in such environments. For *H. atra*, over a year a loss of 50–70 % of the total population occurred (Ebert 1978). For *I. fuscus* animal condition (Kn) in relation to post-reproductive maturity declined, reflecting a corresponding decline in the health of animals (Herrero-Perezrul and Reyes-Bonilla 2008). Typically, for *I. fuscus*, the total mortality rate (Z) was 0.70 yr^{-1} (Reyes-Bonilla and Herrero-Perezrul 2003). For *I. fuscus*, the instantaneous natural mortality rate (M) was 0.67 but the median was 0.354 (Reyes-Bonilla and Herrero-Perezrul 2003). The natural mortality rate of *I. fuscus* was also found to be 0.174 (Hearn et al. 2005), and for *H. floridana* was 0.72 (Fuente-Betancourt et al. 2001). In the present study, the instantaneous mortality rate, the natural mortality rate of *A. mollis*, was 0.58 but was also close to 0.0 at certain times. Note that for sea cucumbers, due to several anti-predator characteristics, predation on adults is thought to be rare (Francour 1997). Although in the present study both total population mortality rate and the instantaneous mortality rate appeared high, these numbers are likely confounded by the seasonal variation in weight that occurs within the population and the lack of distinct juvenile cohorts recruiting into it. Despite this, evidence suggests that for sea cucumbers that live in increasingly ruderal, unstable, and dynamic environments, the growth rate will increase, but mean adult size will be reduced while mortality rates will be high but seasonally variable as appears to be the case for *A. mollis*.

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Southward transplanted cage-culture of sea cucumbers *Apostichopus japonicus* in China's Shengsi Islands

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Abstract

Three sizes of the sea cucumber *Apostichopus japonicus* were cultured in abalone cages, and survival and growth were monitored semi-monthly or monthly, from December 2007 to May 2008, using fermented seaweed as feed. The sea cucumbers in four sites had high survivorship (≥83%). Growth of large individuals (~70 g mean live weight) was slow when densities reached approximately 5 ind. layer^{-1}. Growth rates were negatively correlated with culture densities; for large juveniles at high densities, growth rates were the same as those for medium sized juveniles (about 30 g mean live weight) and small juveniles (50 g mean live weight) that were not stunted at high densities. Juveniles of all three sizes grew progressively except after April when sea temperatures increased. *A. japonicus* with a body weight of 40 g and in densities of 3–5 ind. layer^{-1} can be farmed successfully in abalone cages. Translating cages to more southerly (i.e. warmer) sites can extend the growing period of sea cucumbers, allowing them to reach commercial size over the course of the year. Naturally occurring populations of *A. japonicus* in the northern end of the East China Sea have a low growth rate during winter. Field-based growth trials for the purpose of culturing *A. japonicus* in the Shengsi Islands (southern China) were carried out.

Introduction

Sea cucumbers, especially *Apostichopus japonicus*, are among the most economically important and commercially exploited organisms in China due to their high quality meat and the successful techniques used in commercial hatcheries (Liao 1997). Sea cucumbers have been successfully bred to provide large numbers of juveniles (Sui 1988; Ito 1995), which holds great promise for restocking, stock enhancement, and sea ranching programmes.

A. japonicus is found in Russia, northern China, Japan, and North and South Korea (Sloan 1984). Sea ranching of sea cucumbers was initiated in Japan in the late 1930s and by the Yellow Sea Fisheries Research Institute in China in 1980 (Sui 1988), and was also developed more recently in the Pacific Islands (Battaglene and Bell 2004). In recent years, many sea cucumber farming techniques have been developed, such as farming in shrimp ponds, in offshore ponds, and in cofferdams filled by gravity-fed seawater (Chen 2003). Currently, in north China, *A. japonicus* is mainly farmed in nearshore waters in depths less than 15 m, which are often polluted — a problem that reduces the number of suitable areas for farming. The extension of farming areas to deep water and to southern China would provide more favourable environmental conditions and reduce the stress induced by farming in coastal areas.

The culture of hatchery-bred juveniles in southern China could reduce the time required to reach harvest size. Xiao and Gu (1981) transplanted adult and juvenile sea cucumbers in Xiamen, southern China for culture and spawning experiments. Sun et al. (2006) also transplanted juvenile sea cucumbers in Nanji Island (27°27'N, 121°05'E) in southern China; the results showed that the sea cucumber grew well. Juvenile sea cucumbers were bred artificially and acted normally, with good conditions and high survival rates even after aestivation from early June to the middle of November, which lasted for 160 days in the summer.

In northern China, seawater temperatures in winter drop below 5°C, which constrains the growth and survival of sea cucumbers. Cage-culturing sea cucumbers in southern China's warmer waters would provide many additional potential farming areas, reduce growth time before harvest, and make it possible to farm sea cucumbers in the winter months.

The Shengsi Islands (30°72'N, 122°45'E) in southern China comprise some 200 islands with a long history of marine aquaculture. However, rubble and rocky substrates needed for sea cucumber farming are scarce in the Shengsi Islands, where most substrates consist of sand and mud bottoms at depths that range between 5 m and 20 m. Sea cucumber

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habitat could be artificially simulated by adding hard substrata, although the cost would be high. Furthermore, light penetration decreases with depth, thereby constraining the growth of seaweed, which is used as cover and food for sea cucumbers. In addition, the nylon-mesh enclosures of scallop suspended-culture results usually in ulcers and death of sea cucumbers. By contrast, abalone cages suspended from rafts used by farming facilities are easily accessed.

There has been an increasing interest in the possibility of culturing deposit-feeding sea cucumbers that would consume sediments from the cages or pens used in scallop farming, thereby reducing the negative effects of scallop culture on the benthic environment and potentially producing a valuable secondary product. A previous study showed that *A. japonicus* grew well and reduced organic wastes when polycultured with scallops in lantern nets in northern China (Zhou et al. 2006). Paltzat et al. (2008) used oyster grow-out trays, which were designed to collect biodeposits and prevent sea cucumber escape, for the production of *Parastichopus californicus* Stimpson.

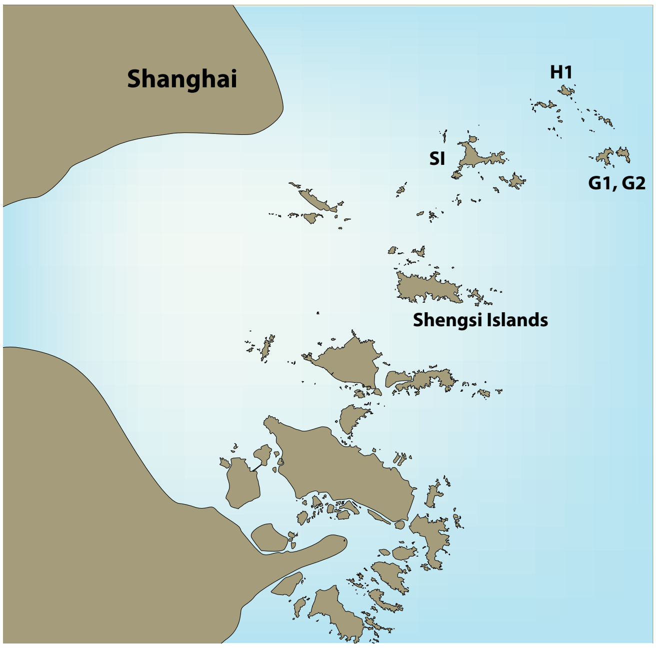

Figure 1. Locations of *Apostichopus japonicus* culture.
G1, G 2: Gouqi Island (sites 1 and 2); HI: Huaniao Island; SI: Shenshan Island.

Deposit-feeding holothurians ingest sediment bearing organic matter, including bacteria, protozoa, diatoms, and detritus of plants and animals (Yingst 1976; Moriarty 1982; Zhang et al. 1995). In recent years, fermented seaweed, especially *Laminaria japonica* Aresch and *Ulva pinnatifida* have been used as food sources of cultured sea cucumbers in China (Sui 1988). Fermented seaweed mixed with debris such as mud, dead algae, and sea cucumber faeces that settle on the inside of the cages can provide the main organic nutrient resource for sea cucumbers. Those sea cucumbers that were fed with fermented seaweed or mixed diets grew well, indicating that fermented seaweed could be an ideal food for sea cucumbers (Yuan et al. 2006).

Only if juvenile sea cucumbers survive to commercial size will culturing them add value to local economies. This study determined growth and survival of the sea cucumber *A. japonicus* during southward transplantation in the Shengsi Islands in southern China. Sea cucumbers were in abalone cages with fermented seaweed as feed to test the feasibility of sea cucumber culture in southern China.

Materials and methods

Animal materials

Sea cucumbers were obtained from hatchery larvae produced in March 2007 in Yantai, Shandong Province in northern China. The mean size of sea cucumbers at the start of the experiment was 40.72 ± 17.18 g (n = 330). Body weight was measured while juvenile sea cucumbers were fully extended. Sea cucumbers were then packed into insulated boxes and transported by air to the farm within six hours. All animals were acclimatised in a 10-m^3 land-based, concrete tank with composite sand and natural light for at least one week before the experiments.

Study sites

The study was conducted from December 2007 to May 2008, in the area east of Shengsi Island in Zhejiang Province, in the East China Sea. The study areas were shielded by the mussel farming area in depths of 5–20 m. Seawater was clean with no obvious pollution. Tides and currents in this area are gentle and steady. Four sites were chosen for culturing juvenile sea cucumbers: two at Gouqi Island (G1: 122°38′E, 30°42′N and G2: 122°50′E, 30°39′N), one at Huaniao Island (HI: 122°44′E, 30°52′N), and one at Shenshan Island (SI: 122°24′E, 30°43′ N) (Fig. 1).

Environmental conditions

Seawater temperatures ranged from 7.5°C in February 2008 to 17.2°C in December 2007 (Fig. 2), which is within the optimal temperature range (10–17°C) for *A. japonicus* growth. Water transparency was around 2 m. The seawater was well mixed and remained saturated with dissolved oxygen. pH values were 7.8–8.2 and salinities were 30–32 ppt.

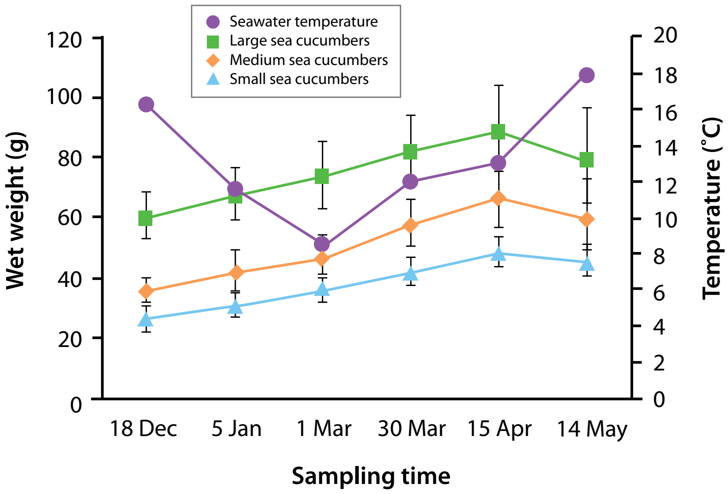

Figure 2. Seawater temperature and mean growth of large, medium and small *Apostichopus japonicus* at site G1. Bars represent standard errors (n = 20).

Culture facility

Six-layered abalone culture cages (0.4 m length × 0.3 m width × 0.8 m height, 1,250 cm^2 $layer^{-1}$) (Fig. 3) were used for the experiments. For each layer of the rigid plastic cages, six perpendicular substrates of 10 cm width were placed inside to provide sea cucumbers with extra habitable area and to trap sediment. Each underside was intact without impacting surrounding layers. A door was included on each cage for feeding and access. The cages were anchored to the longlines of a raft fixed on the sandy sea bottom, and suspended in depths of 3–6 m.

Experimental design

Three sizes of sea cucumbers were placed in a density of 6 ind. $layer^{-1}$ in fixed abalone cages at each site. Densities of large individuals were 3, 5, and 7 ind. $layer^{-1}$; densities of medium sized individuals were 4, 6, and 8 ind. $layer^{-1}$; and densities of small individuals were 6, 8, and 10 ind. $layer^{-1}$. Initial wet weights (mean ± standard error) were 60.18 ± 14.74 g for large sea cucumbers (n = 90), 35.73 ± 4.90 g (n = 109) for medium sized sea cucumbers, and 26.25 ± 5.43 g (n = 131) for small sea cucumbers in G1. Treatments were monitored fortnightly or monthly for six months.

Fermented seaweed, *Laminaria japonica* Aresch, and *Undaria pinnatifida*, were ground and placed in abalone cages twice a week; the weight of the seaweed equalled the wet weight of the sea cucumbers. About 13,500 kg of juvenile sea cucumbers — of individual weights of at least 40 g — were placed in the four sites; site SI had the greatest number of juveniles (7,500 kg).

Maintenance of culture area and measurement of survival and growth

During the experiments, survival and growth were quantified by counting and weighing juvenile *A. japonicus* in each cage and at all study sites. All sea cucumbers were measured every 15 or 30 days and then placed back in their respective layer within each cage until the next sampling period. Survival was recorded as the presence or absence of individual sea cucumbers in the assigned cage. Body weight was measured while each juvenile sea cucumber was fully extended.

Temperature, salinity, pH, and fouling were monitored every one to three days. Longlines, floats, and cages were inspected every day. Abalone cages were cleaned to remove the fouling organisms every week.

The specific growth rate (SGR) and growth rate (GR) were calculated as follows:

$SGR\ (\%\ d^{-1}) = 100\ (\ln W_2 - \ln W_1)\ T^{-1}$;

$GR\ (mg\ d^{-1}) = 1000\ (W_2 - W_1)\ T^{-1}$;

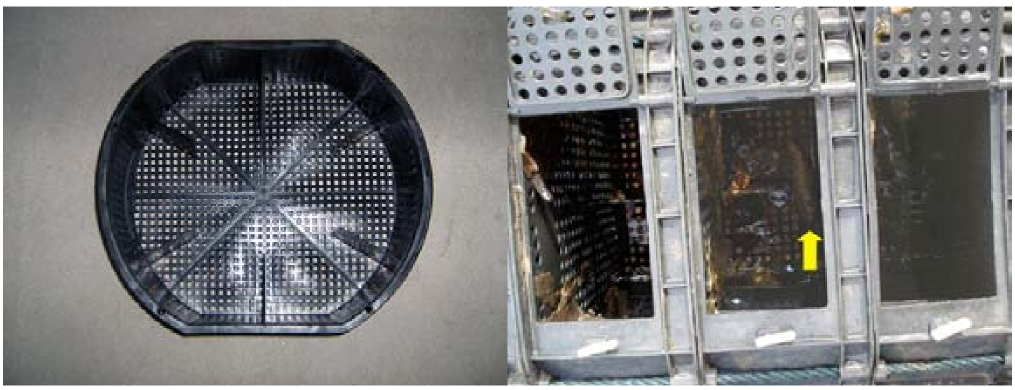

Figure 3. Single cage used for culturing *Aposticopus japonicus* in the present study (0.4 m length × 0.3 m width × 0.8 height, 1,250 cm^2 $layer^{-1}$) and assembled six-layer cage. Note cultured *A. japonicus* (arrow) laid in abalone cage.

Where W_1 is the previous wet weight (g) and W_2 is the current sampling wet weight (g) of the sea cucumber. Temperature was recorded throughout the experiments.

Data analysis

Statistics were performed using SPSS 11.0 software. A two-factor analysis of variance (ANOVA) with cultured density within the size was used to determine any significant differences in survival and growth of juvenile *A. japonicus* cultured in different habitats. Data are presented as means ± standard error of the mean (SE). We analysed the growth of sea cucumbers at three different densities in G1, and compared the difference between SGR and GR for each size at each different density at all four sites. Data were tested for homogeneity of variances with Cochran's tests; all data were suitable for analysis without transformation. One-way ANOVA, followed by Duncan's multiple rang tests, were used to test the differences among treatments. Differences among sampling dates were considered significant (P <0.05).

Results

Sea cucumber survival

Overall, survival at all study sites was high throughout the experiments, reaching as high as 100% for large juveniles, 93% for medium sized juveniles, and 83% for small juveniles. Size and survival of juvenile sea cucumbers were positively correlated.

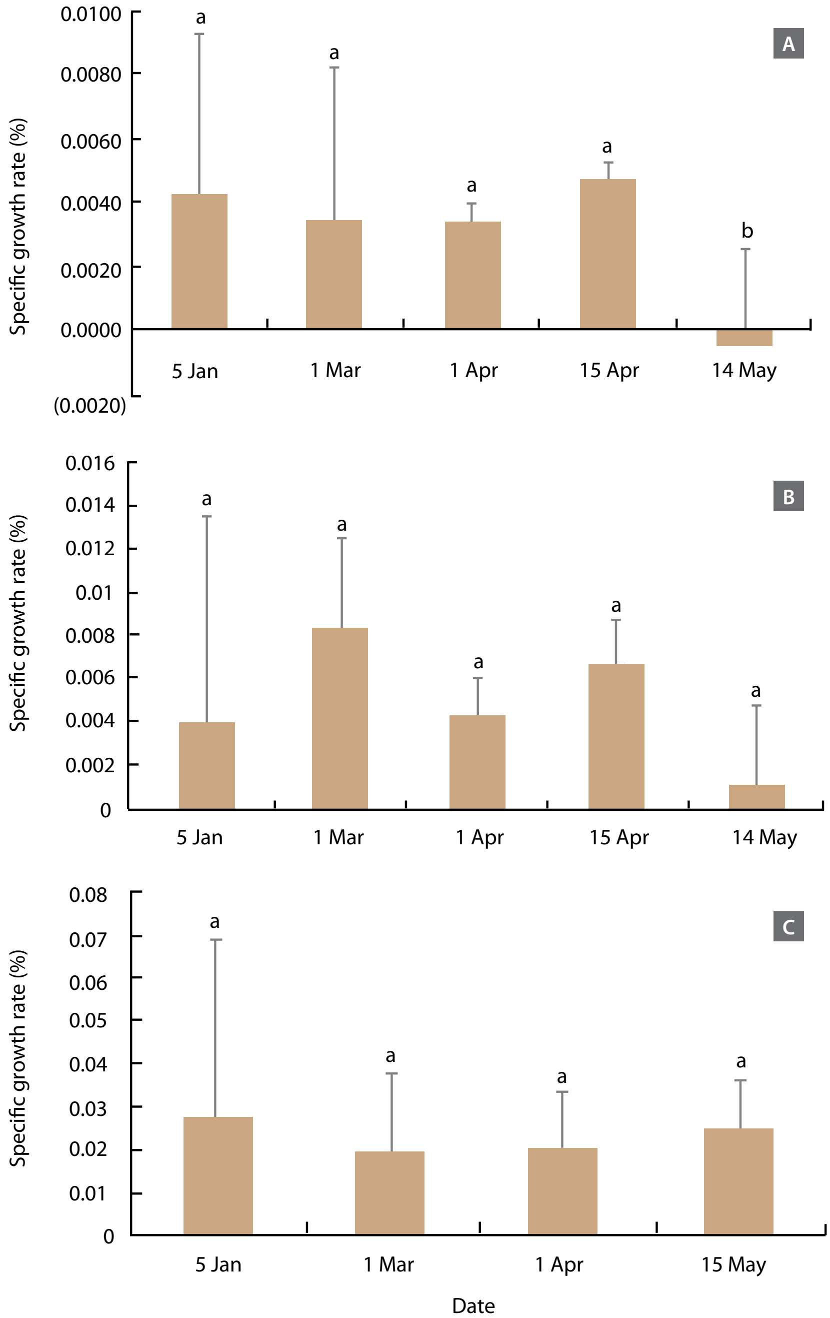

Figure 4.

Specific growth rates of large (A), medium (B) and small (C) *Aposticopus japonicus* during a six-month growth experiment east of Shengsi Island, southern China. Means with different letters indicate significant differences (P <0.05), and bars represent standard errors of the means (n = 4 sites).

Effect of size on specific growth rates of A. japonicus

At G1, initial wet weight (mean ± SE) of small *A. japonicus* 26.25 ± 5.43 g ind^{-1} increased to 45.48 ± 7.95 g ind^{-1} after six months (Fig. 2). Medium sized *A. japonicus* of 35.73 ± 4.90 g ind^{-1} initial weight grew to 60.57 ± 15.29 g ind^{-1}, and large *A. japonicus* of 60.18 ± 14.74 g ind^{-1} initial weight grew to 79.87 ± 20.81 g ind^{-1}.

SGR of juvenile sea cucumbers of all sizes and times showed progressive growth, except that the lowest SGR occurred in May for large juvenile sea cucumbers (Fig. 4A), perhaps because temperature increased. Differences in SGR were not significant for small and medium sized sea cucumbers (Figs. 4B and 4C) as determined by a one-way ANOVA (P <0.05).

Effect of culturing density on growth rates of **A. japonicus**

The GR at different densities and times was variable and density-dependent (Fig. 5) as determined by a Duncan multiple comparison test. There was negative correlation between GR and culturing densities (p <0.05), for example, absolute daily growth rates for large juvenile sea cucumbers farmed at different densities averaged 0.18 ± 0.10 g d^{-1} at a density of 3 ind. $layer^{-1}$ over the whole experiment, which was not significantly different from GRs of 0.13 ± 0.04 g d^{-1} at a density of 5 ind. $layer^{-1}$, or 0.09 ± 0.06 g d^{-1} at a density of 7 ind. $layer^{-1}$. Daily GRs decreased with increasing densities of sea cucumbers.

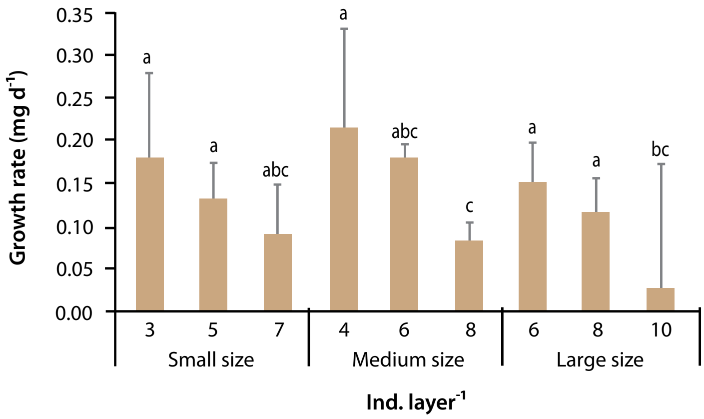

Figure 5. Effect of culture density on the growth rate of *Aposticopus japonicus* during a six-month growth experiment east of Shengsi Island in Zhejiang Province, southern China. Different letters indicate significant mean differences (P <0.05), and bars represent standard errors of the means (n = 4 sites).

Discussion

This study employed a caging method that would be practical for the commercial culturing of the sea cucumber *A. japonicus* in southern China. Other experiments with *A. japonicus* culture in southern China were mainly restricted to hatcheries and ponds (Xiao and Gu 1981), and experiments were of small scale (Sun et al. 2006). This study examined about 13,500 kg of juvenile sea cucumbers of three different sizes packed in 900 cages, making this the biggest field-based transplanting experiment in southern China. The high survival at all densities in this study showed that transporting small sea cucumbers in mass numbers was logistically feasible.

In terms of maintenance, removal of fouling organisms on the outside of the abalone cages periodically can maximise water flow and inputs of organic sediments to ensure high survival and growth rates of sea cucumbers in culture. Habitats and culture facilities should be protected against strong storms.

The main limiting factor appeared to be temperature, which became too high after April. During the experiment, the optimal temperature range for sea cucumber growth proved to be 10–17°C. GR decreased with temperatures above 17°C after April.

Juvenile size at release significantly affected long-term survival, but survival was density-independent within the experimental range (Purcell and Simutoga 2008). There was high survival of *A. japonicus* of all sizes and densities in our experiment. Other recent studies have shown similar results: survivorship of *A. japonicus* was high when co-cultured with bivalves in lantern nets (Zhou et al. 2006); high survivorship of *Australostichopus mollis* occurred beneath a mussel farm across all caging densities (Slater and Carlton 2007); and survival of *Parastichopus californicus* was 100% in oyster grow-out trays (Paltzat et al. 2008).

A. japonicus preferentially inhabits bottom areas with flourishing macroalgae and rich detritus, which provides the sea cucumbers' main feed (Li and Wang 1994; Zhang et al. 1995). In hatcheries, newly settled larvae are commonly fed with diatoms, and later, juveniles in nursery tanks are fed with powdered seaweed. In China, Japan, India and Indonesia, powdered seaweed has been used for hatchery-produced juveniles of *A. japonicus* and *Holothuria scabra* (Sui 1988; Battaglene et al. 1999), and individuals reached an average of 40 g on naturally occurring algae. Thus, it is appropriate to use seaweed as a food source for sea cucumbers. Growth in *H. scabra* slowed when individuals averaged 40 g without any addition of seaweed in land-based nursery tanks (Battaglene et al. 1999). Therefore, it is necessary to add artificial food for this commercial sea cucumber to continue growing. Our results showed that *A. japonicus* could grow well on fermented seaweed and other organic debris, and in our experiment, the addition of fermented seaweed improved survival and growth of juvenile sea cucumbers.

GR and sea cucumber density were correlated. Juveniles stunted from being held at densities of 5–7 ind. $layer^{-1}$ subsequently grew at the same rate as juveniles that were not stunted at densities of 3 ind. $layer^{-1}$. We suggest that the optimal size and densities for culturing sea cucumbers is 3–5 ind. $layer^{-1}$. *A. japonicus* can be farmed successfully at a size of 40 g, and after six months of culturing can grow to a commercial size of 100 g.

Kang et al. (2003) demonstrated that cage-cultured *A. japonicus* sea cucumbers grow well with the charm abalone *Haliotis discus hannai* in suspended cages; sea cucumber survival was high, and abalones in co-culture groups grew significantly better than in monoculture. Zhou et al. (2006) reported that *A. japonicus* grew well by feeding on biodeposits from filter-feeding bivalves and that co-culture with bivalves in suspended lantern nets could be feasible. Cage culturing of sea cucumbers with scallops, and the extension of the new culture facility, should be the next target for mass production of sea cucumbers by culturing. Further research is needed on the effects of cage culturing of sea cucumbers and other species.

There are at least three advantages to sea cucumber cage-culture in southern China:

- cages are easily accessible and cost-efficient;
- culture facilities provide relative protection against storms and predators; and
- the cost of cage-culture is much lower than that of placing stone blocks on mud or sand substrate, as would be required for *A. japonicus* pond culture in southern China.

Co-culturing sea cucumbers with abalone enables farmers to add great value to their production. But, much remains to be learned about the growth and survival of sea cucumbers before they can be mass produced, and appropriate management regimes need to be in place before this happens.

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Observations on habitat utilization by the sea cucumber *Stichopus chloronotus*

Hampus Eriksson,[1] Alban Jamon, Julien Wickel

Abstract

This paper adds to the list of observational studies of habitat utilization by juvenile and adult aspidochirotid holothurians. We used length data for *Stichopus chloronotus* collected in a nearshore, soft benthos area and its proximal reef flat, to assess the potential separation between adult and juvenile habitats. Individual sea cucumbers on back reefs in soft benthic areas were significantly smaller than those on adjacent hard benthic reef flats, indicating that juveniles and adults use separate habitats. We consider these results in relation to other similar observations and recruitment patterns of echinoderms to argue that the separate habitats used by juveniles and adults require specific attention in order to support decision-making with regard to ecosystem-based management.

Introduction

Many marine organisms show linkages across multiple tropical habitats for growth, survival and movement (Parrish 1989). This feature of connectivity among seascape habitats is critically important to understanding and managing commercially important marine organisms. For example, the nursery function of seagrass beds for many marine organisms underlines the importance of understanding life-history characteristics for sound ecosystem-based management (Nagelkerken 2009). Spawning success and recruit input among echinoderms are highly stochastic (Uthicke et al. 2009), and larval input varies depending on substrate, location and time of year (Lamare and Barker 2001). This uncertainty restricts the ability to predict future population sizes and make informed fisheries management decisions. It is, therefore, important to improve the understanding of the patterns and processes involved in the recruitment of commercially important echinoderms.

Recruitment of commercially harvested sea cucumbers is poorly understood, including patterns and processes related to habitat use throughout the sea cucumbers' life history. Shiell (2004) compiled observations of juvenile and adult habitats for a range of sea cucumber species, and concluded that they are often separated. Specific knowledge gaps are attributed to the difficulty in finding juveniles in the wild. This is, for example, illustrated in the protected population of *Stichopus herrmanni* at One Tree Reef on the Great Barrier Reef in Australia. This population has been regularly monitored during the day and night over a period of nearly two years without having recorded any juveniles (<160 mm) (Eriksson et al. 2010). The lack of detailed ecological knowledge regarding habitat utilization in the early life-history stages of sea cucumbers restricts the ability to manage sea cucumber fisheries in an informed manner and with a wider ecosystem-based perspective, as prescribed by Purcell (2010).

In this study, we investigate how the size of *Stichopus chloronotus* differs between a back reef seagrass area and the proximal hard benthic reef flat at a site in Mayotte in the western Indian Ocean, and analyse habitat utilization in relation to size (as a proxy for age).

Methods

We sampled the back reef seagrass area and adjacent hard benthic reef flat near the village of Sohoa in Mayotte, western Indian Ocean at low tide on 10 June 2010 (Fig. 1). We used 40 m x 1 m transect lines to sample the density of the commercial sea cucumber *S. chloronotus*. Transect lines (n = 18) were laid out perpendicular to the shoreline in both nearshore seagrass areas and on reef flats. The distance between the two sampled habitats varied between 100 m and 200 m. *S. chloronotus* individuals were measured along their centerline to the nearest 10 mm. Variance in length of *S. chloronotus* between the two habitats was tested with a one-way analysis of variance (ANOVA), with habitat as a fixed factor using the program R.2.9.2.

Results

In the back reef seagrass area, 17 individuals of *S. chloronotus* were encountered in depths of 20–30 cm and and 26 individuals were recorded on the reef flat. The mean length (±SE) of individuals

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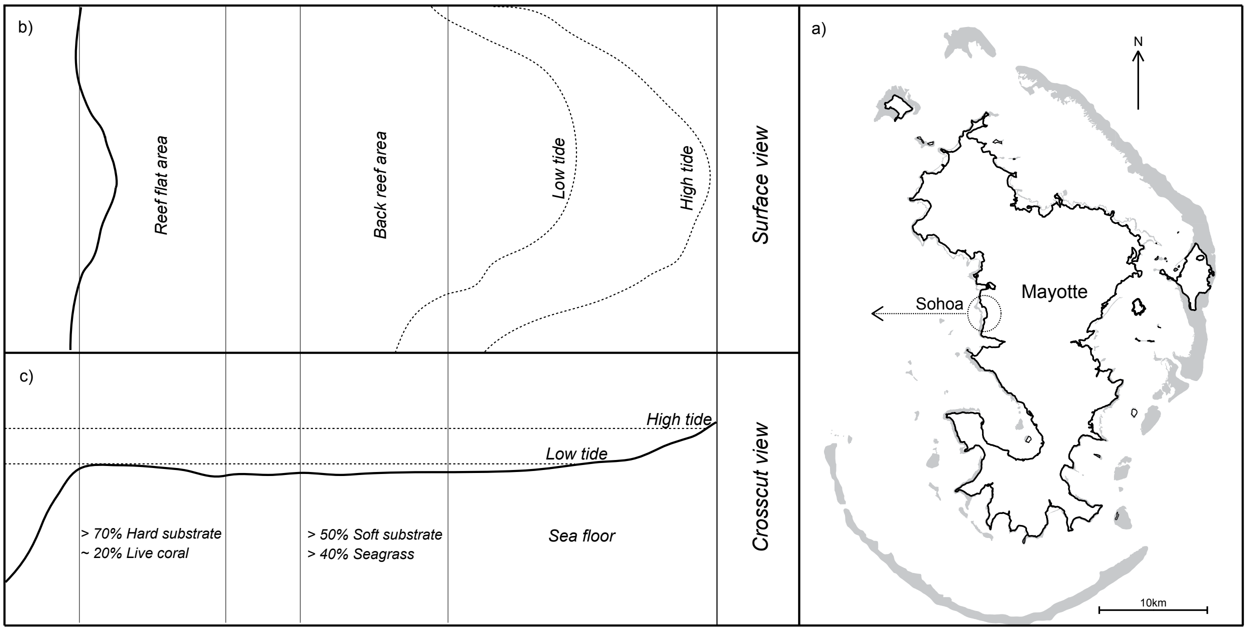

Figure 1. Substrate composition in the back reef seagrass area and adjacent hard benthic reef flat in front of the village of Sohoa in Mayotte.

of *S. chloronotus* recorded in the back reef area was 104.1 ± 8.7 mm and differed significantly ($F_{1,41}$ = 10.8, p = 0.002) from the mean length (143.8 ± 7.9 mm) of individuals recorded on the reef flat (Fig. 2). The smallest animal (50 mm) was recorded in the seagrass area while the largest (280 mm) was recorded on the reef flat. In addition, aggregations of small juveniles were observed in the nearshore shallow waters outside the sampled transects of 5–10 animals (~ 30–40 mm) on football-sized boulders that were partially submerged during low tide.

Discussion

As with other organisms (e.g. Nagelkerken 2009) and specific observations reported by Shiell (2004), our findings suggest that *S. chloronotus* utilizes different habitats throughout its life history. Similar to *H. scabra* (Hamel et al. 2001), seagrass beds are likely to be important settlement substrates for this species within the back reef habitat. We postulate that when individuals grow larger they migrate to the harder substrate on the proximal reef flat, about 200 m away. Similar observations of aggregated juvenile *S. chloronotus* have also been noted elsewhere (e.g. Samoa) (see Friedman et al. 2011) (Fig. 3). In addition, during the survey in Mayotte, we observed subadult (10–15 cm) white teatfish *H. fuscgogilva* on nearshore shallow seagrass areas within a larger group of adults in deeper water (15–20 m) outside the sandy reef front area; these indiviudals exhibited a similar pattern to that of *S. chloronotus* reported on in this study. Identical observations have also been made by Reichenbach (1999) who concludes that recruitment of *H.*

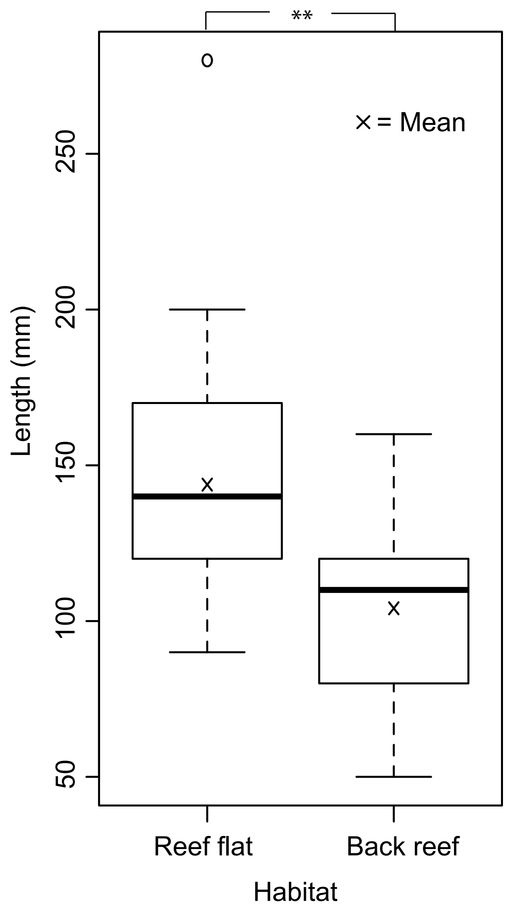

Figure 2. Mean length (±SE) of individuals of *Stichopus chloronotus* recorded in the back reef area and on the reef flat near the village of Sohoa in Mayotte.

fuscogilva occurs in shallow seagrass areas. In addition, subadults (10–15 cm) of black teatfish *H. nobilis* have been observed in intertidal seagrass areas in Zanzibar (pers. observ. by one of the authors of this paper H. Eriksson), inside its preferred adult general habitat on the reef flat. Similar observations have also been recorded for the species *H. whitmaei* in the Pacific (Byrne et al. 2004). Conand (1993) has also noted similar patterns for *S. herrmanni* recruiting into shallow waters (shallow reef flats, or seagrass beds). These observations show that many sea cucumber species harvested for the beche-de-mer trade depend on various habitats within the coastal seascape, and underline the fact that an ecosystem-based perspective is indeed important for managing sea cucumber stocks. *S. chloronotus* exhibit both sexual and asexual reproduction (Franklin 1980; Conand et al. 2002), and fission seemingly occurs during colder winter months when sexual reproduction is inactive (Uthicke 1994; Conand et al. 1998). The animals observed in this study showed no signs of being fission products, despite sampling being performed during the winter.

Figure 3. Aggregated juveniles of *Stichopus chloronotus.*

In conjunction with our sea cucumber study in Mayotte, an interview-based study on the importance of seagrass beds to local communities found that over the last 10–20 years there has been extensive losses of seagrass cover due to anthropogenic development (e.g. land reclamation, road and construction work) and cyclones. In addition, previously lush extensive seagrass meadows of *Thalassodendron ciliatum* in barrier reef areas in Mayotte have disappeared (pers. observ. by one of the authors of this paper, J. Wickel). Contextualising this loss of substrate for sea cucumber recruitment, Mercier et al. (2000) found that in the absence of suitable substrate (i.e. the seagrass *Thalassia hemprichii*) the sandfish *H. scabra* delays settlement for about four days, and that survival then is <0.5%, illustrating the potential bottleneck in recruitment and stock recovery from overfishing if this habitat is lost. Our conclusion is that even if overfishing is acknowledged to be the most apparent reason for depleted stocks (e.g. Friedman et al. 2011), the issue is potentially worsened by the loss of settlement areas that are important during the early life-history stages of sea cucumbers. Therefore, fisheries managers need to monitor stocks and identify areas of settlement and recruitment because these areas vary (Lamare and Barker 2001), and apply ecosystem-based management accordingly (Purcell 2010).

This study was constrained by 1) a methodology that did not aim to collect the maximum number of lengths, and 2) a sample unit that was too coarse to capture the highly aggregated behaviour of juveniles on boulders in nearshore areas. Our findings warrant further studies on habitat selectivity that can provide insight into juvenile and adult utilization of habitats. For example, because *S. chloronotus* is selective with regard to feeding sediment (Uthicke 1999), investigating sediment granulometry or feeding substrate in relation to body size can prove useful. We propose that more research is needed on the issue of habitat connectivity and cross-habitat movement for commercial sea cucumbers. We also stress the need to develop a better understanding of habitat utilization by moving away from general geomorphologic descriptions of distribution, and to further explore and quantify habitat utilization at a scale that incorporates habitat substrates as well as the coverage of seagrass or coralline algae, both of which are settlement substrates for echinoderms (Mercier et al. 2000; Hugget et al. 2006).

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The sea cucumber fishery in Semporna, Sabah, Malaysia

Poh Sze Choo[1]

Introduction

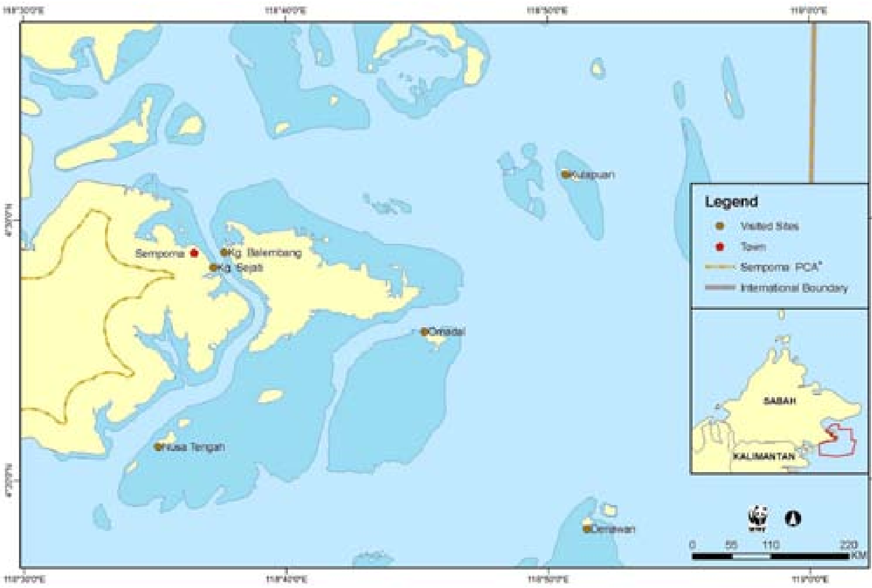
Fishing for sea cucumbers, pearl shells, abalone and other marine products in Southeast Asia dates back many centuries ago. Trepang (dried, processed sea cucumber) was an important trade item in the 1700s and was exported to China together with turtle and pearl shells (Butcher 2004). Coastal communities in Southeast Asia have a long history of fishing for sea cucumbers.

Butcher (2004) provided descriptions of the fishery in this region during the 1600s to 1800s. In Sulawesi, fishers located sea cucumbers in shallow waters by feeling them with their feet, but collected samples from deeper waters by diving. In the Kangean Islands, women collected sea cucumbers by hand in shallow waters while men collected them from deeper waters by lowering a weighted, three-pronged spear. In the 1800s, the Sultan from Sulu employed the Bajau Samal Laut people and slaves to collect marine products. As demand for these marine products grew in China, the Sultan and his chiefs encouraged the Iranun and the Balangingi Samal to capture people to provide the necessary labour to procure these products. People from the islands and those from the Malay Peninsula were captured and forced to work as slaves for the Sulu Sultanate. At the height of the pearl shell and trepang trade in the 1830s, as many as 68,000 people were engaged each year in collecting marine products (Butcher 2004).

In present day Malaysia, sea cucumber landings are relatively insignificant in comparison to fish and prawn catches that average approximately a million tonnes a year. Almost all commercial sea cucumber landings are from the state of Sabah in East Malaysia, and catches are landed mostly by artisanal fishers. In 2005, 139 t of sea cucumbers were landed in Sabah (Annual Fisheries Statistics, Sabah, 2000–2005).

This study describes the sea cucumber fishery in Semporna, Sabah and examines the size and sustainability of the fishery. Information on fishing methods, time of fishing, species and amount caught, earnings derived from the fishery, and downstream activities were documented. Information was gathered through 1) interviews using a structured questionnaire, 2) informal observations in the fishing villages visited, and 3) conversations with fishers. In total, 51 fishers were interviewed.

Several sites in Semporna were visited (Fig. 1), including Kampung Balembang, Kampung Berjasa, Kampung Sejati, Pulau Denawan, Pulau Kulapuan, Pulau Nusa Tengah and Pulau Omadal.



* PCA: Priority conservation area

Figure 1.
Study area, showing places visited during the survey of fishers involved in abalone and sea cucumber fishing (Map© WWF Malaysia).

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Findings

The gender of sea cucumber fishers

Fishers who collect sea cucumbers in Semporna belong to either the Bajau Tempatan or Bajau Laut communities. Most of the fishers are men who mainly fish at night either alone, with friends or with family members (usually their sons). A small number of fishers in Denawan and Nusa Tengah fish with their wives and daughters. In areas where sea cucumbers are still found on shallow reef flats (e.g. Nusa Tengah), women and children frequently glean for sea cucumbers during low tide.

Species targeted

There are no regulations regarding the size of fresh sea cucumbers that can be fished as well as the processed sea cucumbers that are allowed to be sold locally. Fishers normally target both abalone and sea cucumbers. All respondents from Kampung Balembang (five) and Pulau Kulapuan (six) reported targeting both abalone and sea cucumbers. In Pulau Denawan, 92% of fishers targeted both abalone and sea cucumbers, with two fishers or 8% fishing only for sea cucumbers. In Pulau Omadal, six out of seven fishers (or 86%) fished for abalone and sea cucumbers, with only one fisher fishing for sea cucumbers. In Nusa Tengah, six out of seven fishers fished for both abalone and sea cucumbers, with one fisher fishing for only sea cucumbers. Table 1 shows the number of respondents from the various localities and the number who fished for both abalone and sea cucumbers.

Table 1. Number of respondents from various locales in Semporna and the number of fishers from each locality who fished for both abalone and sea cucumbers.

Location	No. of respondents	No. and percentage of fishers who fished for both abalone and sea cucumbers
Kampung Balembang	5	5 (100%)
Kampung Berjasa	0	0 (0%)
Kampung Sejati	1	0 (0%)
Pulau Denawan	25	23 (92%)
Pulau Kulapuan	6	6 (100%)
Pulau Nusa Tengah	7	6 (86%)
Pulau Omadal	7	6 (86%)
Total	51	46 (90%)

The most abundant species of sea cucumbers landed include: *Stichopus herrmanni* (curryfish), *Holothuria coluber* (snakefish), *Actinopyga lecanora* (stonefish) and *Actinopyga echinites* (deep-water redfish) (Fig. 2). Species frequently sold to processors in the wet market in Semporna include: *Stichopus herrmanni* (curryfish), *Bohadschia vitiensis* (brown sandfish), *Bohadschia* sp., *Bohadschia argus* (tigerfish), *Holothuria coluber* (snakefish) and *Actinopyga echinites* (deep-water redfish). *Holothuria whitmaei* (black teatfish) and *Holothuria scabra* (sandfish), both high-value species, are still occasionally caught in waters off Semporna (Fig. 3) but were rare and both species could be overfished. In the early 2000s, sea cucumber landings from Semporna comprised an estimated 50% of the total landings from Sabah (Annual Fisheries Statistics, Sabah, 2000–2005).

Sea cucumber fishing grounds

Due to decades of overfishing, fishers are no longer able to find enough sea cucumbers in areas close to their village and so need to scour the islands to sustain their livelihood. Information gathered for this study shows that fishers from different villages

Table 2. Scientific, English common names and local names of sea cucumbers collected in Semporna, Sabah.

Scientific name	Common name	Local name
Actinopyga echinites	Deep-water redfish	Brown beauty
Actinopyga lecanora	Stonefish	*Boli-boli*
Bohadschia argus	Tigerfish/Leopardfish	*Kulirau*
Bohadschia sp.	-	*Tadik*
Bohadschia vitiensis	Brown sandfish	Mother *tadik*
Holothuria coluber	Snakefish	*Sumping*
Holothuria edulis	Pinkfish	*Merah perut*
Holothuria fuscopunctata	Elephant trunkfish	*Gajah*
Holothuria whitmaei	Black teatfish	*Susu*
Holothuria scabra	Sandfish	*Putian*
Stichopus herrmanni	Curryfish	*Gamat*
Thelenota ananas	Prickly redfish	*Talipan, Lipan*

Figure 2. Sea cucumbers landed in Kampung Balembang: *Actinopyga lecanora* (stonefish) (bottom center); *Actinopyga echinites* (deep-water redfish) (left); *Stichopus herrmanni* (curryfish) (top center); *Holothuria coluber* (snakefish) (top right) (photo © Choo P.S.).

Figure 3. Fisher holding *Holothuria scabra* (sandfish) caught in Semporna waters (photo © Choo P.S.).

fished in overlapping grounds. Table 3 shows the areas where fishers from various villages frequently fished. Those interviewed from Kampung Sejati are mainly processors and traders and most of them obtain their sea cucumber supplies from other fishers, with a couple of fishers engaged in part-time fishing on an irregular basis.

Table 3. Fishing grounds for sea cucumbers in various localities in Semporna, Malaysia.

Fishers' village	Fishing grounds
Kampung Balembang	Boheyan, Omadal and Menampilik
Denawan	Denawan, Ligitan, Mabul, Buasan
Kulapuan	Mantabuan, Denawan, Boheyan, Omadal, Timbun Mata
Nusa Tengah	Nusa Tengah, Menampilik
Omadal	Balimbang, Omadal, Mabul, Ligitan, Kapalai, Tawau

Fishing methods

Due to almost two decades of intense fishing in shallow reef areas, gleaning for sea cucumbers is becoming increasingly difficult. In Balembang, 2 out of 5 fishers (or 40%) gleaned, in Denawan, 3 out of 25 of fishers (or 12%) gleaned, in Kulapuan, 2 out of 6 (or 33%) gleaned, and in Omadal 2 out of 7 (or 29%) gleaned. In Nusa Tengah, however, 6 out of the 7 fishers still gleaned for sea cucumbers. Most fishers free-dived at night with a small percentage using compressors, fins and goggles.

Processing

This study found that a considerable number of fishers sold sea cucumbers in processed or semi-processed form. In Pulau Denawan, 80% of fishers sold sea cucumbers in either semi-processed or processed form; in Omadal, 71%; in Nusa Tengah, 70%; in Kampung Balembang, 33%; and in Pulau Kulapuan, 22%. In the Bajau Laut community, both men and women are actively involved in processing sea cucumbers. Women in the more remote Bajau Laut communities participate in many livelihood activities, including fishing and processing (Fig. 4).

Small-scale processors *cum* traders were mainly in Kampung Sejati in Semporna town. They obtained their sea cucumber supplies from Bajau Laut or Suluk fishers in Semporna as well as fishers from the Philippines and Indonesia. Some of the sea cucumbers obtained from fishers were semi-processed but most were brought in fresh to the processors from the previous night's fishing. Monthly earnings of processors *cum* traders were significantly higher than that of fishers.

Earnings

Sea cucumber fishers consistently reported low monthly earnings. Of the 48 respondents who reported on their monthly income, only 5 registered monthly earnings of USD 330 or more.[2] Fishers night fishing with compressors, hook fishing and diving with accessories such as goggles and fins earned more than gleaners whose monthly incomes ranged from less than USD 33–231. Taking into account that Sabah's household poverty level income for a family of 5 is USD 317, about 90% of those surveyed lived below the poverty line.

The average monthly income of processors *cum* traders was documented from only one respondent and appeared to be significantly higher than the income from fishers. An interviewee involved only in processing and trading reported a monthly income of USD 990 from the sale of sea cucumbers. Apart from selling sea cucumbers, most processors *cum* traders also traded in other marine products, including dried molluscs and fish as well as tapioca dough. Some of them were also part-time fishers, fishing two to three times a month.

Sea cucumber prices

Generally, prices of sea cucumbers per kilogram of dry or wet weight quoted by fishers varied, and prices of trepang (processed sea cucumber) quoted by them were well below the market price quoted in the Tawau market.[3] For example, dried tigerfish was quoted by fishers in Semporna to be around USD 18–30 kg^{-1} whereas in Tawau, the better quality ones were quoted at USD 192 kg^{-1}. One explanation is that sea cucumbers processed by fishers or small backyard processors are not very dry (still containing 20–30% water content) and were only semi-processed; therefore, they fetched lower prices. Fishers gave the impression that they were not aware of the global market prices for trepang. Fishers have no control over the price of sea cucumbers and trepang, and accepted whatever price paid to them by processors; as as one processor said, "the fishers needed instant cash". Table 4 shows the prices reported by fishers for their catch (wet weight) and their processed trepang (still with at least 20–30% water content).

A small-scale processor from Semporna town reportedly paid below-normal prices to fishers for different species of sea cucumbers (according to size, which determines the grade: XL, L, M, S):

- *Actinopyga lecanora* (wet): USD 6.60 kg^{-1}
- *Bohadschia* sp. (9–10 cm in size, wet): USD 1.00 kg^{-1}
- *Holothuria whitmaei* (wet): USD 16.50 kg^{-1}
- *Actinopyga echinites* (wet): USD 2.65–3.00 kg^{-1}
- *Holothuria coluber* (wet): USD 2.00–2.65 kg^{-1}

Figure 4. Fishers in Nusa Tengah; both women and men participated actively in our interviews (photo © Choo P.S.)

Table 4. Prices of sea cucumbers (wet and semi-dry) quoted by fishers in Semporna.

Scientific name (English common name and local name)	Price USD kg^{-1} (wet)	Price USD kg^{-1} (dry)
Actinopyga echinites (deep-water redfish, brown beauty)	2.60–3.00	8.30
Actinopyga lecanora (stonefish, *boli-boli*)	10–20	50–53
Bohadschia argus (tigerfish or leopardfish, *kulirau*)	8.30	18-30
Bohadschia vitiensis (brown sandfish, mother *tadik*)	2.60	10
Bohadschia sp. (*tadik*)	3.30	6.60–13.20
Holothuria coluber (snakefish, *sumping*)	2–4	15–16.50
Holothuria edulis (pinkfish, *merah perut*)	1.60–4.95	11.60
Holothuria fuscopunctata (elephant trunkfish, *gajah*)	3.30	8.30
Holothuria scabra (sandfish, *putian*)	10	92.50
Holothuria whitmaei (black teatfish, *susu*)	26.50	99
Stichopus herrmanni (curryfish, *gamat*)	5–10	46
Thelenota ananas (prickly redfish, *talipan*)	13	73

1 Note from the Editor. All values have been converted from Malaysian ringgits (MYR) to US dollars (USD). 1 USD = 3.02600 MYR (as of February 2012)

2 Tawau is a bigger city that is about one hour's drive by car from Semporna.

In the Semporna wet market, sandfish are not sold because they are rarely caught. Brown beauty (*Actinopyga echinites*), which is commonly caught in Semporna, is sold to traders in Tawau who then export them to Hong Kong, where they are re-exported to China. Common species of sea cucumber sold in Semporna include *Bohadschia* sp., *B. argus*, *Thelenota ananas*, *Actinopyga lecanora* and *A. echinites*. Processed sea cucumbers are sold in the Semporna market for the following prices:

- *Holothuria whitmaei* (5–6 pieces kg^{-1}): USD 115 kg^{-1}
- *Actinopyga echinites*: USD 8.25 kg^{-1};
- *Bohadschia* sp. (100–150 pieces kg^{-1}): USD 33 kg^{-1}
- *Holothuria coluber:* USD 5.00 kg^{-1}
- *Thelenota ananas* (6 pieces kg^{-1}): USD 66 kg^{-1}

Large sandfish are not sold in the Tawau market, and small-sized sandfish are imported from Indonesia. Trepang are also sold vacuum-packed. Prices of trepang in the Tawau market and marine products specialty shops are:

- *Holothuria whitmaei* (2–3 pieces kg^{-1}): USD 413 kg^{-1}
- *Holothuria scabra* (60–65 pieces kg^{-1}, from Indonesia): USD 132 kg^{-1}
- *Thelenota ananas* (6 pieces kg^{-1}): USD 73 kg^{-1};
- *Bohadschia argus* (13 pieces kg^{-1}): USD 192 kg^{-1}

Changes in sea cucumber landings

Overall, fishers seem to agree that sea cucumber landings have decreased over the last 10 years . In Kampung Sejati, all five respondents agreed that landings have decreased. In Denawan and Omadal, 88% and 86% (respectively) agreed that there was a decrease in catch over the last 10 years. In Kulapuan, Kampung Balembang and Nusa Tengah, 67%, 50% and 50% (respectively) thought that catches had dropped. In view of the fact that wild-caught fisheries have declined, most fishers showed interest in sea cucumber farming.

Regulating sea cucumber fisheries

Fishers were equally divided on whether sea cucumber fisheries should be regulated. More fishers favoured imposing a minimum size limit on fresh individuals of sea cucumbers than imposing a closed season. Table 5 shows feedback from fishers on whether sea cucumber fisheries should be regulated.

Processing sea cucumbers

There are some small variations in the methods of preparing dried, processed sea cucumbers. One method involves the following steps.

Fresh sea cucumbers are placed in boiling freshwater and boiled for one hour. Sea cucumbers with hard skins (such as *Bohadschia* sp. and *Bohadschia argus*) are then placed in a basin where slices of unripe papaya are added to soften the skins. The boiled sea cucumbers, together with the sliced papaya, are stirred with a wooden pole for 30 minutes to an hour and kept overnight. They are boiled a second time the following day for another 30 minutes. The sea cucumbers are cooled to room temperature and fishers then rub them with hands to remove the hard skin. Any remaining hard skin from sea cucumbers is gently brushed off with a plastic brush and the sea cucumbers are taken out to dry in the sun for two to three days.

Discussion

Sea cucumbers in Semporna appear to be heavily fished. In general, fishers have moved away from gleaning to free-diving at night (in some cases using compressors), which indicates that overfishing is occurring on the shallow reef flats. The sea cucumber fishery in Semporna has also followed the boom-and-bust trend observed in neighbouring countries, and species that are of high value (such as *Holothuria whitmaei* and *Holothuria scabra*) and were abundant in the 1980s and mid-1990s are now rare, while medium- and low-value species that were not fished before are now being harvested. *Actinopyga echinites* and *Bohadschia* sp. are caught in greater abundance as compared with other species.

There are no regulations that prevent the overfishing of sea cucumbers. Regulations governing

Table 5. Responses by fishers on whether sea cucumber fisheries should be regulated.

Locality	Regulation (No)	Regulation (Yes)	Comments
Kampung Balembang	4	2	1 fisher suggested imposing a minimum size limit on fresh individuals, and 1 person suggested a closed season.
Denawan	10	13	12 fishers suggested implementing a minimum size limit on fresh individuals, and 1 person suggested implementing a closed season.
Kulapuan	2	4	3 fishers suggested implementing a minimum size limit on fresh individuals, and 1 fisher suggested a minimum size limit as well as a closed season.
Nusa Tengah	7	3	3 fishers suggested imposing a minimum size limit on fresh individuals.
Omadal	3	4	4 fishers suggested imposing a minimum size limit on fresh individuals.
Kampung Sejati	3	2	1 fisher suggested imposing a minimum size limit on fresh individuals, and 1 fisher suggested a minimum size limit as well as a closed season.

a minimum size limit on fresh individuals and a closed season should be given high priority to prevent a collapse of the fishery. We should learn from other countries such as India, which has banned sea cucumber fishing and serving sea cucumbers in restaurants (Varma 2010), and from the Pacific Islands region where moratoriums on fishing, closed seasons and minimum size for harvesting are often used to regulate the fishery (Kinch et al. 2008).

The processing of sea cucumbers by small-time processors needs to be improved to enhance the quality and value. Fishers should have access to bank loans that would help them acquire processing tools (such as drums and drying racks), and training to process their catch and to enhance their earnings. Fishers say they need instant cash for their catch because many of them earn incomes below Sabah's poverty line of USD 320 per month per household.

Prices of wet and dry sea cucumbers quoted by fishers during the interview are inconsistent and varied significantly among fishers. At times, it was difficult to find out the actual price they received from processors. During field visits, a few sale transactions were observed between processors and fishers, and these figures were more reliable than those quoted by fishers during interviews.

It is generally believed that fishers received the least profit in the supply chain from the sale of freshly harvested products. The dry weight of most properly processed sea cucumber is 5–12% of the wet weight (Choo 2008). Price of processed sea cucumbers quoted by small-scale processors is generally 10 times the price they paid for the wet product. However, most processors in Semporna did not dry the sea cucumbers thoroughly and even if they sell their products 10 times higher than the price they pay for the sea cucumbers, they would have made substantial profits. Traders in Tawau were seen to label their products at very high prices, in some cases almost 20 times the price of the wet weight. For example, *Holothuria whitmaei* (black teatfish) is sold in one shop at USD 413 kg^{-1} when the wet weight paid to fishers is about USD 16.50 kg^{-1}.

The Bajau communities (including the Bajau Laut and Bajau Tempatan) are among the poorest of the poor in Sabah and are solely dependent on sea cucumber (and abalone) fishing for their livelihood. Providing Bajau communities with training and financial resources to initiate sea cucumber farming will be beneficial and will help them to earn a supplementary income.

Conclusion

The government should take immediate steps to address the issue of the fast-depleting sea cucumber resource. Regulating the fisheries by imposing a minimum size for harvest could be a first step and, if necessary, could be supported by closed seasons. Steps should be taken to aggregate juveniles and adults of highly threatened species in pens located in areas where collection is banned (such as marine parks) so as to enhance recruitment and restore the sea cucumber population.

Fishers should be frequently informed of the global market price for the various commercial species of sea cucumbers so that they are aware if processors underpay them. Fishers and processors should be provided with resources and training on correct processing methods so as to help them add value to their products. Coastal communities in Semporna appear to be interested in sea cucumber farming and should be given an opportunity to secure an alternative livelihood.

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Breeding and rearing of the sea cucumber *Holothuria scabra* in Iran

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Abstract

Induced spawning of *Holothuria scabra* was achieved for the first time in Iran in September 2011. Broodstock spawned when induced through combined stimulation. Larvae were kept at 26ºC and fed with unicellular algae. Early juveniles were first observed on day 24. Juveniles grew better under partial shade with natural sunlight than indoors. However, after one year, juveniles averaged only 22 g in weight.

Introduction

Because A-grade beche-de-mer produced from sandfish (*Holothuria scabra*) fetches a high price on the international market, this can lead to overexploitation (Agudo 2006). Dr James was the pioneer of artificial production of juvenile *H. scabra* (Pitt and Duy 2004; Laxminarayana 2005). Subsequently, several researchers have also worked on this species (Battaglene et al. 1999; Bell et al. 2007; Dabbagh et al 2011a, b; Hair et al. 2011; James et al. 1994; Lavitra et al. 2009; Mercier et al. 2000; Pitt and Duy 2004; Purcell et al. 2006). As an approach to commercial aquaculture production of sandfish, and sometimes to attempt to restock overexploited populations, this species has been bred and reared in Australia, Indonesia, New Caledonia, Maldives, Solomon Islands and Vietnam in recent years (James 2004). Sea cucumber culture in Iran started when, for the first time, juvenile *H. leucospilota* were produced by Dabbagh et al (2011a) at the research station in Bandar-e Lengeh. This paper outlines methods that have since been applied to breed and rear *H. scabra* in Iran.

Materials and methods

Broodstock

In June 2011, 25 *H. scabra* were bought for broodstock from dealers in Qeshm Island, and maintained in the hatchery in a bare 1-tonne (t) polyethylene tank. The water in the broodstock tank was changed daily. Animals were fed with an extract of *Sargassum* sp. and unicellular algae (*Chaetoceros* sp. and *Isochrysis* sp.).

Spawning and larval rearing

The methods used for inducing the spawning of broodstock were based on those developed by Dabbagh et al (2011b), which involve water pressure jetting followed by thermal stimulation. Normal temperature in the broodstock tank was 24°C, but this was raised by 5°C by a heater when carrying out thermal stimulation.

After females spawned, eggs were left for one hour to be fertilised. The collected eggs were washed in fresh seawater to remove excess spermatozoa. Eggs were then transferred to three larval rearing tanks that were stocked at a density of 0.7 eggs ml^{-1}. The temperature in the larval tanks was maintained at 26°C.

The eggs and early larvae were held in darkness by covering the larval tanks with opaque plastic covers. Larvae were fed with phytoplankton, including *Isochrysis* sp., *Chaetoceros muelleri*, *C. calcitrans* and *Pavlova lutheri.* The algae were given twice daily, at gradually increasing concentrations of 20,000 cells ml^{-1} to 40,000 cells ml^{-1}. Complete water changes (100%) were carried out every second day until the late auricularia stage was reached. At the start of the metamorphosis from late auricularia to doliolaria (Fig. 1), preconditioned polyethylene plastic sheeting, rough-surfaced tiles and 500-m planktonic netting were added to the tanks. During this stage, water was drained from the floor while fresh seawater was added at the top of the tanks. When settlement plates were placed into the tanks, the pentactula larvae were fed with spirulina powder and Algamac Protein Plus at a concentration of 0.25 g m^{-3}.

Rearing juveniles

Newly metamorphosed juveniles were fed with Spirulina powder and Algamac Protein Plus. When juveniles reached 2 cm, they were fed with *Sargassum* and *Padina* extract. The water in juvenile tanks was changed daily. A fine layer of sand was added to tanks as soon as juveniles reached 4 cm.

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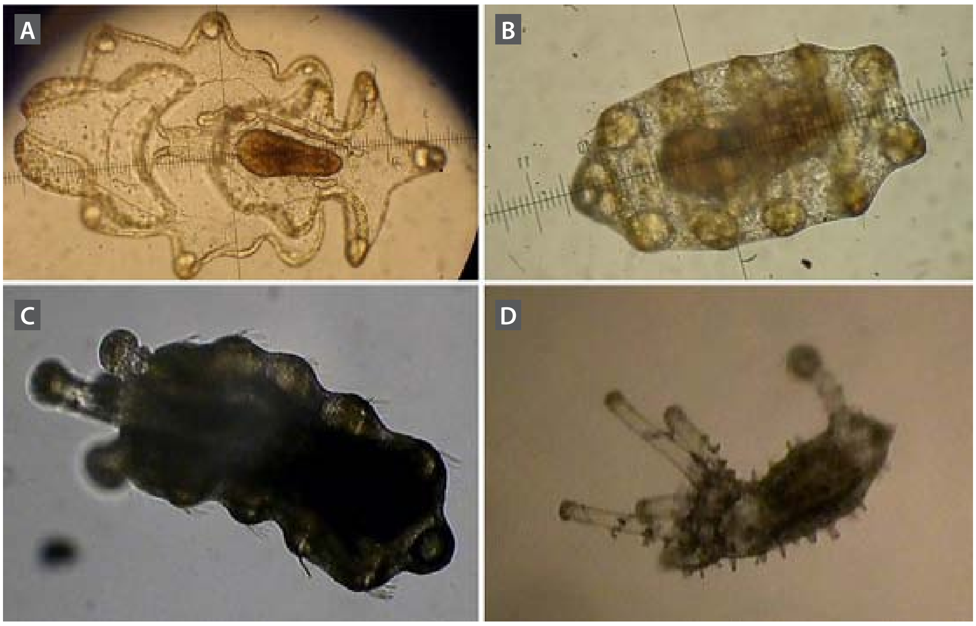

Figure 1. Developmental stages of *Holothuria scabra*:
A - auricularia; B - doliolaria; C - pentactula; D - early juvenile.

Results

Two days after broodstock were obtained they were exposed to several stresses but no spawning occurred. After further rearing, spawning occurred in September (Fig. 2). Attempts at spawning induction started at 11:00. By 15:05, 11 males had released sperm by raising their anterior ends. At 16:15, two females had spawned a total of 4 million eggs.

Figure 2. *Holothuria scabra* specimen standing erect and ready to spawn.

After 48 hours, embryos had developed to early auricularia (350–450 μ). On day 15, first non-feeding doliolaria (420–620 μ) were observed. On day 24, juveniles were easy to see on settlement plates (Fig. 3). After one year, juveniles were 22 g (Fig. 4). Juveniles reared in a large tank with natural sunlight reached larger sizes than juveniles under artificial light. Likewise, juveniles fed on extracts of *Sargassum* and *Padina* reached larger sizes than those fed with other feeds.

Figure 3. Early *Holothuria scabra* juveniles on settlement plates.

The timing for each developmental stage is shown in Table 1. Details of results according to the type of settlement plates and feed used for pentactula larvae and juveniles have

Figure 4. One year-old juvenile *Holothuria scabra*.

been described previously in Dabbagh et al. (2011a, b) and Dabbagh and Sedaghat (in press).

Table 1. Time after hatching for the different developmental stages of *Holothuria scabra*.

Stage	Time after fertilisation
Early auricularia	2 d
Mid auricularia	4 d
Late auricularia	8 d
Doliolaria	14 d
Pentactula	20 d
Juvenile 1 mm	30 d
Juvenile 22 g	1 yr

Discussion

Several species of sea cucumbers are processed to produce high value beche-de-mer (e.g. *Apostichopus japonicus*, *Holothuria spinifera, H. scabra, H. lessoni*, *Isostichopus fuscus*). The very highg demand for beche-de-mer from Asian markets has led to the overexploitation of many wild populations and has induced farmers to culture sea cucumbers (Ivy and Giraspy 2006; Agudo 2006). Attempts at breeding and rearing *H. scabra* in captivity have been conducted in several countries, including Australia, Fiji, India, Madagascar, New Caledonia, Solomon Islands and Vietnam (Bell et al. 2007; Battaglene et al. 1999; Hair et al. 2011; James, 2004; Lavitra et al. 2009; Morgan 2001; Pitt and Duy 2004).

The most common method for inducing *H. scabra* to spawn is thermal stimulation (James et al 1988; Morgan 2000; Battaglene et al. 1999; Giraspy and Ivy 2005). However, in this project, *H. scabra* was induced to spawn by applying combined stresses. Spawning may be seasonally limited in some countries. In Vietnam, for example, broodstock could be induced to spawn year round, but egg yields have been shown to be best from December to April (Pitt and Duy 2004). Spawning was obtained from October to March in the Gulf of Mannar in India and from March to October (James 2004). There seem to be spawning peaks in Iran in early and late summer. Induced spawning has also occurred in the middle of summer and in fall in Bandar-e Lengeh in the case of broodstock maintained under ideal conditions. Most aspidochirote holothurians go through the same larval stages, although development times may vary from species to species, or be related to latitude (Agudo 2006). *H. scabra* larvae in India took less than 15 days to reach the non-feeding doliolaria stage. Our larvae reached this stage on day 15.

Because this activity is new to Iran, various problems were encountered. One, for which a solution is yet to be found, is the high water temperature in Bandar-e Lengeh — over 30ºC year round. In addition, there is limited space for rearing juveniles at sufficiently low densities for good growth. Sea cucumbers have still only reached an average weight of 22 g one year after spawning. That is a very low growth rate. However, we think that if a special hatchery and nursery for sandfish were established in Bandar-e Lengeh, we would be able to overcome these problems.

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The effect of fishing pressure on the ecology of sea cucumber populations in the Gulf of Aqaba, Red Sea

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Abstract

Sea cucumber populations in the Gulf of Aqaba were surveyed in 2006, 10 years after fishing ended. Data here are compared with findings of previous surveys carried out in the same area in the years 1995, 2002 and 2003.

This study revealed that species diversity and density of sea cucumbers were significantly reduced between pre-fishing (1995) and post-fishing (2002–2006) periods in all study sites. In total, 18 species were recorded from 5 surveyed sites. The highest diversity in 1995 was found at Wadi Quny with 13 species, but decreased to only 4 species in 2006. The diversity of sea cucumbers at the Eel Garden was 12 species in 1995, but decreased to only 2 species in 2006. There was no available data for Shark Reef, Nakhlet El-Tall and Abu Negilla Lagoon for the years 1995 and 2002. Shark Reef and Nakhlet El-Tall recorded the same number of species between 2003 and 2006, while Abu Negilla Lagoon recorded a reduction in the number of species from 8 in 2003 to 5 in 2006. The study revealed that both diversity and density of sea cucumbers in the Gulf of Aqaba were below sustainable levels. This is a result of overfishing and the biological constraints that may have reduced their reproductive success.

Introduction

Populations of sea cucumber are being overfished worldwide. Some studies indicate that sea cucumber populations in overexploited fishing grounds may require as many as 50 years in the absence of fishing pressure to rebuild (Battaglene and Bell 1999; Bruckner et al. 2003; Skewes et al. 2000). The Gulf of Aqaba is valued for its unique environment and wide range of habitats and outstanding biodiversity (Head 1987). In spite of the suitable conditions for sea cucumber species to reach high population levels, low density and diversity have been recorded from the Gulf (Hasan 2003; Hasan and Hasan 2004; El-Ganainy et al. 2006). The rapid decline in sea cucumber populations worldwide to support the beche-de-mer market (Conand 2001) has led to the start of fishing activities in the Gulf of Aqaba in late 1996. Several years later, a severe depletion in sea cucumber stocks took place in many areas of the Gulf. This depletion occurred in populations of all sea cucumber species of different economic values. Although the fishery began on a small scale, it rapidly expanded and much of the fishery was illegal. The expansion of the fishery led to serious depletion in sea cucumber stocks, in which both density and diversity were greatly reduced. This led to a ban in 2006 on all sea cucumber fishery operations in the Gulf of Aqaba.

The sea cucumber fishery in the Gulf of Aqaba was carried out without baseline biological data or a monitoring plan. The lack of awareness of fishermen and the absence of management (of fishing and trade) increased the problem.

The current study aims to describe the variations in sea cucumber diversity and population density in the Gulf of Aqaba between pre-fishing and post-fishing periods. It investigates the effect of overfishing on sea cucumber species in Iran.

Materials and methods

Sea cucumber populations at five sites in the Gulf of Aqaba (Shark Reef, Wadi Quny, the Eel Garden, Nakhlet El-Tall and Abu Negilla Lagoon) were surveyed during April and May 2006. The results were compared with other data previously collected

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during the same time in 1995, 2002 and 2003 from Wadi Quny and the Eel Garden. For Shark Reef, Nakhlet El-Tall and Abu Negilla Lagoon, previously collected data were only for 2003.

Field survey and sampling

Sea cucumber populations at the five study sites were estimated using underwater visual transects. Direct visual assessment is the conventional method used and is effective for directly counting specimens of epifauna (Lokani et al. 1996). At each site, transects were made starting from the highest watermark, parallel to the shore covering different depths, zones and habitats. The length of each transect was 150 m. Between five and nine replicates were made at each zone and/or depth. Along each transect 10, 100 m^2 (10 m × 10 m) quadrates were placed. The reef flat was surveyed by snorkeling, while the deep water was surveyed by scuba diving. The following data were collected:

- Sea cucumber faunal composition by recording all species found at each site.
- Population density, expressed as the number of individuals 100 m^{-2}.
- A description of the biotope of each quadrat was made. The benthic composition of the substrate was described in terms of the percentage cover of sand, seagrasses, algae, rocks, dead and live corals.

Statistical analyses

At each site, paired *t*-test (Sokal and Rohlf 1995) was used to compare densities of sea cucumber populations recorded in pre-fishing (1995) and post-fishing (2002, 2003 and 2006) periods. Also, the same test was used to compare populations during post-fishing years 2002–2003 and 2003–2006. The analysis was done using Origin 6.1. The t-test values were compared with the p-value (probability) to indicate the level of significance.

Cluster analysis of years according to the densities of sea cucumber populations was performed to figure out the relationship between these years using an unweighted, pair-group average method. Linkage distances were measured using the Euclidian distance method according to Sneath and Sokal (1973), and the analysis was done using Statistica 5.5.

Study sites

Shark Reef

Shark Reef is a marine protected area inside Ras Mohamed National Park, thus, it is fully protected. It has a vast reef flat extending about 800 m, composed of dead and live corals with sandy patches. The site is rich with algae and seagrasses. The reef slope is steep, dropping to about 15 m, and is composed of coral patches among clean coralline sand. The main coral species recorded were *Acropora pharonis, Stylophora pistillata* and *Favia favus*. Then the reef drops again to 30 m, where it is composed of sand and seagrasses. The site is flourishing with marine life and has a high species index for major taxonomic groups, particularly corals and fishes. It also has a high abundance of molluscs and echinoderms.

Wadi Quny

Wadi Quny is located to the north of Dahab city along the coast of the Gulf of Aqaba. This site has a typical fringing reef, and the reef flat area is divided into three zones. The back-reef is composed of a fossil reef with very high algal cover (e.g. *Padina pavonia, Sargassum latifolium, Cystoseira myrica* and *Laurancia papillosa*). The mid-reef is composed of rocky and sandy patches over a rocky base from a fossil reef. The fore-reef is mainly composed of live corals (e.g. *Acropora hemprichi, Stylophora pistillata* and *Porites solida*) with a small percentage of dead corals. The reef slope has diverse coral formations. The slope ends at a depth of 20 m into a sandy substrate. This site has rich communities of fauna and flora. Benthic algae and seagrasses were recorded in high percentages, especially on the reef flat and surrounding sandy areas of the sea bed.

Eel Garden

The Eel Garden is characterised by a very long reef extending for approximately 1,100 m and inhabited by very rich benthic communities and a variety of ecological niches and substrates. The depth of the reef flat ranges from 0.5 m to 2.0 m. The reef flat begins with a rocky substrate followed by extensive sandy areas covered in a rich growth of algae and seagrasses. Live corals begin to appear on the fore-reef and reef slope (e.g. *Acropora pharoansis, Stylophora pistillata, Serriatopora* sp., and *Montipora* sp.). The reef slope drops to about 20 m where the sea bottom is composed of sandy substrate interrupted by small rocky and dead coral patches. A large community of Bedouins resides in the surrounding area. Their main business is fishing and tourism.

Nakhlet El-Tall

Nakhlet El-Tall starts with a moderate reef flat composed mainly of sand and rocks and extending to around 400 m. The reef slope drops to 25 m, ending in a sandy bottom of coralline white sand interrupted by coral patches. Coral patches rise 4–6 m from the sea bed. The site is characterised by a high abundance of invertebrates (e.g. sponges), a high percentage cover of algae and seagrasses, and low to moderate numbers of fishes.

Abu Negilla Lagoon

This site is a large protected lagoon with an extensive sandy substrate, characterised by a large seagrass bed of *Halidula uninervis* and *Halophilla stipulacea* and a high cover of diverse algal species. The depth of the lagoon ranges from 0.5 m at its edges to about 2.5 m towards the center. The lagoon has a small opening to the sea about 10 m wide, permitting the exchange of water between the lagoon and the sea. Very rich invertebrate communities and a low abundance of fishes were observed in the lagoon.

Results

Species diversity

In total, 18 sea cucumber species were recorded from all of the surveyed sites.

At Wadi Quny, 13 species were recorded in 1995 compared with 4 species in 2006. Species diversity decreased from 13 species in 1995, to 8 species in 2002 (with the disappearance of two high-value species, *Holothuria fuscogilva* and *Stichopus variegatus*), and decreased further to five species in 2003 with the disappearance of another two species (*Holothuria nobilis* and *Holothuria atra*). By 2006, only four species were recorded.

At the Eel Garden, 12 species were recorded in 1995 compared with only 2 species in 2006. Diversity decreased from 12 species in 1995 to 7 species in 2002 (with the disappearance of several high-value species (*Holothuria scabra*, *Holothuria fuscogilva* and *Stichopus variegatus*), and sharply decreasing to 2 species in 2003 and 2006 with the disappearance of another high value species (*Holothuria nobilis*).

At Shark Reef, Nakhlet El-Tall and Abu Negilla Lagoon, there are no records for 1995 and 2002. At Shark Reef, four species were recorded in 2003 and 2006 with no record of any high-value species. The same situation was observed at Nakhlet El-Tall, where five species were recorded in 2003 and 2006. The number of species recorded from Abu Negilla Lagoon decreased from eight in 2003 to five in 2006 (Table 1).

Table 1. A comparison of species composition at the different survey sites between the period of pre-fishing (1995) and the period of post-fishing (2002, 2003 and 2006).

Species	Shark reef				Wadi Quny				Eel Garden				Nakhlet El-Tall				Abu Nigella Lagoon			
	1995	2002	2003	2006	1995	2002	2003	2006	1995	2002	2003	2006	1995	2002	2003	2006	1995	2002	2003	2006
Actinopyga miliaris	n.r.	n.r.			+				+	+			n.r.	n.r.			n.r.	n.r.		
A. echinites			+	+	+	+	+	+	+						+	+			+	+
A. mauritiana			+	+	+		+	+	+											
A. crassa															+	+			+	
A. serratidens																			+	
Bohadschia marmorata					+	+	+		+	+					+	+				+
B. vitiensis					+	+			+	+										+
Holothuria atra			+	+	+	+	+	+	+	+	+	+			+	+			+	+
H. leucospilota			+	+	+	+	+	+	+	+	+	+			+	+			+	+
H. nobilis					+	+			+	+										
H. fuscogilva					+				+											
H. scabra					+	+			+											
H. hilla					+				+	+										
H. impatiens																			+	
Stichopus variegatus					+				+											
Thelonota ananas					+	+														
Synapta maculata																			+	
Synaptula resprocanus																			+	

n.r. = not recorded; + = present

Species density

In addition to the fluctuation in species diversity, density has also changed during the years of investigation. The data showed a great reduction in species density at most surveyed sites from pre-fishing to post-fishing periods.

Wadi Quny showed a remarkable reduction in species density, not only between pre-fishing and post-fishing periods, but in post-fishing years as well (Fig. 1). The pattern of reduction was uniform among all recorded species, except for the non-commercial *H. leucospilota*, which showed a reduction in density only between 1995 and 2002. Its density even increased slightly from 2003 to 2006. Two high-value species were recorded in 1995, *Holothuria nobilis* and *Holothuria scabra*. The density of *Holothuria nobilis* in 1995 was as high as 16.7 ind. 100 m^{-2}, but dramatically declined to only 0.7 ind. 100 m^{-2} in 2002. The species disappeared altogether in both 2003 and 2006. The density of *Holothuria scabra* was also high (19.4 ind. 100 m^{-2}) in 1995, but decreased to 1.1 ind. 100 m^{-2} in 2002 before completely disappearing in 2003 and 2006.

The Eel Garden showed a great reduction in species density from pre-fishing (1995) to post-fishing (2002) periods (Fig. 2). After 2002, all commercial species disappeared except for *Holothuria atra*, which showed a significant reduction in density, but could still be found. The high-value species *Holothuria nobilis* was recorded at a density of 18.7 ind. 100 m^{-2} in 1995, but decreased to 1.3 ind. 100 m^{-2} in 2002, and totally disappeared in 2003 and 2006. There was a reduction in density of *Holothuria leucospilota* from 1995 to 2002, but its density increased in the following survey years of 2003 and 2006.

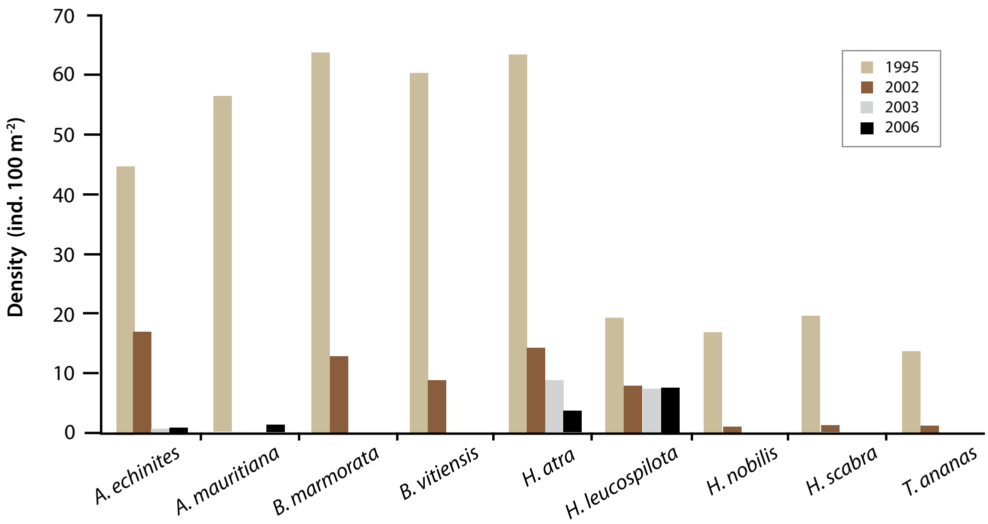

Figure 1. Variation in densities (ind. 100 m^{-2}) of sea cucumber species recorded in 1995, 2002, 2003 and 2006 at Wadi Quny, Gulf of Aqaba.

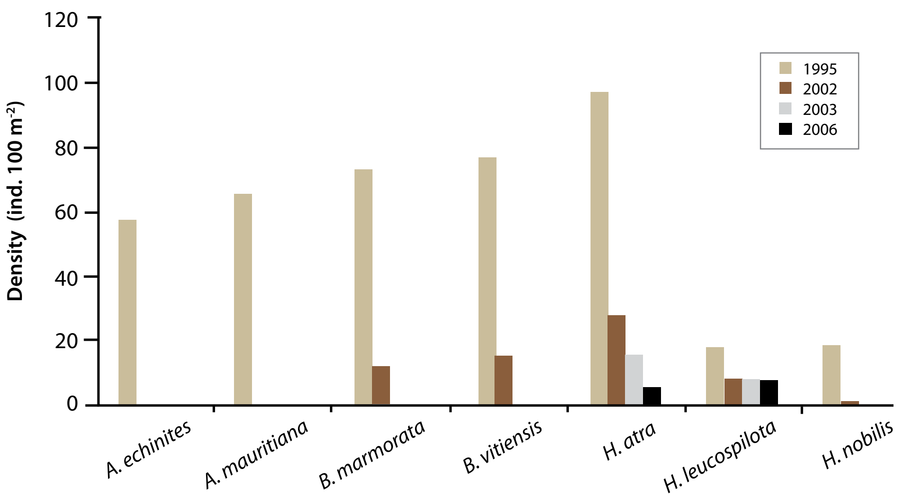

Figure 2. Variation in densities (ind. 100 m^{-2}) of sea cucumber species recorded in 1995, 2002, 2003 and 2006 at Eel Garden, Gulf of Aqaba.

There were no available records for 1995 and 2002 for Shark Reef, Nakhlet El-Tall or Abu Negilla Lagoon, but in both 2003 and 2006 four to six species total were recorded. At Shark Reef, the densities recorded in both years were low, but with no significant changes from one year to the other, despite the increase in densities of all species from 2003 to 2006, except for *H. atra*, which showed a slight decrease between the two years. At Nakhlet El-Tall, there were significant reductions in densities of commercial species between 2003 and 2006 (*Actinopyga crassa, A. echinites, Bohadschia marmorata* and *Holothuria atra*). The density of the non-commercial species *Holothuria leucospilota* did not change from 2003 to 2006. At Abu Negilla Lagoon there were no significant differences in the density of any species between 2003 and 2006, except for *Actinopyga crassa*, which was recorded at 3.9 ind. 100 m^{-2} in 2003 and completely disappeared in 2006.

Table 2. Statistical analysis of sea cucumber populations at different surveyed sites using t-test (paired) at a 0.05 significance level.

Site	Compared years	*P* value
Abu Negilla Lagoon	2003–2006	0.07061^{0}
	1995 and 2002–2006	0.00189**
Eel Garden	2002–2003	0.03065*
	2003–2006	0.16799^{0}
Nakhlet El Tall	2003–2006	0.01647*
	1995 and 2002–2006	4.8 x 10^{-4}**
Wadi Quny	2002–2003	0.03618*
	2003–2006	0.37176^{0}
Shark reef	2003–2006	0.60418^{0}

o = not significant; * = significant (p<0.05); ** = highly significant (p<0.01).

Sea cucumber populations at all study sites were statistically analysed (Table 2). Significant differences in sea cucumber populations were detected between pre-fishing (1995) and post-fishing (2002–2006) periods. Also, significant differences were evident between 2002 and 2003 at all sites. Differences in densities, however, were not significant between 2003 and 2006 at any of the sites except at Nakhlet El-Tall, which recorded a significant decline between the two periods.

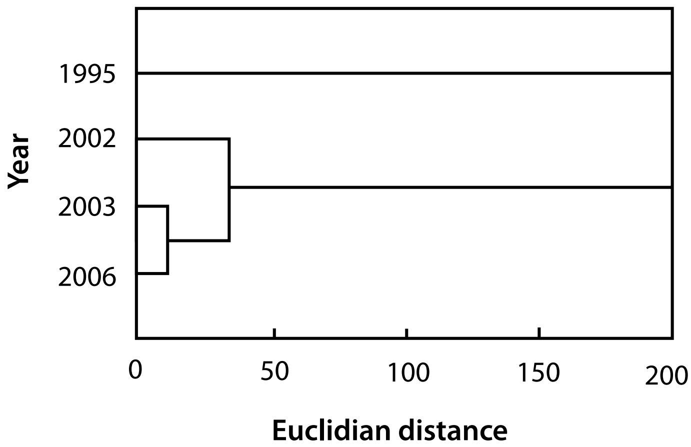

Figure 3. Tree cluster analysis of sea cucumber populations at the investigated sites for 1995, 2002, 2003 and 2006.

Study sites were grouped according to their sea cucumber population densities in time, using a cluster analysis (Fig. 3). The results of the cluster analysis revealed three different groups: the first group included sea cucumber populations in 1995, the second included populations in 2002, and the third included populations in 2003 and 2006.

Discussion

During the past few years, overexploitation of sea cucumbers has occurred in the Gulf of Aqaba, causing a severe decline in population densities of almost all species (Hasan 2003) at almost all sites (Hasan and Hasan 2004). The high fishing pressure exerted on sea cucumber species led to the disappearance of many commercial species and the reduction of others. The results obtained from this study not only showed a high reduction in sea cucumber populations between pre-fishing and post-fishing periods, but also the reduction was evident between successive years at post-fishing periods, indicating the continuity of the fishing process. This trend of sea cucumber overexploitation has been recorded not only from the Gulf of Aqaba, but also from many other parts of the world. There are a growing number of reports indicating that sea cucumber populations are declining worldwide in tropical and subtropical countries, including from areas in Australia (Uthicke and Benzie 2000), the Philippines (Surtida and Buendia 2000), Indonesia (Tuwo and Conand 1992), Japan (Conand and Byrne 1993), New Caledonia (Conand 1990), Fiji Islands (Adams 1992), East Africa (Kithakeni 2001), Mozambique (Mmbaga and Mgaya 2004), Yemen (Conand 2004), the Gulf of Aqaba (Hasan 2003), the Egyptian Red Sea (Hasan 2005), Eritrea (Kalaeb et al. 2008) and Saudi Arabian Red Sea (Hasan 2008).

The study of the spatial distribution of sea cucumber populations provided an understanding of the extent of the impact of environmental factors affecting the animals' lives (Young and Chia 1982; Kerr et al. 1993). Most of the sites surveyed have excellent conditions for sea cucumber survival, including suitable substrate, high food availability, a wide variety of ecological niches, different depths that meet with the difference in depth preferences for different species, and a low number of natural enemies. However, there was a severe drop in these species during successive years and all of the stocks in the visited sites were destroyed with no sign of recovery. Holothurians are susceptible to overexploitation due to their late maturity, density-dependant reproduction, and low rate of recruitment.

The data obtained from the pre-fishing (1995) and post-fishing (2002–2006) periods from the different areas were compared, and a high reduction in population was evident. Despite the low density and diversity recorded at Shark Reef, there was no fishing effort recorded at the site because it is a marine protected area with full protection. The low density at this site may be attributed to other factors because it is not a traditional ground for sea cucumber populations and because of the high level of tourism activities at the area. Abu Negilla Lagoon, which has excellent conditions for sea cucumber establishment, has a very low level of tourism and a healthy sea cucumber population. The site showed an insignificant decline in its population between 2003 and 2006, indicating low fishing pressure due to tight control by the South Sinai marine park authorities. The opposite occurred at the other three investigated sites, which showed a high reduction of population not only between the pre-fishing and post-fishing periods, but also between successive years of post-fishing (2002 and 2003), indicating the continuity of fishing effort at least until 2003. At Wadi Quny and the Eel Garden, a very significant reduction in sea cucumber populations was recorded between pre-fishing (1995) and post-fishing (2002–2006) years. No decline was recorded between 2003 and 2006, indicating the cessation of fishing operations after 2003.

Nakhlet El-Tall was the only site with a significant decline in sea cucumber populations between 2003 and 2006, revealing that fishing operations started late at the site and continued until 2006 due to the availability of populations there. The data indicated that the decline in population reduction after 2003 at the fished sites was not due to good management regimes, but to the disappearance of the populations from the area as a result of overfishing. This presumption is accentuated by the cluster analysis, which indicates that 1995 represents a separate case because it represents the condition of pre-fished populations (i.e. virgin population). On the other hand, no intrinsic variation was noticed between 2003 and 2006. The study revealed that fishing effort ended but recovery was not evident.

The same conclusion was obtained by Skewes et al. (2000) who reported that after seven years of the *Holothuria scabra* fishery being closed in the Torres Strait, the biomass estimated was less than 8% of the virgin biomass. Sea cucumber populations are greatly depleted to the extent that there are doubts as to their ability to recover. The recovery of overfished sea cucumber stocks is a lengthy process, sometimes taking several years (Purcell et al. 2002) because holothurians, like many other invertebrates, are broadcast spawners and fertilisation success is highly dependent on population density (D'Silva 2001). A reduction in population density by overfishing may render remaining individuals incapable of successful reproduction. It is now apparent that depleted stocks of high-value sea cucumber species at the surveyed sites may even take decades to recover. Not only was the density negatively affected, but also, species diversity. For sea cucumber populations that show chronically low levels in the Gulf of Aqaba, remnant species need to be protected. The present study suggests that the use of marine protected areas in this respect could be an effective management tool.

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Sea cucumber fisheries of Qeshm Island, Persian Gulf

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Qeshm Island (Fig. 1) is the largest Island in the Persian Gulf's Strait of Hormuz. It has an area of 149 km^2 and is three times the size of Singapore. Fishing is a major occupation that is practiced by many of the island's inhabitants.

Information on the exploitation, fishing techniques, and processing and trading of sea cucumbers at Qeshm Island was obtained through direct field observations[5] and through a questionnaire that was given during interviews with fishermen and local authorities. More than 15 people answered the questionnaire. Data were collected from local fishermen who actively fished for sea cucumbers from 2004 to 2006.

The most harvested sea cucumber species in Iran is the sandfish, *Holothuria scabra* (*khiar daryaei* in the local language, meaning "sea cucumber"). Sandfish fishing at Qeshm Island began in 2004 — in response to offers made by Indian and Bangladeshi traders — and lasted until 2006. It involved five to six diving groups (with at least four to five experienced skin-divers in each group), and was composed exclusively of men (Table 1). Fresh sea cucumbers were sold to foreign buyers at USD 0.3–0.4 per specimen in 2004 and for USD 0.9–1.0 in 2006. Foreigners processed sea cucumbers into beche-de-mer and sent the product by air to the United Arab Emirates from where they were transferred to international markets. There were seven main *H. scabra* fishing grounds at Qeshm Island: Hamoon, Kovei, Hormoz, Tolla, Ramchah, Massen and Hengam (Fig. 1).

The estimated number of fishers increased from 150 in 2004 to 200 in 2006. The average number of fishing hours per fisher per working day was five to six, with an average collection of 150 to 200 live sandfish per fishing trip. Men involved in this fishery had no other income-generating activities. All of the processing steps were carried out by the traders. Customs inspectors at the border checkpoint (airport) were not familiar with sea cucumbers, especially dried ones, and so the product was exported without proper identification. Fortunately, local fishing operations were stopped by authorities in 2006. The sea cucumbers sampled in 2010 were over 20 cm long and the estimated abundance was more than 30 ind. ha^{-1}.

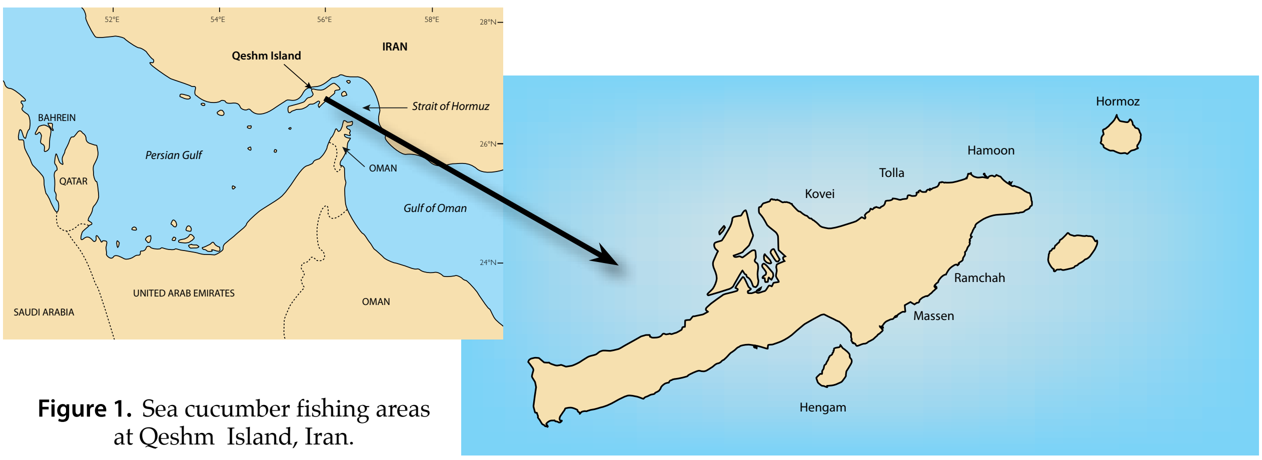

Figure 1. Sea cucumber fishing areas at Qeshm Island, Iran.

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5 Samplings were carried out in the summer and autumn of 2011 on the north coast of Qeshm Island between Hamoon jetty and Laft Port in depths of 5–12 m.

Table1. Comparison of sea cucumber fishery indicators between Oman and Iran (2004–2008).

Indicators*	2004–2005 (Iran)	2004–2005 (Oman)	2007–2008 (Oman)
Targeted size (cm)	>20	>25	All sizes (including <15cm)
Abundance in 2010 (ind. ha^{-1})	>30	25	<
Price to fisher (USD)	0.4–0.9	0.3–0.7	3.5–5
Targeted species	*H. scabra*	*H. scabra*	*H. scabra, H. atra* and *H. leucospilata*
Number of fishing areas	7 recorded in Qeshm Island	6 recorded in Mahut Bay	7 recorded grounds in Mahout Bay + 2recorded in Marish strait
% of women and children among fishers	0%	50%	15%
Fishing methods	Skin diving (100%)	Low tide collection by hand	Low tide collection by hand (70%) and skin diving (30%)

Information comes for Oman comes from Al-Rashdi et al. 2007a, b., and Iranian indicators come from information given by fishermen who collected sea cucumbers during the years 2004–2005 (except for data collected in 2010).

The abundance of *H. scabra* reported from Qeshm Island in 2010 is similar to that observed in Oman in 2005 (Al-Rashdi et al. 2007b) (see Table 1). It seems that the area of Qeshm Island still has adequate reserves. From the above observations, several suggestions concerning management could be proposed.

- Plan research projects so that they identify species, and describe the density and distribution of sea cucumber species, especially those at Qeshm Island.
- Ban sea cucumber fishing until a stock assessment has been conducted.
- Only allow harvesting to provide broodstock for hatchery centers.
- Establish programmes (e.g. trainings, study tours, participation in national and international meetings and workshops) on sea cucumbers. These should be conducted and supported by government organisations.
- Protect natural habitats of *H. scabra* — such as Qeshm Island — in order to supply broodstock to other parts of the country.

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Observation of juvenile *Stichopus vastus* in Pohnpei Lagoon, Federated States of Micronesia

From: Jeff Kinch, Principal, National Fisheries College, Papua New Guinea [jkinch@fisheries.gov.pg]

Species: *Stichopus vastus*

Note: During visits to coastal and island communities as part of an evaluation of sponge and coral farming in Pohnpei, large numbers of juvenile *Stichopus vastus* were sighted on the northeastern side of Pohnpei Lagoon adjacent to Pharewm Island. All of the juveniles were located on shallow seagrass beds with soft sandy substrate in around 1 m of water (flood tide).

Date observed: 2 March 2011 (~ 10.30 am)

Reference:

Byrne M., Rowe F. and Uthicke S. 2010. Molecular taxonomy, phylogeny and evolution in the family Stichopodidae (Aspidochirotida: Holothuroidea) based on COI and 16S mitochondrial DNA. Molecular Phylogenetics and Evolution 56(3):1068–1081.

Stichopus vastus (image: Jeff Kinch)

Communications...

from: *Steven W. Purcell and Alessandro Lovatelli*

SCEAM: A forum to strengthen an ecosystem approach to managing sea cucumber fisheries

Pandemic overfishing to critical levels threatens the existence of sea cucumber fisheries and the important role they play in the livelihoods of coastal fishers (Toral-Granda et al. 2008). Sea cucumbers are a key resource, contributing to poverty alleviation for more than 3 million fishers globally (Purcell et al. 2012). They are fished in every Pacific Island country (PIC) (Kinch et al. 2008) and are a vital marine export commodity for numerous countries elsewhere (Anderson et al. 2011).

To help fisheries managers, the Australian Centre for International Agricultural Research (ACIAR) and the Food and Agriculture Organization of the United Nations (FAO) coordinated and published manuals on sea cucumber fisheries management (Lovatelli et al. 2004; Friedman et al. 2008; FAO 2010; Purcell 2010). The manuals provide a "roadmap" and guidelines for developing and implementing better management of sea cucumber fisheries. To further assist fisheries agencies, a strategy was developed to hold workshops in each major region of the world where sea cucumbers are fished artisanally. To this objective, FAO, ACIAR, the Secretariat of the Pacific Community (SPC) and the Southern Cross University (SCU) partnered to coordinate the first regional workshop in the Pacific during November 2011: Sea Cucumber Fisheries: an Ecosystem Approach to Management (SCEAM).

The three and a half-day workshop aimed to bring about significant changes to management systems (both regulatory measures and actions by fishery agencies) in 13 PICs, focussing on the approaches provided in the ACIAR and FAO manuals. Participants were fishery managers or senior fishery officers in charge of managing sea cucumber fisheries. Each one submitted responses to questions about current management regulations, enforcement capacity, management capacity, stakeholder participation and fishing activities in their fishery.

Seminars by the workshop facilitators (Steven Purcell, Ian Bertram, Kalo Pakoa and Alessandro Lovatelli) included topics such as sea cucumber biology, management principles and regulations, management actions and the preparation of management plans. Participants then used the ACIAR and FAO manuals to assess the status of their fishery stocks using various indicators, and decided on appropriate regulatory measures and management actions, and ranked fishery objectives. Regulatory measures, management actions and constraints were also examined more closely for four important case-study fisheries.

The three primary outputs of the workshop will be:

- sets of regulatory measures and management actions decided on by each participant to be applied in their sea cucumber fishery;
- an FAO report summarising the outcomes; and
- a paper on the constraints, needs, management practices and potential solutions for the 13 fisheries reviewed.

Collation of responses to a post-workshop survey showed that most participants felt the workshop was neither too long nor too short. Most strongly agreed that they gained new knowledge from the workshop presentations and all stated that the workshop will be useful to the future management of their fishery. As a measure of success, all participants responded that the workshop had changed their opinion about how best to manage the sea cucumber fishery in their own country.

Future steps will be to coordinate similar workshops in other regions, namely the Indian Ocean, Southeast Asia and Latin America. The next phase is expected to be a "SCEAM Indian Ocean" workshop in Zanzibar at the end of 2012, depending on identification of suitable funding.

Acknowledgements

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Participants and facilitators at the 15–18 November 2011 meeting of SCEAM Pacific in Fiji.

from: *Maria Byrne*[1]

Sea cucumbers could be key to preserving coral reefs

Source: The University of Sydney – http://sydney.edu.au/news/84.html?newsstoryid=855930 – January 2012

Tropical sea cucumbers could play a key role in saving coral reefs from the devastating effects of climate change, say scientists at One Tree Island, the University of Sydney's research station on the Great Barrier Reef.

"We have found that sea cucumbers play a vital role in reducing the harmful impact of ocean acidification on coral growth," said Professor Maria Byrne, the director of One Tree Island Research Station.

"When they ingest sand, the natural digestive processes in the sea cucumber's gut increases the pH levels of the water on the reef where they defecate, countering the negative effects of ocean acidification," said Professor Byrne.

One of the byproducts of the sea cucumber's digestion of sand is calcium carbonate ($CaCO_3$) a key component of coral. To survive, coral reefs must accumulate $CaCO_3$ at a rate greater than or equal to the $CaCO_3$ that is eroded from the reef.

"The research at One Tree Island showed that in a healthy reef, dissolution of calcium carbonate sediment by sea cucumbers and other bioeroders appears to be an important component of the natural calcium carbonate turnover," said Professor Byrne.

"The ammonia waste produced when sea cucumbers digest sand also serves to fertilise the surrounding area, providing nutrients for coral growth," she added.

Stichopus herrmanni,
Lizard Island, Australia

The research, recently published in the Journal of Geophysical Research,[2] was carried out by an international group of scientists from the University of Sydney, the Carnegie Institute for Science, Stanford, and several other institutions studying the impact of climate change on coral reefs.

Sea cucumbers are among the largest invertebrates found on tropical reefs. Some 30 species are commercially harvested by the fishery industry along the Great Barrier Reef and throughout the tropics.

"We urgently need to understand the impact of removing sea cucumbers and other invertebrates on reef health and resilience at a time when reefs face an uncertain future," Professor Byrne said.

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[2] http://www.agu.org/journals/jgr/

Abstracts and new publications...

An overview of the Australian psolid sea cucumbers (Echinodermata: Holothuroidea: Psolidae) with the description of 5 new species

M. Mackenzie and E. Whitfield

Zootaxa 3037: 21–36 (2011)

Four new species of *Psolus* Oken from Australia are described: *Psolus parantarcticus* sp. nov. from Macquarie Island, *Psolus salottii* sp. nov. from South Australia and Macquarie Island, *Psolus steuarti* sp. nov. from Victoria, and *Psolus springthorpei* sp. nov. from Queensland. One new species of *Psolidium* Ludwig from Australia is described: *Psolidium oloughlini* sp. nov. from King Island. All Australian psolid species are included in the overview: *Ceto cuvieria* (Cuvier), *Psolidium berentsae* O'Loughlin and Maric, *P. granuliferum* H.L. Clark, *P. hutchingsae* O'Loughlin and Maric, *P. karenae* O'Loughlin and Maric, *P. laperousazi* O'Loughlin and Maric, *P. marshae* O'Loughlin and Maric, *P. mccallumae* O'Loughlin and Maric, *P. minutum* (H.L. Clark), *P. nigrescens* H.L. Clark, *P. parmatum* (Sluiter), *P. ravum* Hickman, *P. spinuliferum* (H.L. Clark), and *Psolus antarcticus* (Philippi). A key to the Australian species of Psolidae is provided.

Holothuria (*Selenkothuria*) *carere*, a new species of sea cucumber (Echinodermata: Holothuroidea) from the Mexican Pacific

M. Honey-Escandón, F.A. Solís-Marín and A. Laguarda-Figueras

Zootaxa 2922: 27–33 (2011)

A new species of sea cucumber of the subgenus *Selenkothuria* is described. *Holothuria (Selenkothuria) carere* was found in the Mexican Pacific, from intertidal to 1 m depth. The absences of ossicles in the body wall, as well as in the dorsal and ventral tube feet make this species unique among the rest of the species of this subgenus. Smooth straight rods with distal perforations and projections are only present in the dorsal and anal papillae, papillae at the base of the tentacles and in the tentacles. This species is clearly distinctive within the subgenus. The shape of the ossicles shows some similarities with *H. (S.) glaberrima*.

Present status of the commercial sea cucumber fishery off the north-west and east coasts of Sri Lanka

D.C.T. Dissanayake and G. Stefansson

Journal of the Marine Biological Association of the United Kingdom. DOI: 10.1017/S0025315411001019

The sea cucumber fishery has been providing an important means of livelihood to the coastal fishing communities in Sri Lanka for centuries. Stock status, level of exploitation and mortality parameters of eleven commercial sea cucumber species were studied off the north-west and the east coasts of Sri Lanka using data collected from an underwater visual census and fishery-dependent surveys carried out in 2008 and 2009. The total abundance of sea cucumbers was higher in the north-west than the east ($P < 0.01$). However, the total abundance of all the species declined between 2008 and 2009. The commercial fishery predominantly relies on two nocturnal species: *Holothuria spinifera* and *Thelenota anax. Holothuria spinifera* had the highest contribution (73.2%) to the total landings in the north-west while this was provided by *T. anax* (93%) in the east. Both catch per unit effort and total landings declined in 2009 compared to 2008 having three exceptions (*H. spinifera, Holothuria atra* and *Stichopus chloronotus*) in the north-west. Further, the collection of immature individuals, reduced landings of high-value species and temporal shifting of fishing activities were observed in both areas. Two approaches (simple linear regression and random effects models) were used to estimate the natural mortality of sea cucumbers and the estimated values were 0.50 yr^{-1} and 0.45 yr^{-1}, respectively. Apart from the management of local sea cucumber resources, this information is important to update the regional and global sea cucumber statistics as well as for launching regional management

Habitat preference of sea cucumbers: *Holothuria atra* and *Holothuria edulis* in the coastal waters of Sri Lanka

D.C.T. Dissanayake and G. Stefansson

Journal of the Marine Biological Association of the United Kingdom. DOI: 10.1017/S0025315411000051

Despite their economic importance, the ecology of many sea cucumber species is poorly understood and factors influencing their habitat preferences remain largely unexplained. The distribution and habitat preference of two sea cucumber species; *Holothuria atra* and *Holothuria edulis* were studied off the north-west coast of Sri Lanka by underwater visual census in October 2008. The relationships between the density of each species and the habitat variables, such as mean grain size, organic content (% of dry weight), gravel (%), silt–mud (%), and depth, were examined using a generalized additive model. All these variables except silt–mud have significant influence ($P < 0.05$) on the habitat association of *H. atra*. The shallow water (<10 m) seagrass habitat with sediments characterized by 2–3.5% organic content, 15–25% of gravel and coarse sand (0.7–1.2 mm) were the most preferred conditions by *H. atra*. High densities of *H. edulis* were found in the shallow (<10 m) depths of rocky areas with algae and seagrass. Favoured bottom sediment conditions of *H. edulis* were mainly similar to the conditions preferred by *H. atra*, except organic content which did not significantly influence the habitat preference of this species. The preference towards the specific habitat characteristics seems to be associated with their feeding and protection. An understanding of habitat preference would be useful to improve the management of these sea cucumber populations and enable more precise stock assessment.

Potential influence of sea cucumbers on coral reef CaCO3 budget: a case study at One Tree Reef

K. Schneider, J. Silverman, E. Woolsey, H. Eriksson, M. Byrne and K. Caldeira

Journal of Geophysical Research, vol. 116 (2011). DOI:10.1029/2011JG001755

To endure, coral reefs must accumulate CaCO3 at a rate greater or equal than the sum of mechanically, biologically and chemically mediated erosion rates. We investigated the potential role of holothurians on the CaCO3 balance of a coral reef. These deposit feeders process carbonate sand and rubble through their digestive tract and dissolve CaCO3 as part of their digestive process. In aquarium incubations with *Stichopus herrmanni* and *Holothuria leucospilota* total alkalinity increased by 97 ± 36 and 47 ± 18 μmol kg^{-1}, respectively. This increase was due to $CaCO_3$ dissolution, 81 ± 34 and 34 ± 16 μmol kg^{-1} and ammonia secretion, 16 ± 4 and 14 ± 4 μmol kg^{-1}, respectively for these species. Surveys conducted at a long term monitoring site of community calcification (DK13) on One Tree Reef indicated that the density of sea cucumbers was ca. 1 individual m^{-2}. We used these data and data from surveys at Shark Alley to estimate the dissolution of $CaCO_3$ by the sea cucumbers at both sites. At DK13 the sea cucumber population was estimated to be responsible for nearly 50% of the nighttime $CaCO_3$ dissolution, while in Shark Alley for most of the night time dissolution. Thus, in a healthy reef, bioeroders dissolution of $CaCO_3$ sediment appears to be an important component of the natural $CaCO_3$ turnover and a substantial source of alkalinity as well. This additional alkalinity could partially buffer changes in seawater pH associated with increasing atmospheric CO_2 locally, thus reducing the impact of ocean acidification on coral growth.

Putting into practice an ecosystem approach to managing sea cucumber fisheries

FAO

Source: FAO, Rome. http://www.fao.org/docrep/013/i1780e/i1780e00.htm

Artisanal and industrialized fishers from more than 40 countries harvest more than 60 species of sea cucumbers. These low-food-chain resources play important roles in nutrient recycling and sediment health in marine habitats. Owing to ease of capture and vulnerable biological traits, sea cucumbers have been easily overexploited in most countries, sometimes to local extinction. Few sea cucumber fisheries are currently managed sustainably. They differ greatly in the scale of the fishing activities, status of stocks and management capacity. This document summarizes general management principles and a general framework for developing and implementing a management plan. Through a few questions and simple indicators, managers are guided to choose appropriate sets of regulatory measures and management actions for different sea cucumber fisheries. Safeguarding sea cucumber stocks for current and future generations will require an ecosystem approach to fisheries (EAF) that applies precautionary measures with the participation of stakeholders. Success in applying an EAF will require consideration of the reproductive productivity of stocks, ecosystem health and the socio-economic systems that drive exploitation.

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Comparative study of reproductive synchrony at various scales in deep-sea echinoderms

S. Baillon, J.-F. Hamel and A. Mercier

Deep-sea Research Part I 58(3): 260–272 (2011)

This study examined the influence of temporal and spatial factors on the determination of reproductive cycles in selected deep-water echinoderms. The prevalence of inter-individual synchrony in the gametogenesis of three ubiquitous species, *Phormosoma placenta* (Echinoidea), *Hippasteria phrygiana* (Asteroidea) and *Mesothuria lactea* (Holothuroidea) collected off the coast of Newfoundland and Labrador (eastern Canada), was determined. Analyses revealed diverse degrees of gametogenic asynchrony at the scales examined (within trawls, between trawls over similar or different periods, as well as among depths and locations over the same period). Taken as a whole, samples did not show any annual or seasonal patterns, whereas some sets of samples, taken over a particular time period in the same area and at the same depth, revealed well synchronized maturing and/or spawning periods in *P. placenta* and *H. phrygiana*. This study presents evidence that determination of reproductive cycles in many deep-sea species may be affected by low sampling resolution inherent to most deep-sea studies. More accurate assessments of reproductive patterns and periodicities may require much tighter collection designs as several species are likely to rely on long-term or transient pairing and aggregation to synchronize their breeding activities.

Genetic population structure in a commercial marine invertebrate with long-lived lecithotrophic larvae: *Cucumaria frondosa* (Echinodermata: Holothuroidea)

So J.J. , S. Uthicke, J.-F. Hamel and A. Mercier

Marine Biology *158:859–870 (2011)*

The patterns of genetic diversity and connectivity were investigated in *Cucumaria frondosa*, the most abundant sea cucumber in the North Atlantic, to assist in the management and conservation of this ecologically important marine invertebrate, which is the target of an emerging fishery. Mitochondrial DNA COI sequences of 334 *C. frondosa* were obtained and analyzed, mainly from its western North Atlantic range, where the commercial fishery is being developed, with complementary sampling in the mid- and eastern North Atlantic. Analysis of molecular variance showed no significant ($P>0.05$) differences among subpopulations in the western region suggesting that it constitutes one panmictic population. The same analysis showed low, but significant differences between eastern and western Atlantic populations. Coalescent analyses using isolation with migration models and a Bayesian skyline plot indicated historical divergence and a general increase in population size prior to the last glacial maximum and highly asymmetric gene flow (nearly 100 times lower from west to east) between sea cucumbers from North America and Norway. Results suggest that subpopulations of *C. frondosa* within the western North Atlantic have been highly connected. We propose that aided by the high-connectivity local subpopulations can recover rapidly from natural (i.e., ice ages) or anthropogenic (i.e., overfishing) population declines through recruitment from deep refugia.

Synchronized breeding events in sympatric marine invertebrates: role of behaviour and fine temporal windows in maintaining reproductive isolation.

A. Mercier and J.-F. Hamel

Behavioral Ecology and Sociobiology 64: 1749–1765 (2010). http://www.mun.ca/osc/amercier/Pages_from_BES_2010.pdf

While breeding synchrony among conspecifics is increasingly well understood with regards to the reproductive success of vertebrate and invertebrate taxa, the occurrence of simultaneous multispecies breeding events remains intriguing. The fairly recent discovery of mass annual spawnings in reef corals has provided a first glimpse at putative strategies of reproductive isolation during such events. However, the mechanisms and advantages of same-day heterospecific breeding are still poorly understood and have not yet been investigated in non-coral taxa with different life history strategies. In an effort to bridge this gap, we investigated spawning periodicity and synchrony among 26 sympatric species of free-spawning, capsule-laying, and brood-protecting macroinvertebrates belonging to six different phyla. Twenty-four of these species released gametes or larvae between early March and late April. We analyzed the events over fine temporal scales to test the hypothesis that breeding activities were not random in time or relative to each other. We found that the two main reproductive pulses followed a lunar periodicity and that consistent species- and gender-specific modulations in the timing of spawning occurred during same-day episodes involving up to six free-spawning species. Mass spawning accounts from the literature were reviewed and compared. This work suggests that many species participate in synchronous heterospecific spawning events either because they respond to the same environmental cues or rely on cross-cueing and that reproductive isolation is favored by species-specific circadian patterns, spawning behaviors and cross-gender signaling.

Habitat, growth and predation as key factors in fishery management of *Cucumaria frondosa* (Echinodermata: Holothuroidea)

J.J. So, J.-F. Hamel and A. Mercier

Fisheries Management and Ecology 17:473–484 (2010). http://www.mun.ca/osc/amercier/Pages_from_Fish_Manag_Ecol_2010.pdf

Biological traits of the sea cucumber *Cucumaria frondosa* (Gunnerus) relevant to both ecological and management perspectives were investigated in the Newfoundland region. Abundance, size and fitness of adults were maximal on hard substrates. Larvae settled ~5 weeks post-spawning and juveniles reached a maximum length of 6 mm after 24 months. Additional size classes of sea cucumbers kept under natural environmental conditions exhibited slow seasonal growth attuned to phytoplankton blooms, indicating that ~25 years may be required to reach market size. Juveniles of the predator sea star *Solaster endeca* (L.) readily fed upon 1.5–2 mm long sea cucumbers. Predation rates on adult *C. frondosa* by adult *S. endeca* were modulated by temperature and biased towards injured specimens, suggesting that trawling may exacerbate predation pressure. The combination of slow growth and high predatory pressure enhanced by fishing activities emphasises the need for precautionary management of this emerging fishery in Atlantic Canada.

First record of the sea cucumber *Trachythyone nina* (Echinodermata: Holothuroidea) in Canadian waters with a redescription of the species and notes on its distribution and biology.

A. Mercier, D. Pawson, D.L. Pawson and J.-F. Hamel

Marine Biology Research 6:315–320. http://www.mun.ca/osc/amercier/Mar_Biol_Res_2010.pdf

The original and only description of the cucumariid holothurian species *Trachythyone nina* (Deichmann, 1930) is based on material collected near George's Bank, by the US Fish Commission Steamer Albatross 125 years ago. No additional material of this species has been formally reported ever since. We hereby record *T. nina* for the first time in Canadian waters, from several sites along the continental slope of Newfoundland and Labrador (43–55° N) at depths of 1088–1308 m and from the Arctic (60° N) at 590 m, as well as from two sites near the type locality at 132–155 m along the coast of New England. A more detailed and accurate description of the species is provided, along with notes on its ecology and distribution. This tiny (<15 mm long) gonochoric sea cucumber is usually associated with hard substrata, including deep-sea corals.

Endogenous and exogenous control of gametogenesis and spawning in echinoderms.

A. Mercier and J.-F. Hamel

Advances in Marine Biology *55:1–302 (2009)*

Most echinoderms display seasonal or other temporal cycles of reproduction that presumably result from the complex interplay of endogenous and exogenous signals. Various environmental, chemical and hormonal factors, acting directly or indirectly, individually or in combination, have been proposed to cue, favour or modulate a suite of reproductive functions from the onset of gametogenesis to gamete release. From as early as the nineteenth century, an astonishing array of studies has been published on topics related to the control of reproduction in echinoderms, ranging from fortuitous behavioural observations to complex experimental demonstrations and molecular analyses. Although the exact pathways involved in the perception of external signals and their transduction into coordinated spawning events remain obscure for most species, significant advances have been made that shed new light on the information gathered over decades of research. By compiling the existing literature (over 1000 references), interpreting the main results, critically assessing the methodologies used and reviewing the emerging hypotheses, we endeavour to draw a clearer picture of the existing knowledge and to provide a framework for future investigation of the mechanisms that underlie reproductive strategies in echinoderms and, by extension, in other marine invertebrates.

Sea cucumber aquaculture in the Western Indian Ocean: Challenges for sustainable livelihood and stock improvement

H. Eriksson, G. Robinson, M.J. Slater and M. Troell

AMBIO. DOI: 10.1007/s13280-011-0195-8

The decline in sea cucumber fisheries that serve the Asian dried seafood market has prompted an increase in global sea cucumber aquaculture. The tropical sandfish (*Holothuria scabra*) has, in this context, been reared and produced with mixed success. In the Western Indian Ocean, villagers often participate in the export fishery for sea cucumbers as a source of income. However, with a growing concern of depleted stocks introduction of hatcheries to farm sandfish as a community livelihood and to replenish wild stocks is being promoted. This review identifies and discusses a number of aspects that constitute constraints or implications with regard to development of sandfish farming in the region. The conclusion is that for sandfish farming to live up to its expectations the possible impacts need to be further studied, and that improved evaluation of ongoing projects is required. In the interim, a precautionary approach toward new enterprise activities is suggested.

Abstracts of the presentations of the 7th WIOMSA International Scientific Symposium, 24–29 October 2011 Mombasa, Kenya

Strengthening capacity for the sustainable management of the sea cucumber fisheries of the Western Indian Ocean: perspectives and main results from the regional MASMA project

Conand C. and Nyawira M.

The sea cucumber fisheries in the Indian Ocean contribute approximately 35% of the worldwide trade in beche–de–mer or trepang Sea cucumbers in the western Indian Ocean (WIO) are mainly harvested for the export market, generate foreign exchange and also form an important component of livelihoods for local communities However, increasing coastal populations, the high worldwide demand for beche–de–mer, the ease of collection in shallow coastal waters and the introduction of SCUBA, have combined to cause overfishing of this valuable resource. Despite their importance, information on the biology and ecology of sea cucumbers that is crucial for management is scarce In an effort to address the challenges of the fishery, a MASMA project 'Sea cucumbers, a Poorly Understood but Important Coastal Resource: A Regional Analysis to Improve Management' was initiated in 2005 to improve our knowledge on these fisheries. The main components of the project included, species inventories and ecological studies, assessing the effectiveness of Marine Protected Areas in the management of sea cucumbers, studies on the reproductive biology of the key commercial species, studies on the socio–economics and management of the fishery and training in the taxonomy and fisheries biology of sea cucumbers In this presentation, we update the status of the fisheries in the Indian Ocean focusing on the WIO region based on reported national statistics and information from various sources The exports have declined in several countries and many other indicators show that over–exploitation seems to be main cause. Management interventions existing (or planned) at national level are often insufficient to protect the stocks, as illegal or unreported fisheries remain important. Suggestions for strengthening management at the national level are presented and regional and international agreements are recommended. The final report of the project is published in the WIOMSA Book Series .

Scales, mobility and learning: A regional perspective on management of sea cucumber fisheries

H. Eriksson, de la Torre Castro M., O. Per and N Kautsky

The sea cucumber fishery for export of beche-de-mer to Asian consumers is common across the Western Indian Ocean region Coastal communities and nations have benefited from this activity for a long period of time, yet it seems that management has not kept up with the rate of development of the fishery as seen by the many reports of overfishing. In addition, informed management decisions are made difficult due to knowledge gaps in ecology and the data poor situation of the fishery. We here analyse the scales of the fishery and trade using data collected by participatory methods and stock census from two islands in the region (i e Zanzibar and Mayotte) Firstly, our results show that due to the lack of management in Zanzibar, and the associated depletion of coastal stocks, a new fishery beside the "traditional" village fishery has evolved – the industrial mobile fishery that operate with scuba gear to target new and remote areas and depths This roving bandit style operation undermines fishing opportunities for coastal fishers, it undermines management efforts in nearby nations, and poses a threat to the ecosystem In addition, it seems that Zanzibar upholds a trade network that captures catch and products from around the region. This illustrates the regional structure of the fishery and calls for a regional approach for management Secondly when we compare the situation in Zanzibar to the heavily controlled fishing situation in Mayotte we find large differences in commercial stock value We use our results to elaborate on the need for a regional governance regime and institutional measures to eradicate illegal fishing in order to allow the fishery to contribute to village economies to its full potential and prevent large–scale ecological degradation

Spatial distribution of sea cucumbers in protected exploited areas of Unguja Island, Zanzibar

R. Mkenda, C. Muhando and N.S. Jiddawi

Zanzibar long term fisheries catch statistics show that sea cucumber catches are declining (probably over-exploited) in most of the shallow coastal waters around Unguja Island. This observation, however, is not verified or backed up by field data. In this study, the distribution pattern and stock sizes (density) of these organisms in zones open for collection in Menai Bay area and in fully closed Chumbe marine reserve was assessed. Information was obtained through interviewed local fishers and visual census (manta tows and scuba dives). ArcMAP 9 3 software was used to visualize the distribution patterns and production of thematic maps for different sea cucumber species with respect to respective habitat characteristics. The Shannon Weaver Diversity for sea cucumber species was highest in Chumbe reserve (H'=1.585). The high and medium value commercial species (*Holothuria fuscogilva, Stichopus herrmanni, Thelenota ananas* and *Thelenota anax)* were only encountered in Chumbe reserve while the other sites were mainly composed of low value species and at low density. The ANOVA Single factor showed significantly higher densities of *Holothuria atra* (F = (5,132), DF = 5, P = 0 0004) and *Bohadschia graeffei* (F = 2 815, DF = 4, P = 0 028) in the reserve. However, there was no significant difference in densities of *Holothuria edulis* and *Stichopus monotuberculatus* among the sites This study provides field evidence that commercially important sea cucumber species in the study areas are rare, most likely over-exploited. There is an urgent need for a proper management scheme to protect sea cucumbers (the high value species in particular) from high exploitation levels in most of the shallow waters around Unguja Island

Community–led sea cucumber aquaculture in mainland Tanzania – Drivers and expectations

S.J. Matt, Y. Mgaya and S.M. Stead

We identify current gaps in socio–economic knowledge needed for aquaculture to fully optimise its potential in addressing food security science/policy research to support sustainable management of marine ecosystems in Tanzania. Empirical evidence is missing to test whether aquaculture can be an attractive and viable livelihood to offer to fishing communities traditionally dependent on marine ecosystems. We outline findings linking attitudes, perceptions and socio–economic factors as variables to determine communities' willingness to embrace sea cucumber aquaculture. Face–to–face interviews were carried out with coastal village heads of households in two peri–urban and one countryside village in Tanzania (Buyuni, Kunduchi and Ununio – n=299). Data collected described livelihoods, perceptions of marine health and governing instruments, economic status along with willingness to include aquaculture in livelihood activities. Material style of life and nine further explanatory variables were tested for significant explanatory strength by fitting a logistic regression model to the probability of respondents being willing to participate in aquaculture. Gender and occupation were significantly related to likelihood of aquaculture uptake. Likelihood of uptake was significantly higher amongst fishermen and farmers than all other primary occupations and higher amongst males than females. Potential earnings were identified as primary incentive for commitment to becoming involved, however expected earnings were comparable with modest income estimates for aquaculture. Despite stated willingness, less than 5% of respondents considered aquaculture a desirable future occupation for their children and only 18% of respondents said the same of fishing, indicating a general lack of esteem and/or perceived future prospects in coastal livelihoods For aquaculture to realise its potential as a livelihood in fishing communities socio–economic research that captures attitudes and perceptions of targeted communities needs to be included as part of policy making to provide the corresponding context for governance that seeks wide stakeholder support.

Abstracts of posters

Assessing spatial population structure of Seychelles sea cucumber stocks based on fishing effort, habitats, and refugia

K. Haruko, J. Robinson, P. Usseglio and A. Friedlander

Sea cucumbers targeted for "beche de mer" are currently being overfished throughout the world. Its ease in harvesting coupled with recent increases in demand has led many local stocks to become commercially extinct Seychelles sea cucumber fishery provides a unique opportunity to measure fishery impact on sea cucumber stock density and its distribution since the fishery keeps track of their spatial fishing effort. The project plans to survey the main granitic islands of Seychelles for stock size structure/density data, habitat data, as well as fishing effort data spanning over several consecutive years and produce spatially explicit population dynamic models to aid future stock management. Seychelles sea cucumber fishery is solely operated with SCUBA, thus it is hypothesized to create a natural refugia for the population inhabiting deeper than 40 m. Additionally, Seychelles has set various MPAs around their islands These combined allow a rare opportunity to study the impact of fishery and its relationship to refugia. The project collected fishery log data, VMS data, port location, habitat data, fishery independent survey data for each commercially targeted species, which then were incorporated into GIS for further analysis and modeling. Size structure and densities were analyzed to assess its relationship to various habitat types and fishing intensity. The project also assessed the quality of habitat map created from hyper–spectral satellite imageries (Hyperion) using the collected data The preliminary result from the first year of field season will be presented

Optimization of the sea cucumber farming within the Madagascar Holothurie SA company

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Holothuria scabra, commonly known as sandfish is one of the most prized and valuable sea cucumber species among the tropical species. Consequently, it is also one over-exploited in the Indo–Pacific region. However, several studies and project proved that this holothurian is the most promising in aquaculture. Madagascar Holothurie SA (MHSA) is the first trade company based on sea cucumber aquaculture in Madagascar and involves the coastal villagers. Created on April 2008, the society aims to produce 100 000 *H. scabra* juveniles per year. During the 3 years of its existence, several rearing parameters have been optimized as well in the hatchery as in the nursery ponds. This optimization includes (i) the use of gonads collected directly from collector villagers (ii) the finding of optimal rearing density at each developmental stage of *H. scabra*, (iii) the selecting and regrouping of the batch header in one rearing tank for the epibenthic juveniles stage, (iv) the use of the greenhouse for the nursery ponds during the fresh season and (v) the reduction of the layer of sediment used for endobenthic juveniles stage. The results show that, the average production yield of *H. scabra* juveniles increased from 1584 individuals per month on 2008 to 3738 on 2009 and 5148 on 2010. The company stopped to buy broodstocks since May 2010. The amount of the sediment used for the nursery ponds decreased from 4 cm deep on 2008 to 0,5 cm from April 2010. The results obtained from these 3 years of the existence of MHSA are very promising and now the company prepares the industrial level and expects to produce 4 to 5 millions of *H. scabra* juveniles for the next years

Development of multi–stakeholder *Holothuria scabra* aquaculture forum in Madagascar: a promising tool to promote best practice and information sharing

A. Rougier and S. Peabody

Village based aquaculture of sea cucumbers *Holothuria scabra*, first pioneered in southwest Madagascar in 2008, is gathering momentum as a viable sustainable alternative livelihood for traditional Vezo fishing communities. Following renewed investment in hatchery capacity in the regional capital Toliara, as well as in community–based grow–out pens and capacity building, this ambitious mariculture initiative now involves a number of different stakeholders working together to develop this aquaculture technology as a viable business for communities and private sector hatchery investors alike. Recognising the need for coordination of activities amongst the different actors involved in this new initiative, at both hatchery and community levels, a regional forum was established to bring together all sea cucumber aquaculture stakeholders in the region, to share and discuss experiences, lessons learned and best practices from their respective activities The forum, which meets every month, is based on open discussions and roundtable workshops, provides an important platform for exchanging experiences and challenges amongst the diverse stakeholders in the rapidly evolving sea cucumber aquaculture sector. The current favoured model for community–based ranching of hatchery– reared sea cucumbers, which has already been adapted, refined and improvement based on the experiences of conservation NGO Blue Ventures and its partners, is now being replicated by other actors in this region, and sharing experiences through the regional platform offers a vital means for others to learn more quickly the lessons gained from projects already in progress Based on the progress of the Toliara sea cucumber aquaculture platform, experiences indicate that there is considerable potential for replication of such a stakeholders' forum to improve the adaptive management of other fishery and aquaculture sectors in Madagascar and the broader western Indian Ocean region

Sea cucumber fishery in Seychelles - Spatail expansion effect on populations

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Sea cucumbers targeted as "beche de mer" are currently being overfished throughout the world. Its ease in harvesting coupled with recent increases in demand has led many local stocks to become commercially extinct. Seychelles' sea cucumber fishery provides a unique opportunity to measure fishery impact on sea cucumber stock density and its distribution since the government keeps track of its fishery's spatial fishing effort and catch. This project surveyed the main granitic islands of Seychelles to identify each species' size structure, density, and habitat preference. Fishing effort data from the fishery log was combined to assess the relationship between fishing intensity and the surveyed variables. The fishery landing data coupled with fishing effort was also analyzed to evaluate the effect of spatial expansion of the fishery. Canonical correspondence analysis showed sand fish and white teatfish preferred to occur in sandy area whereas black teatfish preferred to occur in coral rubble area. It also showed that fishermen preferred to fish in sandy habitat thus catching more white teatfish which agreed with the catch report. Nonmetric multidimensional scaling showed that larger size of black teatfish were found in deeper less fished area. The fishery log analysis additionally showed that increase in catch was compensated by spatial expansion of the fishing effort.

Community based *Holothuria scabra* farming in South West of Madagascar: lessons learned and improvement of approaches of Blue Ventures' project

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The first trialsof village–based sea cucumber aquaculture in the western Indian Ocean were conducted in southwest Madagascar following an academic research partnership between the universities of Mons, Toliara and the Université Libre de Bruxelles This partnership helped establish the region's first hatchery for the sandfish *Holothuria scabra*. Since 2008, conservation NGO Blue Ventures, working in partnership with MHSA,a spin–off company from the research project and holder of the patent on the in vitro hatchery process used to cultivate *H. scabra* juveniles, launched a preliminary village–based aquaculture project that included the Velondriake locally managed marine area (LMMA). The integration of marine aquaculture into the protected area was aimed to provide communities with sustainable and lucrative alternative activities to fishing. The first two years of the project served to establish a strong base for community–based aquaculture of *H. scabra* in the area, as well as to identify the various technical and socioeconomic limitations of the original model for community–based ranching. With new funding for expansion of this project within Velondriake to at least 2013, partners are now working to capitalise on the good farming practices identified during the preliminary project, as well as overcome challenges encountered in the initial trials, notably to develop tools to prevent poaching and better integrate aquaculture of sea cucumber farming amongst local livelihoods within coastal communities of the region Through adaptive management based on ongoing analysis of problems encountered by Blue Ventures' researchers and technicians, coupled with a participatory approach to engage communities in all aspects of the project, and a strong dialogue with all stakeholders, a refined farming model has evolved This new production system, in constant improvement, offers strong opportunities for sustainable income generation for community farmers, and is potentially replicable in many coastal areas of this region.

PhD Dissertation

Assessment and management of sea cucumber resources in the coastal waters of Sri Lanka

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This thesis addresses the stock status of commercial sea cucumber species in the coastal waters of Sri Lanka and possible management measures to ensure their sustainable utilization. The stock status of commercial sea cucumbers was evaluated using data collected from an Underwater Visual Census (UVC) and fishery dependent surveys carried out off the east and northwest coasts of Sri Lanka in 2008 and 2009. Of the 25 sea cucumber species identified, 21 species are commercially important and 11 species were predominant in the commercial catches. The total abundance of sea cucumbers was higher off the northwest coast (62.3 x 10^6 nos) than the east coast (11.9 x 10^6 nos) and low-value species were predominant in both survey areas. *Holothuria edulis* was the most abundant species in numbers while *Holothuria atra* had the highest stock biomass. In both regions, commercial fishery predominantly relies on two nocturnal species: *Holothuria spinifera* and *Thelenota anax*. *H. spinifera* had the highest contribution (73%) to the total landings off the northwest coast while this was provided by from *T. anax* (93%) off the east coast. Density estimates indicate that all the sea cucumber stocks in the coastal waters of Sri Lanka are at critical level (<30 ind ha^{-1}) except for 3 stocks (*H. atra, H. edulis and H. spinifera*) off the northwest coast and one stock (*H. edulis*) off the east coast.

Biological aspects of *H. atra and H.edulis*, which were found to have potential to contribute to future fisheries, were further investigated. High densities of *H. atra* were found in the shallow (<10 m) seagrass beds and *H. edulis* was commonly reported in shallow reef flats and rocky habitat. Although these two species favoured a similar range of sediment mean grain size (0.7-1.2 mm) and gravel content (15-25%), they have different preferences towards the sediment organic content making it possible for them to have separate niches. When the reproductive biology of *H. atra* was evaluated using gonadosomatic indices and histology of gonads, a synchronous seasonal gametogenesis with some asynchrony among individuals was revealed. Further, this population was sexually active throughout the year having peak spawning in April and October. The main spawning event coincided with the highest temperatures and the size at first sexual maturity of *H. atra* was 16 cm.

Estimates of average natural mortality (M) for sea cucumbers are important findings of this study. Two approaches; simple linear regression and random effects models, were used in this analysis and the estimated values were 0.50 yr^{-1} and 0.45 yr^{-1}, respectively. The random effects model predicted lower natural mortality (M) for nocturnal species than for the diurnal species.

A number of possible management measures were identified, including limiting the exploitation of some commercial species, setting of total allowable catch (TAC) limit and minimum landing size (particularly for highly abundant species), implementation of routine monitoring, reporting of commercial landings and implementation of marine protected areas (MPAs). A multi-area bulk biomass model was used to design MPAs off the east coast of Sri Lanka and spatial management through marine reserves is seen to have potential to rebuild the highly depleted sea cucumber populations. Apart from the management of local sea cucumber resources, the information gained through this study is important for updating the regional and global sea cucumber catch statistics as well as to contribute information for the implementation of regional management programmes.

Master's thesis

Estimation des stocks d'holothuries commerciales dans le lagon de Moorea et recommandations de gestion associées

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Holothurians are eaten by Asian populations since ancient times and are therefore fished in many Pacific islands. In the lagoon of Moorea, five species are now harvested and have been studied to get an estimation of their stock size. Sea cucumbers were surveyed in the lagoon, the reef crest and passes, along transects. In order to correlate the number of individuals and the biomass, size-to-weight relationships from the literature were used, except for *Bohadschia argus*, for which the relationship was established in collaboration with the wholesaler from Moorea. Ecological preferences for each species were also studied. The data set provides management advices to sustainably preserve this marine resource. As a result, recommended quotas (kg of gutted weight/year) and minimum harvestable sizes (cm) are as follow: *Bohadschia argus* (11,430 kg, 35 cm), *Thelenota ananas* (6 kg, 30 cm), *Holothuria fuscogilva* (241 kg, 35 cm), *Holothuria whitmaei* (52 kg, 30 cm) and *Actinopyga mauritiana* (75 kg, 17 cm). These recommendations could be included in de Management Plan of the Maritime Area of Moorea. Fishing gear restriction and regulation for all actors of the sea cucumber's fishery are also recommended.

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