CHAPTER 11

Bêche-de-mer

Garry L. Preston

I. INTRODUCTION

Bêche-de-mer, also called trepang, is the name given to the dried product manufactured from the marine animals commonly called sea cucumbers or, (incorrectly), sea slugs. Sea cucumbers are members of the class Holothuroidea in the phylum Echinodermata and are sometimes referred to as holothurians or holothuroids. Sea cucumbers of various types are found throughout the tropical Pacific, as well as in other tropical and temperate seas. Only certain species are valued for bêche-de-mer production, and many of these are common in the Pacific islands region.

Bêche-de-mer is produced by a process of boiling, cleaning, drying and, in some cases, smoking. The finished product, which has a hard rubbery texture, is normally rehydrated by repeated soaking or boiling prior to consumption. The product is considered a delicacy and an aphrodisiac in China and South-east Asia where it is principally consumed. The expansion of Chinese communities in the West, notably in Canada, the USA and Australia, has led to the growth of non-traditional markets for bêche-de-mer. This has been further accelerated by international trade and currency regulation, especially in mainland China, which has led to the increasing use of certain types of bêche-de-mer as a barter currency.

The nature of the product and the simple, low-technology method of processing makes it an ideal commodity for rural areas in the Pacific islands, where the raw resource is often plentiful, and where cold storage or other facilities needed for trade in alternative types of marine produce may not be readily available. In some Pacific island countries bêche-de-mer fisheries play an important role in maintaining rural social stability by providing income-earning opportunities in remote locations where other earning opportunities may be limited by the lack of resources or infrastructure.

Sea cucumbers are consumed in forms other than as bêche-de-mer, *e.g.* fresh (Japan, Fiji, Palau) or salted (Western Samoa). There are also uses that are not related to human consumption, *e.g.* for fishing bait (Caroline Islands) and for the production of poisons for use in stunning fish (Fiji, Papua New Guinea and elsewhere), and for pig food (Tokelau). In the Pacific islands region, however,

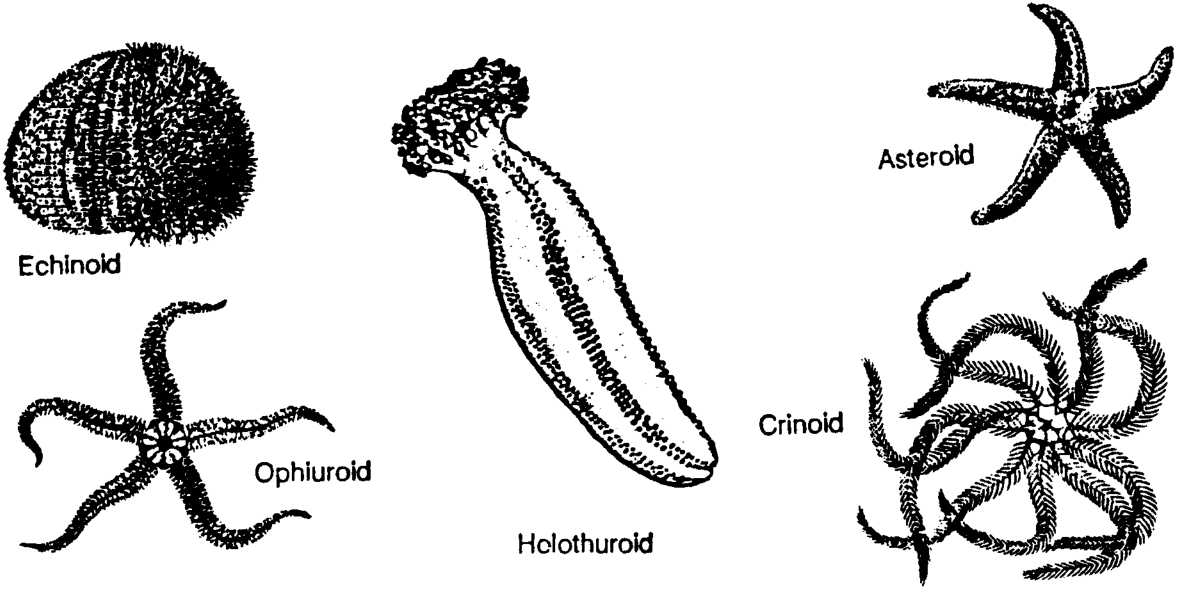

Figure 1. Classes of the phylum Echinodermata (from Anon., 1972)

the greatest use of sea cucumbers is for bêche-de-mer production, and it is this use that will be considered here.

II. BIOLOGY

TAXONOMY

Classification: Sea cucumbers are members of the class Holothuroidea within the invertebrate phylum Echinodermata (which literally means "spiny skins"). Holothurians are related to starfish (class Asteroidea), brittle stars (class Ophiuroidea), sea urchins (class Echinoidea) and crinoids (class Crinoidea), as shown in Fig. 1.

About 1,200 species of holothurians have been described, and about 300 of these occur in the shallow (less than 20 m deep) tropical seas of the Indian and Western Pacific oceans (Guille *et al.*, 1986). The Holothuroidea contains six orders: Aspidochirotida, Dendrochirotida, Apodida, Malpodida, Elasipodida and Dactylochirotida, of which the first four are present in the coastal waters of the South Pacific. A basic key to the classification of Australian sea cucumbers is shown in Fig. 2, based on Cannon and Silver (1986). All the commercially-exploited species of sea cucumber are in the two families Holothuroidea and Stichopodidae in the order Aspidochirotida.

Identification: Being soft-bodied, holothurians tend to lose their obvious external characteristics quickly, especially on handling or after death. This feature makes them among the more difficult of marine groups to identify. Precise taxonomic classification relies greatly on the form of the endoskeleton, which is reduced and which is made of microscopic calcareous spicules, that can adopt a variety of forms, in the skin. Fig. 3 shows some of the typical spicule forms, which range from simple buttons and plates to more complex tables, rosettes and anchors, found in tropical species. More detailed descriptions of spicule types and of the various species in which they occur can be found in Clark and Rowe (1971) and Guille *et al.* (1986).

A simple technique to examine the spicules is described by Cannon and Silver (1986). A piece of epidermis 1 cm square is cut from the sea cucumber and placed on a microscope slide (this can be done without undue harm to the animal). A drop of household bleach (dilute sodium hypochlorite) left on the skin for 10-20 minutes will dissolve away the collagen fibres holding the spicules together and leave them free for examination under a light microscope. For a more detailed examination, or permanent preservation of the specimen, a more elaborate method, which involves boiling the skin in sodium hydroxide, is described by Domantey (1954).

Superficial identification of the most common commercial sea cucumbers,

KEY TO HOLOTHURIOIDEA (Commercially important Pacific Island genera are shown in italics)

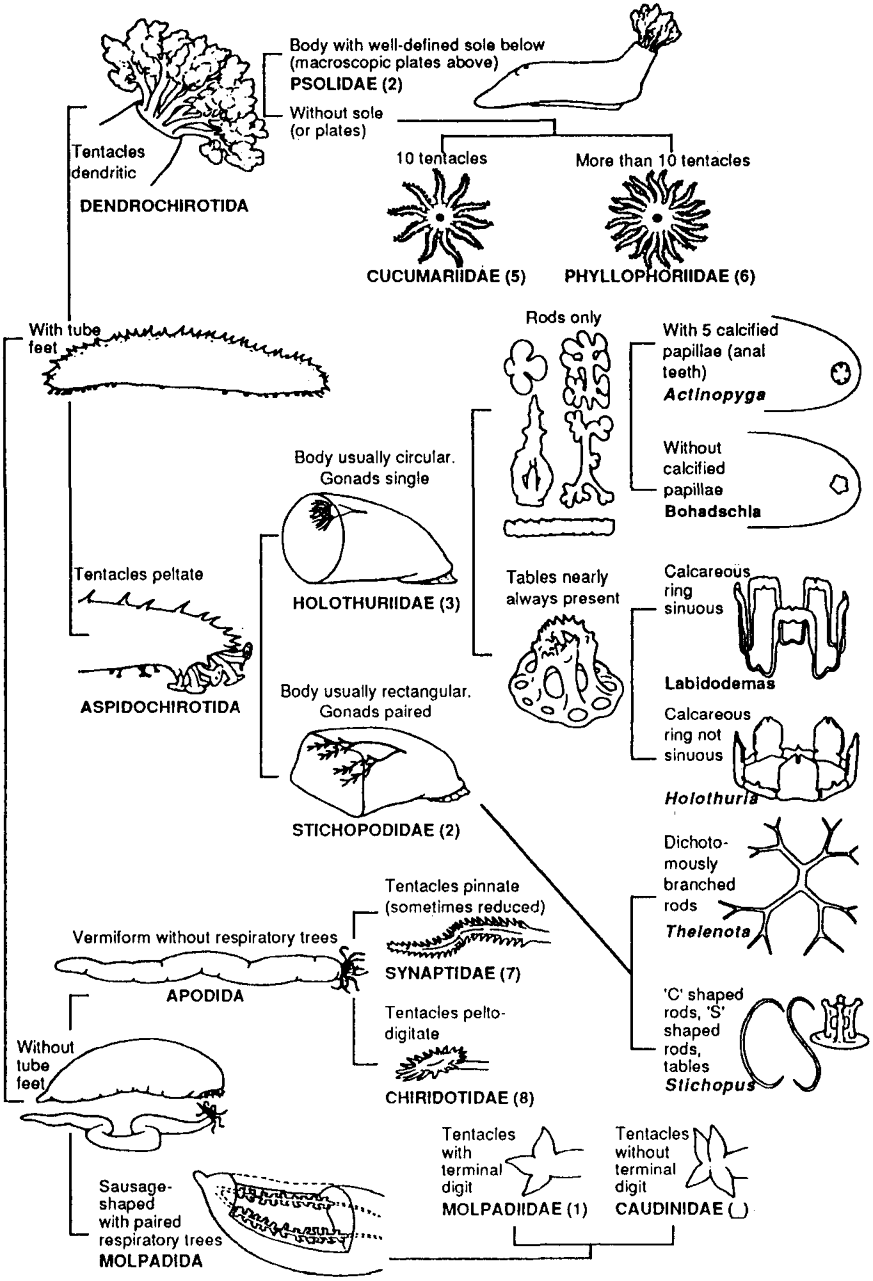

Figure 2. Sea cucumber classification (from Cannon and Silver, 1986).

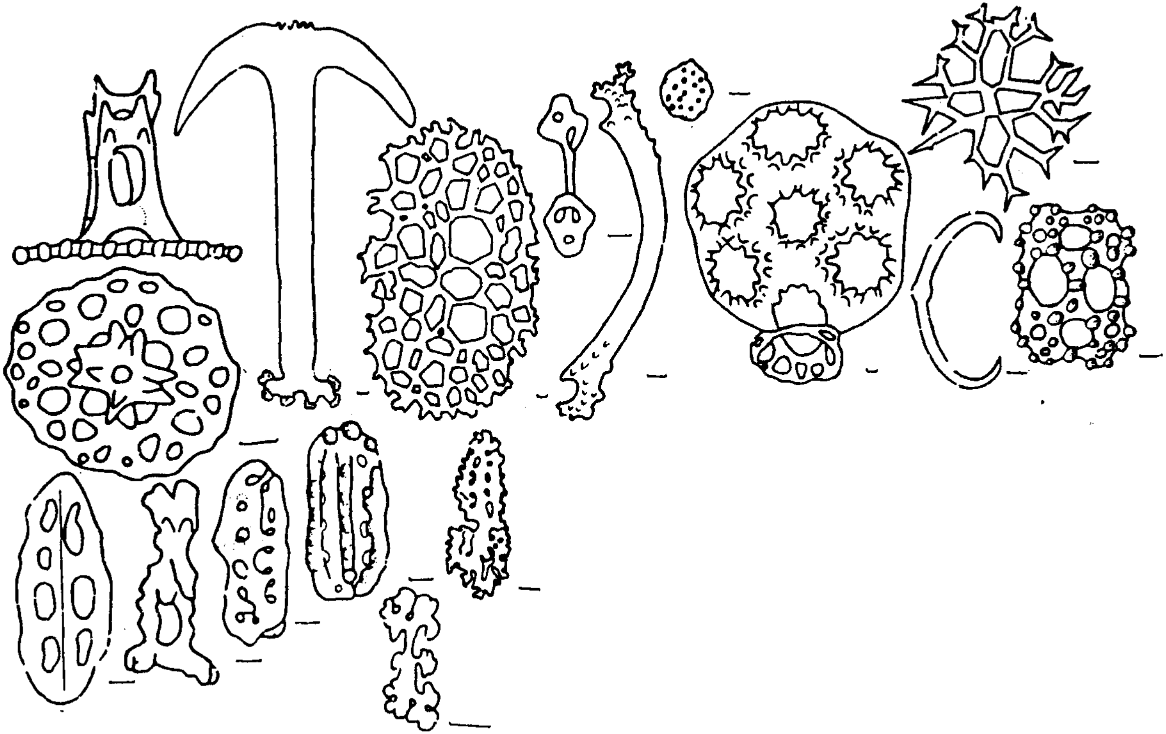

Figure 3. Spicule forms of tropical sea cucumbers (from Guille *et al.*, 1986). Main spicule types (left to right and top to bottom): Table (side and top view), anchor, perforated plate, pseudo-button, rod, biscuit, anchor plate, C-shaped rod, branched rod, lenticular plate, smooth button, pseudo-table, ellipsoid, knobbed button, rosette, sigmoid body.

at least to genus level, and often further, is nevertheless normally possible based on external visual appearance. The Stichopodidae, which contains only two genera (*Stichopus* and *Thelenota*) are easy to recognise because of the somewhat square cross-section of the body. The Holothuriidae are divided into four genera, of which two (*Actinopyga* and *Holothuria*) are commercially important. *Actinopyga* genera are again easy to recognise because of the presence of five distinctive calcified papillae, or "teeth", around the anus. Identification of some *Actinopyga* to species level is, however, difficult for the non-specialist. Most commercial species of *Holothuria* are fairly easy to distinguish, but the genus is subdivided into at least 13 varieties and 114 species (Rowe, 1969) which also contain numerous non-commercial types.

Photographs and descriptions of most of the commercial types of sea cucumber found in the Pacific islands region are contained in Anon. (1979) and in Guille *et al.* (1986). With the exception of the black-coloured members of the genus *Actinopyga*, which require identification by a specialist, these are adequate for the level of recognition normally needed by fisheries workers in the South Pacific region.

ANATOMY

Echinoderms share a pentaradial symmetry that is unique to the phylum. When viewed end-on from the mouth or the anus they are symmetrically divided into five equal segments around a central crown. Unlike the Ophiuroidea, Asteroidea and Crinoidea, whose five-pointed symmetry is more easy to see, the Echinoidea and Holothuroidea do not have the body drawn out into arms, and the polar axis (distance between mouth and anus) is greatly lengthened.

Holothurians have no head and no true brain for overall coordination. The pentaradial plan is organised around the mouth in rings of nervous, haemal (blood) and water vascular tissues. Five major trunks of these tissues run along the body. Surrounding the mouth or oesophagus internally is a ring of calcified plates, the calcareous ring (Fig. 4). The gut lies in a fluid filled cavity, the coelom. Diverse cells (coelomocytes) wander through the coelom and other tissues performing functions similar to those of the blood cells of vertebrates. The single gonad (testis or ovary) lies in one or two tufts in the anterior body and opens anteriorly through the genital orifice. Branched respiratory trees or "gills" lie in the posterior body and open into the cloaca. A fine network of haemal tissue, the *rete mirabile*, lies along the gut and functions to disperse nutrients and metabolites. In some species of *Holothuria* and *Actinopyga*, a cluster of white cuvierian tubules lies posteriorly near the cloaca. These become very sticky on contact with water and are often ejected in self-defence.

Externally, echinoderms are covered by chalky plates just under the skin. These may be massive and tightly linked to one another, as in echinoids,

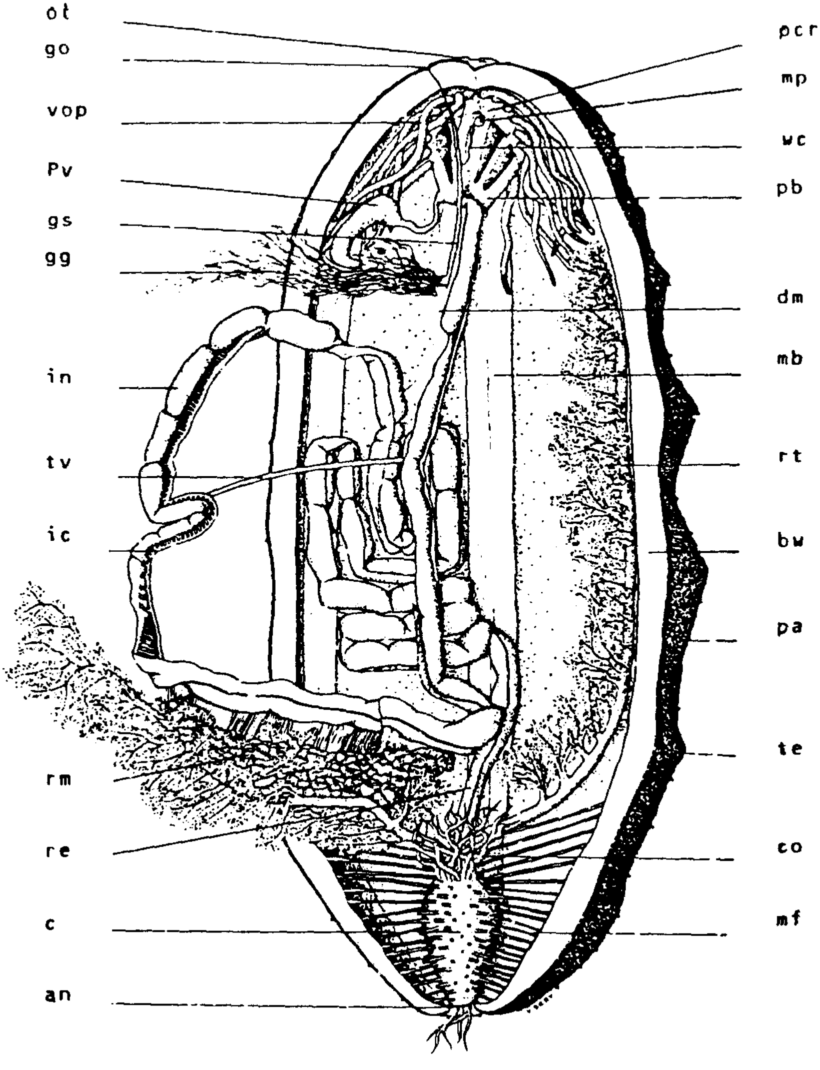

Figure 4. **Anatomy of *Holothuria nobilis* (from Conand, 1986).**
ot - oral tentacles: go - genital orifice: vop - vesicles of the oral podia: mp - madreporite: wc - water ring canal: pv - polian vesicle: pcr - peripharyngeal calcareaous ring: mb - radial muscular band: gs - genital stolon: gg - genital gland: co - cuvierian organs: c - cloaca: an -anus: re - rectum: rt - right respiratory tree: pb - pharyngeal bulb: rm - rete mirabile: tv - transverse muscle: ic - intestinal cavity: dm - dorsal mesentery: mf - muscle fibres: bw - body wall: in - intestine: pa - papillae: te - teats.

or sculptured and independent, as in the holothuroid body wall. This dermal skeleton, which in holothuroids does not provide much skeletal rigidity, is supplemented by a water vascular system which acts as a hydrostatic skeleton. A series of podia, or tube-feet (small extensible sacs protruding into the environment), is arranged along each of the five radial water canals running the length of the body. Extension of the podia is brought about by hydraulic transference of fluid from a muscular bulb, or ampulla, associated with each podium, and fed by the water canals. Tracts of tube-feet, called ambulacra, are the external and locomotory parts of the water vascular system. They mirror the organisation of the five internal tissue trunks and provide motive power. Tube-feet may also serve as feeding devices, and in many holothurians those surrounding the mouth have been modified into tentacles for food collection.

Lying horizontal has led to the lower surface of holothuroids becoming more or less modified and differentiated from the upper surfaces, and it may be so flattened as to form a creeping or clinging surface covered with tube feet. The five radial water canals are also split into two groups, associated with the dorsal and ventral surfaces. This secondary dorso-ventral organisation tends to obscure the pentaradial symmetry of the holothuroids.

EXPLOITED SPECIES

The major exploited holothurian species found in the south-west Pacific are listed in Table I below. All commercial sea cucumbers are members of the class Aspidochirotidae and all are relatively large species with thick body walls.

Conand (1986 and elsewhere) considers that there are two varieties of the sandfish, *Holothuria scabra* and *H. scabra* var *versicolor*. *Holothuria edulis, Bohadschia argus, B. marmorata* and *B. vitiensis* are species that are traditionally considered to be of little or no value for bêche-de-mer production because of their relatively thin body walls. However, McElroy (1990) reports that in 1990 these species were being traded in Hong Kong and Singapore because of the overall high prevailing prices for bêche-de-mer.

DISTRIBUTION

Geographic distribution: Holothurians are found throughout the world's oceans, at all latitudes and at all depths from shallow coastal seas to the abyssal plain. In the deep ocean, holothurians may account for very high proportions of the benthic biomass (Sibuet, 1985). Among coastal species, the aspidochirotid holothurians, which contain the commercial species, tend to predominate in tropical waters, while dendrochirotid species are more common in temperate seas (Conand, 1986).

Most commercially important species found in the Pacific islands region are

Table I. Commercially exploited holothurians found in the tropical Pacific.

Scientific name	Common name
Actinopyga echinites	Deep-water redfish
Actinopyga lecanora	Stonefish
Actinopyga mauritiana	Surf redfish
Actinopyga miliaris	Blackfish
Holothuria atra	Blackfish
Holothuria fuscogilva	White teatfish
Holothuria fuscopunctata	Elephant's trunk fish
Holothuria nobilis	Black teatfish
Holothuria scabra	Sandfish
Holothuria edulis	Pinkfish
Stichopus chloronotus	Greenfish
Stichopus variegatus	Curry fish
Thelenota ananas	Prickly redfish
Thelenota anax	Amberfish
Bohadschia marmorata	Chalkfish
Bohadschia argus	Leopard fish
Bohadschia vitiensis	Brown sandfish

also distributed in the waters of Indonesia, Australia, the Philippines, China and southern Japan (Clark and Rowe, 1971). Many members of the family Holothuriidae, including commercial species such as *Holothuria nobilis* and *H. scabra*, and some of the Stichopodidae, are found as far west as East Africa and Madagascar. Indeed, the bêche-de-mer trade began in the waters of India, Indonesia and the Philippines over 1,000 years ago (Conand and Sloan 1989), only spreading to the Pacific in the latter half of the 20th century. Species diversity decreases in an easterly direction across the Pacific and few of the commercially exploited holothurian species are found as far east as the Hawaiian islands.

Habitat: Most sea cucumbers are benthic, living on or in the bottom sediments, but some are found on hard substrates, some are epibionts on plants or invertebrates, and a few are pelagic. Within the area of geographic distribution, habitat is critical in determining localised patterns of distribution of given species.

In sandy or muddy biotopes the nutritional composition of the sediment (distribution of particle sizes, richness in bacteria and organic matter) will be one of the important factors in determining the distribution of adult holothuroids. In rocky biotopes where there is little sediment, the presence of numerous microhabitats seems to be more important than the amount of food available (Massin, 1982a). Small islands countries with a smaller range of habitats are likely to have fewer species of holothurian, especially where habitat requirements are specific. *Holothuria scabra*, for instance, tends to occur in areas of freshwater influence and offshore from mangrove swamps, and therefore is generally absent from atolls.

Conand and Chardy (1985) conducted a detailed study of holothurian distribution in the lagoon of New Caledonia, and its relationship with a range of environmental descriptors. These authors categorised the lagoon into 16 biotopes and found that holothurian distribution closely reflected the organisation of the reef system and these component biotopes. The density and biomass of holothurians overall increased from the outer reef slope to the coast, and were highest on inner reef flats and in coastal areas. In terms of density, commercial species were least abundant on the barrier reefs, outer reef slopes and outer lagoons, but predominated on inner reef flats and in the coastal zone. The relatively large sizes of the commercial species found on barrier reefs and outer lagoons led to higher biomasses in these areas, but otherwise the biomass distribution was broadly similar to that of density.

As a result of the study, several holothurian categories were defined, as follows:

- outer reef slope species, including *Stichopus chloronotus* and *Actinopyga mauritiana*;
- pass and inner slope species, including *Holothuria nobilis*, *H. fuscogilva*, *H. fuscopunctata*, *Thelenota ananas*, and *T. anax*;
- inner reef-flat species, including *Holothuria scabra*, *Actinopyga echinites*, and *A. miliaris*; and
- lagoon species, including *Holothuria scabra* var *versicolor*, and *Stichopus variegatus*.

Some species, such as *Holothuria scabra* and several *Bohadschia* species in the study of Conand and Chardy (1985), and *Holothuria fuscopunctata*, which dominated some inner lagoon areas in northern Fiji (author's unpublished data), appear to occur in more than one habitat, or across habitat boundaries, and their habitat preferences do not appear to be as well defined as those of other species. It may therefore be that the distribution of some holothurian species is influenced not only by adult habitat preferences, but also by interspecific competition, or difficult-to-quantify factors such as juvenile predator/prey population dynamics, and patterns of water movement at times of larval settlement.

Massin (1982a) notes that, when there is no interspecific competition, one holothurian species may occupy a variety of habitats and be able to exploit a range of different food sources. When several species co-occur, each occupies a well-defined ecological niche and, even if their trophic categories are similar, captured food is different and competition between species minimal. It may therefore be the case that the habitat(s) in which a given species is found varies from one island group to another, depending on the presence or absence of competitor species.

Abundance: Abundance of holothuroids may be expressed relatively, in terms of number or biomass of animals per unit area, or absolutely, as the total number or biomass of animals in a given area. In either case, abundance estimates are usually derived from field density surveys that involve counting and collecting animals from a known area. In addition to density data, calculation of biomass or absolute abundance requires information on the size-frequency distribution of the population, and on the size of the area over which the population extends, respectively.

Direct surveys use quadrats or transects to achieve a measure or estimate of the surface area in which the animals are counted. Indirect surveys use timed swims during which catch per unit of time is measured; this is then converted to a density measure using a suitable conversion factor. Indirect surveys are normally considered too inaccurate for detailed population studies, but they are suitable for many fishery purposes and have the advantage of being rapid to perform. Survey methods for bêche-de-mer are similar to those used for other marine invertebrates and have been reviewed in depth by a number of authors, including Harriott (1984) and Conand (1986).

The abundance of a given holothuroid species may vary considerably according to the geographic and localised patterns of distribution. Areas of relatively high density (hundreds or thousands per hectare) may exist alongside areas where the same species are rare or absent, for reasons that are not always clear.

Table II below shows holothurian densities (expressed as numbers of animals per hectare) recorded by workers carrying out bêche-de-mer surveys or resource assessments in the region. In each case, survey stations where the species of interest was absent have been excluded from the data before density calculations were made.

As can be seen, density measures vary considerably among species, but tend to be lower for the large high-value species (*Holothuria nobilis*, *H. fuscogilva*, *Thelenota ananas*). *Holothuria scabra* appears to be an exception as it occurs in very high densities in some areas. *Actinopyga miliaris* and *A. echinites*, medium- to low-value types, have also been found to occur in very high densities.

NUTRITION

The information in this section is mainly taken from the review of holothurian food and feeding mechanisms by Massin (1982a).

Table II. Holothurian densities recorded in the Pacific islands region.

Species	Mean density (no./ha)	Maximum density (no./ha)	Location	Reference
Holothuria nobilis	16.3		Great Barrier Reef	Pearson, cited in Conand, 1986
H. nobilis	13.0	84.0	New Caledonia	Conand, 1986
H. nobilis		275	Papua New Guinea	Lokani, 1991
H. nobilis	18.7	40.3	Tonga	Preston and Lokani, 1990
H. fuscogilva	11	43	New Caledonia	Conand, 1986
H. fuscogilva		54	Papua New Guinea	Lokani, 1991
H. fuscogilva	18.4	81.7	Tonga	Preston and Lokani, 1990
H. scabra	2,900	13,500	Papua New Guinea	Shelley, 1981
H. scabra	683	6,000	New Caledonia	Conand, 1986
H. scabra var *versicolor*	82	450	New Caledonia	Conand, 1986
H. fuscopunctata	22	105.9	Tonga	Preston and Lokani, 1990
H. atra	545	7,270	New Caledonia	Conand, 1986
Actinopyga miliaris		78,900	Fiji	Preston *et al.*, 1988
A. mauritiana		304	Papua New Guinea	Lokani, 1991
A. echinites	1,800	12,500	Papua New Guinea	Shelley, 1981
A. echinites		4,025	Papua New Guinea	Lokani, 1991
A. echinites	847	9,000	New Caledonia	Conand, 1986
A. lecanora		25	Papua New Guinea	Lokani, 1991
A. miliaris	512	5,970	New Caledonia	Conand, 1986
A. sp.	36.4	56.5	Tonga	Preston and Lokani, 1990
A. sp.		38	Papua New Guinea	Lokani, 1991
Thelenota ananas	18	141	New Caledonia	Conand, 1986
T. ananas	17.5	31.4	Niue	Dalzell *et al.*, 1991
T. ananas	16.8	39.8	Tonga	Preston and Lokani, 1990
T. ananas		79	Papua New Guinea	Lokani, 1991
T. anax	41	240.9	Tonga	Preston and Lokani, 1990
Stichopus chloronotus		4,258	Papua New Guinea	Lokani, 1991
S. variegatus		456	Papua New Guinea	Lokani, 1991

Most aspidochirote holothurians are deposit-feeders (although a few non-commercial species are suspension-feeders). They live on the sediment surface, and swallow only the upper few millimetres of sediment which they collect with their peltate tentacles. Because of this method of feeding they are referred to as rake-feeders; other deposit-feeding holothurians are variously referred to as funnel-feeders, conveyor belt-feeders and surface-feeders.

Aspidochirotes generally feed continuously or have a daily rhythm in their feeding frequency, often related to light levels. Some burrow at certain times and may be completely buried (*e.g.* various *Bohadschia* species), but they are not feeding at these moments. Some aspidochirotes, mainly stichopodids, possess a seasonal rhythm and stop feeding completely during the summer (*e.g. Stichopus japonicus*). This period of starvation may be accompanied by auto-evisceration.

The sediment on which holothuroids feed consists of inorganic compounds (silica and limestone), organic detritus (dead and decaying animal or vegetal matter), micro-organisms (bacteria, diatoms, protozoans, etc), and their own or other animals' fecal material. The major nutritional component for most species is bacteria. The complex relationship between bacterial populations and sediment structure may have a major influence on the distribution of holothuroids.

Feeding occurs as the animal creeps on the bottom with the mouth down. The tentacles, fully extended with spread tips, sweep the bottom and act as shovels when the sediment is swallowed. Each tentacle, without a defined order, pushes sand into the mouth, in which the sphincter opens and closes regularly. Sand grains and alimentary particles adhere to the tentacle because of mucus secretions, and as a result of mechanical ensnarement between nodules on the tentacular tips which trap the particles when the tentacle retracts. Although selection of grain size appears to be low, holothurians are able to select for the organically richest particles when feeding. As a result, there is very often a clear increase in organic matter concentration between the bottom sediment and the material found in the pharyngeal bulb.

Larger particles are swallowed as a result of the action of several tentacles together. In some deposit-feeding holothurians, the gut is frequently found to contain quantities of large fragments of seagrass. These plants appear not to be digested, but support epiphytic micro-organisms on which the holothuroids feed.

Many species live in the sediment they feed on - mud or sand - and dig channels through it, disturbing the bottom as they do so. Sediment-feeding holothurians are thought to play a key role in recycling organic material in bottom sediments and in turning over the lagoon bottom (Massin, 1982b).

Other species are found in environments such as coral pavements or reef flat areas where the sediment layer may be thin. These species "vacuum" the surfaces of their habitat (coral rock, algae, etc), cleaning off the film of sediment settled there. Those species found among algae probably ingest substantial amounts of plant material, and this may contribute directly to the diet.

Numerous questions on holothuroid food and feeding mechanisms remain unanswered for many groups and species. The food of many specific holothuroids is unknown, and generally is not clearly defined. Many holothuroids are said to be deposit-feeders without any knowledge of their real nutritional requirements and much is still to be done in this basic field of research.

PREDATION

Juvenile sea-cucumbers are usually cryptic and well-concealed, suggesting that predation may be important during this part of the life history. However, most adult sea cucumbers make little attempt to conceal themselves when actively feeding, yet few attacks on sea cucumbers by predators are observed in nature.

Those few incidents of recorded predation normally involve attacks on *Stichopus* species by the predatory gastropod *Tunna perdrix*, or by other large gastropods. The triton shell, *Charonia tritonis*, feeds on echinoderms and is possibly a predator of sea cucumbers. Starfish have been identified as major predators on some tropical sea cucumber species (Engstrom, 1988). Fish have been suggested as more important predators of temperate species (Bakus, 1974), and predation observations include the swallowing of sea cucumbers by rays. Some sea cucumber species are parasitised by the fish *Carapus*, which lives inside the anus of the holothurian and feeds on its reproductive tissue (Bruce, 1983). In general, however, there appear to be few predators on adult holothurians.

This avoidance by predators is possibly because of the toxic or distasteful compounds found in the skin of many holothurian species. The toxicity of these compounds is attested to by the fact that, in the southern Lau Islands of Fiji and probably elsewhere, a fish poison is traditionally produced by rubbing the skin of *Holothuria atra* into tide pools (V. Vuki, *pers. comm.*). In New Caledonia, sacks of freshly gathered commercial sea cucumbers are left to stand in tidepools in order to poison reef fish (K. Poru, *pers. comm.*). Also in New Caledonia, fish kills were noticed after the water in which bêche-de-mer had been boiled was discarded into the sea from the beach (Fao, 1990). Subsequent laboratory testing confirmed the presence of a toxin called holothurine in water in which sea cucumbers had been standing, and in the water used for boiling. Bakus (1974) tested the toxicity of a number of holothurians from different geographical locations on captive fish and concluded that toxicity in holothurians, especially in tropical seas, has evolved in part as a chemical defence mechanism against predation by fishes, explaining the low incidence of fish predation on tropical sea cucumbers.

Some species of *Bohadschia* bury themselves with sand when dormant; others, such as *Actinopyga miliaris*, will hide in crevices or under rocks. *Holothuria nobilis*, *H. fuscogilva* and *H. atra* are often found covered with a thin layer of sediment and slime, but this does not serve to conceal effectively the animals from view. Most sea cucumbers are clearly visible and exposed when feeding, and often at other times, and it seems unlikely that these sheltering activities are a result of the threat of predation, but rather a response to other environmental factors.

ASEXUAL REPRODUCTION

Some holothurian species may reproduce asexually through fission (dividing into two). In certain species, such as *Holothuria atra*, this form of reproduction is thought to be very important and the products of fission may comprise up to 70 per cent of the population (Harriott, 1982). The importance of fission in other species is unknown, but it appears to occur naturally in several.

Experiments to induce fission by physical means (constricting with tight rubber bands) as a means of promoting population growth for farming purposes have been carried out at the University of Guam (Preston, 1990a: Richmond, *pers. comm.*). Fission can be induced in this way in *Holothuria nobilis* and *Actinopyga mauritiana*, but not in *Thelenota ananas*.

SEXUAL REPRODUCTION

Seasonality: The sexes are separate in holothurians, but there is no mating and fertilisation is external, in sea water. During spawning, the oral end of the animal rears up and gametes (eggs or sperm) are released into the surrounding waters. Like many other marine invertebrates, individuals of a given holothurian species spawn simultaneously at specific times of year, often at night and apparently in synchrony with lunar or tidal conditions. Synchronisation is through a chemical trigger released from spawning animals, which stimulates a spawning response from other animals in the vicinity.

Studies of the reproductive cycles of commercially important holothurians have been carried out by a number of authors, including Krishnaswamy and Krishnan, 1967 (India), Harriott, 1980 (Australia), Shelley, 1981 (Papua New Guinea), and Conand, 1981 and 1989 (New Caledonia). Variations in a number of characteristics have been examined, including the population sex ratio, the anatomy and developmental stages of the gonads, and the evolution of the gonado-somatic index (GSI), expressed as the weight of the gonad as a proportion of the body weight. All the studies have identified seasonal variations in spawning activity by holothurians, and these are reviewed by Conand (1986). In summary:

- In the lagoon of New Caledonia *Holothuria scabra* var *versicolor* spawned throughout the warm-water season. Reproductive activity, as indicated by the proportion of mature animals, began to increase in June, reaching a peak in October-December, then declining from October to February when the number of individuals in the post-spawning stage increased. The fall in GSI continued until May, when, after a resting period of about a month, it began to rise again as the cycle recommenced.
- *H. fuscogilva* showed a similar pattern, with the reproductive season coinciding with the warmer period, although the period of peak activity occurred slightly later (November - January).
- *H. scabra* followed a similar but more complex cycle which showed a secondary peak around August, at the end of the cool-water period. A secondary reproductive peak for this species has also been observed in India, Australia and Papua New Guinea.
- *Actinopyga echinites* in New Caledonia also showed a spawning peak in January-February, with a long phase of sexual resting during the cooler months. The cycle for the same species in Papua New Guinea was less clear, with spawning apparently taking place in February 1979, and October in 1980. This is possibly related to the respective latitudes of the two studies, since seasonality may be more pronounced further from the equator.
- *Thelenota ananas* began maturation around October and spawned during the warm-water season, probably from January-March. A long resting period then continued until the waters began to warm again.
- Although small proportions of sexually mature animals were present throughout the year, *H. nobilis* showed an opposite trend, with the spawning period occurring during the cooler months of June-August.

Fig. 5, from Conand (1989), shows the reproductive seasons of nine holothurian species in the New Caledonian lagoon.

Size at first maturity: Conand (1989) calculated average size at first maturity for selected holothurians by plotting a graph of the per centage of sexually mature animals against drained weight (weight of body wall and internal organs after draining off coelomic fluid through an incision), and determining the point at which 50 per cent of the animals are considered sexually mature. The equivalent total weights and total lengths shown in Table III were then determined using the biometric relationships presented in Table V.

Fecundity: Fecundity in holothurians generally appears to be high, at least among the commercially valuable species, but it is also highly variable depending on seasonal variations in reproductive potential and activity. The relationship between body size and fecundity is uncertain, not least because of the difficulties in obtaining a reliable measure of body size, and because fecundity estimates are influenced by the seasonal variation in GSI. There appears to be no correlation between fecundity and body size in *Holothuria scabra* (Harriott,

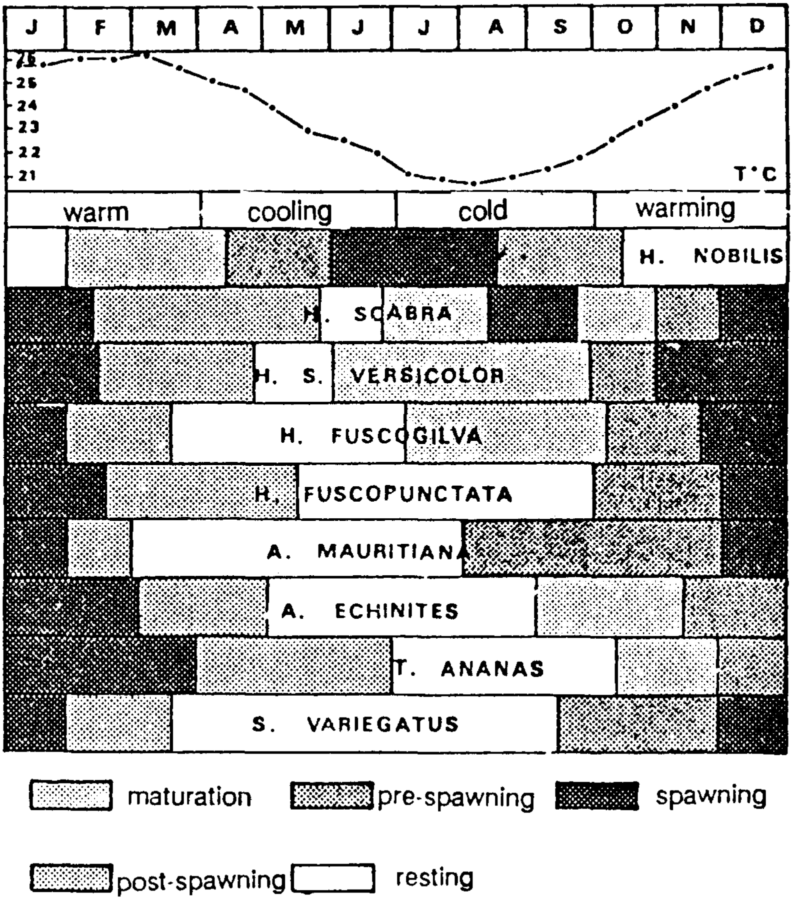

Fig. 5. Reproductive seasons of nine holothurian species and water temperature (°C) variations in the New Caledonian lagoon (from Conand, 1989).

1980; Shelley, 1981), although a correlation does appear to exist in *H. edulis* and *H. atra* (Harriott 1980).

Fecundity estimates for several species have been made by Conand (1989) and are summarised in Table IV.

Table III. Estimates of size at first maturity for selected sea cucumber species (from Conand, 1989).

Species	Drained weight (g)	Total weight (g)	Total length (mm)
Holothuria atra	110	160	165
H. scabra	140	184	160
H. scabra var *versicolor*	320	490	220
H. nobilis	580	800	260
H. fuscogilva	900	1,175	320
H. fuscopunctata	870	1,220	350
A. echinites	75	90	120
A. mauritiana	250	370	220
S. variegatus	450	560	270
Thelenota ananas	1,150	1,230	300

LARVAL DEVELOPMENT

The most striking thing about the larvae of holothuroids, and of other echinoderms, is their bilateral symmetry, which is in complete contrast to the adult body form. Holothurian eggs develop through the process of gastrulation until by about the third day they have become auricularia larvae, which have a ciliated band arranged in a characteristic form around the extremities of the body (Fig. 6). The larva has a complete functional digestive tract with a large ciliated stomodeum, an oesophagus, a stomach, an intestine, and an anus. Particulate food is obtained from currents of water created by the stomodeal cilia. The auricularia larvae of most species is 1 mm or less in length, but giant 15 mm larvae of unknown adults have been collected in plankton off Japan, Bermuda and the Canary Islands (Barnes, 1974).

Further development leads to a barrel-shaped larva, called the doliolaria, in which the original ciliated band becomes broken up and arranged in rings around the larva. The doliolaria larva is typically less than half the size of the auricularia (Arakawa, 1990).

Table IV. Fecundity (millions of oocytes per gram ovary weight) estimates for selected sea cucumber species (from Conand, 1989).

Species	Absolute fecundity	Relative fecundity
Holothuria atra	-	-
H. scabra	9 - 17	133
H. scabra var *versicolor*	2 - 18	93
H. nobilis	13 - 78	208
H. fuscogilva	6 - 14	128
H. fuscopunctata	1 - 13	44
A. echinites	4 - 25	333
A. mauritiana	23 - 33	389
S. variegatus	7 - 13	120
T. ananas	2 - 8	74

After a free-swimming existence, gradual metamorphosis, forming a young sea cucumber, starts during the latter part of planktonic existence. Metamorphosis is dramatic and leads to a complete reorganisation of the body of the animal as the radial symmetry of the adult develops. Tentacles, which will eventually become the buccal tentacles of the adult, begin to appear, and at this stage the metamorphosing animal is sometimes called a pentacula larva. Eventually, the young sea cucumber settles to the bottom and assumes the adult mode of existence.

Production of juvenile sea cucumbers in land-based hatcheries is technically feasible, at least for some species, and has been achieved for *Actinopyga mauritiana* and *Holothuria nobilis* in Guam (Preston, 1990a; R. Richmond, *pers. comm.*). The developing larvae are raised in aerated water in glass containers, dosed with penicillin to prevent infection, and fed on dinoflagellates. The consumed algae can be seen in the gut until the larvae reach the doliolaria stage, at which time they become replaced by unpigmented detrital matter.

Large-scale production and release of juveniles of the commercially important temperate-water sea cucumber *Stichopus japonicus* by prefectural hatcheries in Japan is now a routine feature of the Japanese fishery for this species (Arakawa, 1990). Adult animals are spawned in captivity and the larvae are fed on cultures of the diatom *Chaetoceros gracilis* until they develop to the doliolaria stage. At this time they are encouraged to settle by placing them in tanks containing PVC or polycarbonate sheets on which attached dinoflagellates have been cultured. Settled juveniles measure 0.3-0.4 mm and continue to be fed on

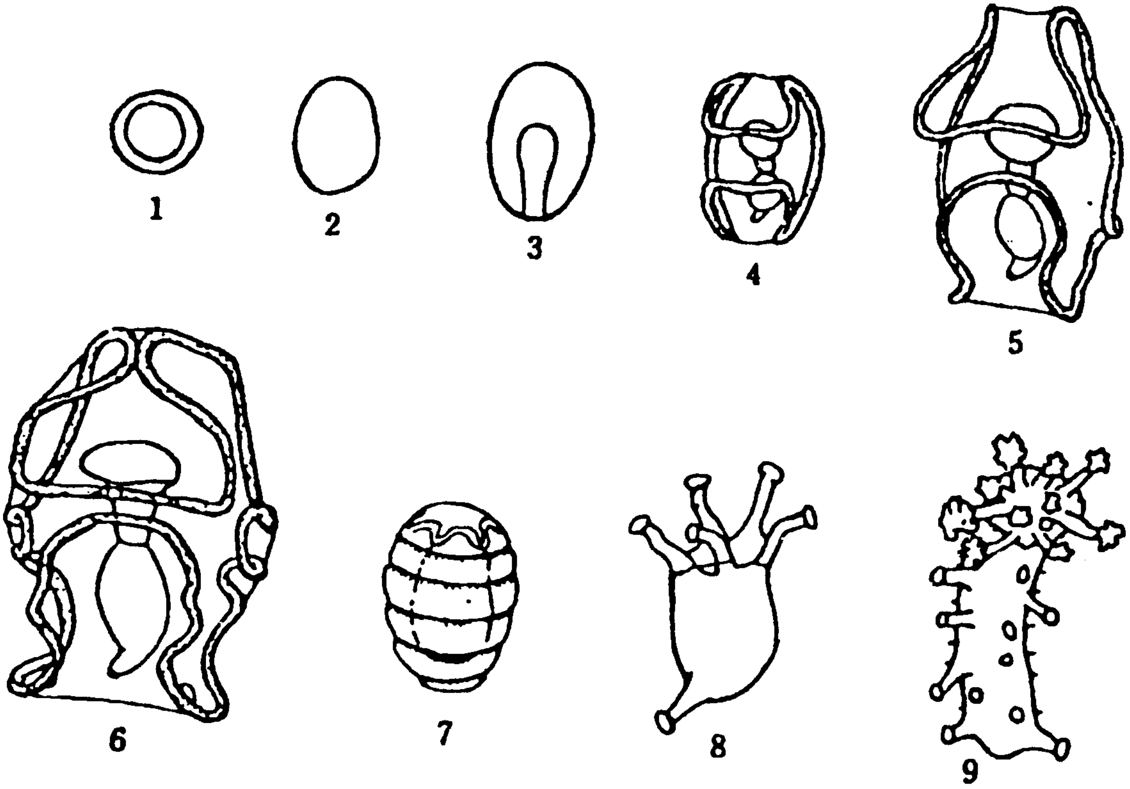

Figure 6. Larval forms of *Stichopus japonicus* (from Arakawa, 1990). 1 - Egg. 2,3 - Gastrulating larva. 4, 5, 6 - Auricularia. 7 - Doliolaria. 8 - Pentacularia. 9 Juvenile sea cucumber.

C. gracilis until they reach a length of about 1 mm, after which they are fed on frozen diatoms. At a length of about 1 cm, powdered dried seaweed *Esenius bicyclis* is introduced to the diet, gradually replacing diatoms. The juveniles are released into the sea when the length is 2-3 cm, and average weight is about 1 g.

In addition, spat collectors are used to provide settlement surfaces for naturally occurring *S. japonicus* larvae, thus enhancing fisheries based on wild stock by concentrating spatfalls in a known area, (H. Tanaka *pers. comm.*). Spat collectors consist of wire baskets filled with oyster shells or, more recently, PVC or polycarbonate sheets (Arakawa, 1990).

RECRUITMENT

Juvenile sea cucumbers are often absent from exploited adult populations, either because they occupy different habitats, or because they are extremely cryptic. Juveniles of some species, such as *Holothuria nobilis* and *Holothuria fuscogilva*, are only rarely seen, if ever. Shelley (1981) studied *Holothuria scabra* and *Actinopyga echinites* in Papua New Guinea and did not find individuals smaller than 60 mm and 50 mm in length respectively. Length-frequency distributions for New Caledonia presented in Conand (1986) show an absence of animals less than 120 mm in length for *H. scabra*, 180 mm for *H. scabra* var *versicolor*, 190 mm for *H. nobilis*, 220 mm for *H. fuscogilva*, 180 mm for *Thelenota ananas*, and 40 mm for *A. echinites*.

Juveniles of many commercial species thus appear to be protected from harvesting at an early age by their own behaviour and/or distribution. However, individuals of most species recruit to adult populations and become vulnerable to fishing pressure well before the age at first maturity (Table III).

Conand (1988) used growth and mortality estimates of *Thelenota ananas* and *Stichopus chloronotus* (see below) to estimate the biomass of theoretical cohorts of these species as they aged. This enabled estimation of the "critical length", *i.e.* the average length at which the biomass of the cohort is greatest and fishing will give the highest yields. She found that the critical length of *T. ananas* was 28 cm, slightly smaller than the average length at first sexual maturity of 34.5 cm. For *S. chloronotus*, the critical length also occurred slightly before the age at first sexual maturity.

GROWTH AND MORTALITY

Few studies have been carried out on the growth parameters of tropical holothurians, and there is little published information on the processes of growth and mortality. The data that is available has been reviewed by Ebert (1983) and Conand (1988), and the following section is drawn from these sources.

Attempts have been made to study growth by a variety of methods, including repeated measurements of tagged or marked animals, monitoring of modal progressions in the length-frequency distributions of natural populations, and observation of captive animals. Each method is hampered by problems. In most holothurians, tags or marks lead to localised necrosis which causes them to be lost within a few weeks or months, although there have been a few exceptions where tags have been retained for longer periods. Modal progressions have yielded growth information in some cases but the results have been complicated due to the occurrence of asexual reproduction (fission), in which unknown numbers of larger animals divide into two, thus altering the population size structure. Both tagging and length-frequency monitoring are further hampered by the difficulties of obtaining an accurate measure of either weight or length of holothuroids in the field, and by the absence of juveniles or small animals, which are often difficult to find or completely absent from adult populations. Captive animals have not provided useful growth information, because, when placed in holding tanks, they normally cease feeding and show negative growth until they die of starvation.

Despite the high inherent variability of both length and weight measurements in holothurians, length-weight relationships for a number of species have been calculated and these normally show reasonable correlation, as shown in Table V.

A number of workers have attempted to elaborate growth information for

Table V. Length-weight relationships, total weight (W g) to total length (L cm), for selected holothuroids.

Species	Relationship	Correlation coefficient	Reference
Holothuria scabra	$\text{Log } W = 2.28 \text{ Log } L - 6.35$	0.78	Conand, 1989
H. scabra	$W = 3.06\ L^{1.61}$	0.75	Shelley, 1981
H. scabra var *versicolor*	$\text{Log } W = 2.26 \text{ Log } L - 5.97$	0.76	Conand, 1989
H. nobilis	$\text{Log } W = 2.34 \text{ Log } L - 6.39$	0.80	Conand, 1989
H. fuscogilva	$W = 11.94\ L - 2712$	0.70	Conand, 1989
H. atra	$\text{Log } W = 2.13 \text{ Log } L - 5.64$	0.90	Conand, 1989
Actinopyga echinites	$\text{Log } W = 2.60 \text{ Log } L - 7.98$	0.89	Conand, 1989
A. echinites	$W = 0.68\ L^{2.00}$	0.61	Shelley, 1981
A. miliaris	$W = 0.824 \times 10^{-3}\ L^{2.441}$	0.96	Conand, 1989
Thelenota ananas	$W = 1.27 \times 10^{-3}\ L^{2.236}$		Conand, 1988
Stichopus variegatus	$\text{Log } W = 2.49 \text{ Log } L - 7.62$	0.92	Conand, 1989
S. chloronotus	$W = 2.22 \times 10^{-3}\ L^{2.10}$		Conand, 1988 (Data from Franklin, 1980)

selected species. Shelley (1985) studied the length-frequency distributions of *Holothuria scabra* and *Actinopyga echinites* in Papua New Guinea. He concluded that *H. scabra* in the size range 10-25 cm were growing at a rate of 0.5 cm per month, equivalent to an average monthly whole weight increase of 14 g. Modal progressions in *A. echinites* were less clear-cut due to the appearance and disappearance of modes between sampling visits. However, growth parameters were devised for this species (L = 23 cm, K = 0.78), and a monthly length increase between 0.6 and 0.9 cm, or 19 and 29 g, was inferred.

Conand (1986) notes that small specimens of *A. echinites* observed at a reef near Noumea had a mean size of 8.5 cm and on average weighed 50 g. Assuming these animals had been spawned in the previous reproductive season, they would have been about 5 months old, inferring an average growth rate of about 1.7 cm and 10 g per month. Similar observations on *A. miliaris* which averaged 6 cm long and 15 g in weight, indicated growth rates of 1 cm and 5 g per month.

More elaborate estimations of growth and mortality have also been carried out for some holothuroids. Estimates of the parameters L_∞ and K of the von Bertalanffy growth equation, and of natural mortality (M), have been made for six species, and these have been summarised by Conand (1988) as shown in Table VI.

The species in question show different growth and mortality characteristics. *Thelenota ananas* is long-lived, with a low mortality and a high asymptotic length, whereas *Stichopus chloronotus*, *Holothuria atra* and *Actinopyga mauritiana* show relatively high mortalities and smaller asymptotic sizes. These differences reflect the different habitat-related demographic and reproductive strategies of these species (Conand, 1988).

There are, however, reservations that apply to each data set. The data of Ebert (1978) for *H. atra* populations are complicated by the process of fission, which is extensive in this species (Harriott, 1982). The estimates of growth

Table VI. Growth and mortality parameters of selected holothurians (from Conand, 1988).

Species	L_∞ (mm)	K annual	M annual	Length interval	Reference
Holothuria atra	324	0.11	1.02	130 - 220	Ebert, 1978
Actinopyga echinites	230	3.00	-	100 - 300	Shelley, 1985
A. echinites	295	0.09	0.64	90 - 240	Conand, 1989
A. mauritiana	340	0.12	1.45	70 - 280	Conand, 1989
Stichopus chloronotus	342	0.45	1.79	40 - 300	Conand, 1988
Thelenota ananas	663	0.20	0.63	160 - 640	Conand, 1988

obtained for *A. echinites* by Conand (1989) are probably underestimates resulting from the bias caused by tag loss. The growth estimates for *A. echinites* by Shelley (1985), and for *T. ananas* and *S. chloronotus* by Conand (1988), on the other hand, may be overestimates, caused by the use of modal progressions in length-frequency or weight-frequency data. These considerations serve to emphasise the difficulties of studying growth and related processes in holothurians.

III. SOUTH PACIFIC HOLOTHURIAN FISHERIES

HISTORY OF EXPLOITATION

The importance of bêche-de-mer in Pacific islands economies dates back to the early days of European contact. Historical accounts describe visits to Northern Australia and Western Pacific locations by Malay vessels in search of bêche-de-mer in the late 1700s. The eastward expansion of the trade began in the first years of the 19th century, with collecting expeditions by European or American trading vessels in New Caledonia, Palau and Papua New Guinea. The first bêche-de-mer from Fiji was collected and cured in 1813, and the South Pacific trade became more or less fully established in the 1820s (Ward, 1972).

Although by European standards it was an insignificant industry conducted by a small number of ships, the bêche-de-mer trade in the Pacific had an enormous influence on the lives of Pacific Islanders, especially during the first half of the 19th century. Bêche-de-mer traders were the principal agents responsible for the introduction of firearms in many areas, as well as large quantities of trade goods, especially iron tools, fishhooks and the like, which reduced the time and labour required for many subsistence tasks in agriculture, fishing, and the making of clothing. The resulting increase in "leisure" time, plus the growing availability of firearms, resulted in increased levels of conflict and local warfare, which in turn led to major demographic and political change in some parts of the Pacific (Ward, 1972).

In more recent times, bêche-de-mer has continued to be an important, although variable, source of revenue to the Pacific islands. Output from the Pacific has varied widely during the last two centuries, in response to changing demand for the product, and the relative value and availability of other trade commodities (especially sandalwood, with which the bêche-de-mer business was originally linked) or opportunities. In addition, the attractiveness of the trade was greatly influenced by the ease of collecting the raw sea cucumbers: the returns from harvesting diminished greatly once the trade began in earnest and overexploitation occurred in many areas (Ward, 1972). Macro-economic factors, including wars and swings in the economies of major nations, have also had important effects on bêche-de-mer production in the Pacific and worldwide.

The bêche-de-mer trade has had significant environmental consequences, some of which are probably irreversible. The most obvious of these is the deforestation of coastal areas of much of their firewood, 10 tonne (t) of which was needed for smoking 1 t of bêche-de-mer. Some islands of Fiji, such as Mali, were completely denuded of any useable firewood during the early 19th century, and the forests have not subsequently recovered. The destruction of forests, especially mangroves, for bêche-de-mer production continues to be a matter of concern today.

FISHING METHODS

Harvesting, which in the Pacific is usually by hand-collection or free-diving, is straightforward and, although labour-intensive, requires little or no capital investment. In many situations holothurians can be harvested by gleaning at low tide. A small boat or floating container is normally required for collecting some of the more valuable species, such as *Holothuria nobilis, H. fuscogilva*, and *Thelenota* species. These types are normally found in water that is too deep for them to be collected while walking, but they can be gathered by free-diving with a face mask.

In deeper waters where free-diving is difficult or too tiring, some collectors use "bombs" made of a lead or concrete weight with a steel barb protruding from the base (Fig. 7). The weight is dropped onto the holothurians by divers swimming at the surface, usually alongside a small boat. Because the weight needs to be very heavy to pierce the tough holothurian skin, the hooked animal is then hauled up by the boatman. This system is not widely used and is only practical in areas of weak current.

The advent of underwater breathing apparatus has made the task of collecting deeper-water holothurian species much easier. The use of SCUBA gear for sea cucumber collection is still relatively limited due to the high capital costs involved in establishing and maintaining tank-filling facilities in remote areas. Hookah gear, however, is rapidly becoming more widespread as small, relatively low-cost compact units enter the recreational diving market. In Fiji, over 100 hookah units were sold during 1991, and most of these will probably be used by collectors of holothurians and other marine invertebrates (T. Adams, *pers. comm.*). The use of this type of equipment has the potential to significantly increase the likelihood of local over-harvesting and consequent adverse effects, as well as presenting a high risk of accidents to untrained users.

PROCESSING

Processing holothurians into bêche-de-mer requires the use of boiling containers, (typically discarded oil drums), smoke-sheds or smoking racks, and

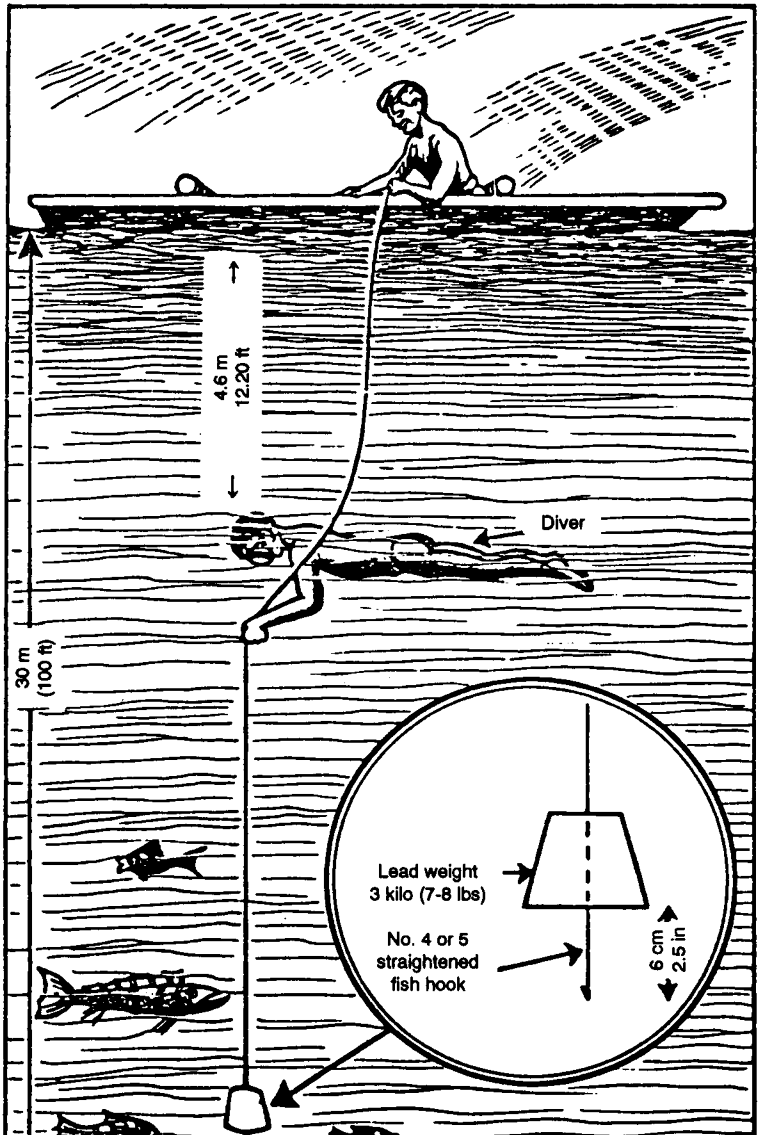

Figure 7. Use of the bêche-de-mer "bomb" (from Anon., 1979)

large quantities of firewood, but is still well within the capacity of rural producers to carry out without the need for sophisticated or costly equipment. When properly processed, bêche-de-mer will keep for many months without the need for refrigeration or other forms of preservation.

A typical bêche-de-mer processing operation is described by Anon. (1979) and comprises the following steps. A number of animals are placed whole in a cooking basket, typically improvised from galvanised wire mesh. This is placed into boiling seawater and left for a few minutes until the animals begin to swell, after which they are removed from the water and allowed to cool. A slit is made down one side of each animal and the bulk of the body contents removed. The animals are replaced in the boiling water and cooked for about a further half-hour until they become hard and rubbery. Care must be taken at this time to avoid under- or over-cooking, both of which will result in a product which is too soft and of low value. The animals are then removed from the cooking vessel and dipped into cool seawater, after which any remaining internal organs are removed. The tissues lining the interior of the body cavity are left in place.

After cooking, the animals are smoked and/or dried, by being placed with the split side facing down on a drying rack suspended above a low, smoky fire. Where copra processing is carried out, bêche-de-mer may be smoked inside the copra driers. More usually, however, they are smoked in small, purpose-built smokesheds or over open fires of mangrove wood close to the landing point. The smoking process typically lasts 24-48 hours, after which the finished bêche-de-mer will have shrunk by between 45 and 68 per cent in length, and lost between 88.8 and 97.4 per cent of its original weight, depending on the species (Conand, 1979; Preston, 1990b)

There are variations on this basic procedure depending on the species being processed. Some examples are as follows:

- For the larger, more valuable species such as white teatfish (*Holothuria fuscogilva*), black teatfish (*H. nobilis*) and prickly redfish (*Thelenota ananas*), a short stick is placed in the body cavity of each animal to hold the cut edges apart and allow the interior to dry thoroughly. Halfway through smoking, the sticks are removed from the body cavity and, with some species, raffia or string is tied around each animal to ensure that it achieves the shape desired by consumers.
- The process of smoking may be reduced or eliminated altogether and the animals simply dried in the sun, in which case the drying process may take several days. This is sometimes the case for low-value species such as blackfish (*Actinopyga spp*) and greenfish (*Stichopus chloronotus*). Van Eys and Philipson (1989) note that Singaporean buyers would prefer to see less smoked product, and a greater use of sun-drying by Pacific islands bêche-de-mer producers.
- The sandfish, *Holothuria scabra*, has a chalky epidermal layer which

requires an additional processing stage to remove. Traditionally, sandfish are not slit open or gutted, except for a small cut across the anus which allows gutting of larger specimens. After the second boiling, they are buried overnight in clean sand, then scrubbed clean and boiled a third time before smoking and drying. In recent times, processors have sought to improve sandfish quality by using cleaning machines (a revolving drum containing abrasive grit, similar to a large stone-polisher or cement mixer), but this is not widespread.

- Small, low-value types such as blackfish (*Actinopyga miliaris*) and greenfish (*Stichopus chloronotus*) are not slit or gutted.
- The boiling time for curryfish (*Stichopus variegatus*) and greenfish (*S. chloronotus*) is considerably reduced due to the tendency for these animals to disintegrate during processing.

Variations to the processing method may also be made according to the requirements of the individual buyer, and these will be reflected in the price paid to the processor. Purchasing agents often provide detailed instructions, including processing demonstrations, to processors as to their particular requirements.

The basic grading criteria for bêche-de-mer are nevertheless universal. Price is first of all determined by species. Buyers dealing with Hong Kong traders will have different species preferences from those shipping to Singapore, and it is not unusual to find quite different prices offered for the same species by different buyers. Within a given species, higher prices are always paid for larger animals with a low moisture content (20-30 per cent by weight is desirable), a firm, hard texture, a regular, even shape, and smooth incisions without ragged edges. Odour and colour are also taken into consideration, as both are used as indicators that the product has been processed correctly and is free of decomposition.

Low-grade product is still readily purchased by most buying agents and is even sought after by some, because it can be re-processed to convert it to a higher-grade product. The economies of scale achieved by doing this at a central location have made it a more profitable activity for some agents than the purchasing of high-grade product direct from individual producers.

INTERNATIONAL TRADE

Production: The quantity of bêche-de-mer produced in the Pacific, although not known with any accuracy, has probably never been a major part of world production. Other production areas are or have been the Philippines, Indonesia, Malaysia, Australia, and the Indian Ocean. During the first half of the 20th century, about 15 countries were producing between 1,000 and 3,000 t annually (Conand, 1986). Landings in the late 1970s and early 1980s ranged between 10,000 and 15,000 t annually, with Philippine and Indonesian fisheries being the largest producers, and Pacific islands countries accounting for only some 10 per cent of this production (Conand, 1986). This increased in the late 1980s and reached a peak in 1987, when Pacific islands countries produced an estimated 29 per cent of the world production of 8,000 t (Conand *et al.*, 1991).

In the early 1980s, the principal Pacific islands bêche-de-mer producers (in order of importance) were Fiji, Papua New Guinea and Solomon Islands (van Eys, 1986). New Caledonia has also undergone periods of relatively high production. Table VII shows export figures from major producing countries in the region during this period. It should be noted, however, that in some countries exports are not always adequately recorded and these figures are probably underestimates. In addition, several other Pacific islands countries produce bêche-de-mer, though in smaller quantities.

Table VII. Bêche-de-mer exports from five Pacific islands countries, 1983-1990 (tonnes dry weight).

Country	1983	1984	1985	1986	1987	1988	1989	1990
Papua New Guinea[1]	8	5	19	105	192	203	195	172
Solomon Islands[2]	9	44	14	134	146	146	87	
Vanuatu[2]	6	3	2	4	12	10	39	
Fiji[2]	33	53	66	229	640	717	365	260
New Caledonia[3]	15	150	89	180	77	135	55	126
Total	58	255	190	652	1067	1211	741	(558)

Notes:

1. Data from Papua New Guinea from Lokani, 1990. 1990 data is provisional, projected from first quarter production.
2. Data for Solomon Islands, Vanuatu and Fiji from S. McElroy, *pers. comm.*, October 1990. 1990 data for Fiji is provisional, based on first half-year production.
3. Data for New Caledonia from Conand and Hoffschir, 1991.

During the period 1983-1990, bêche-de-mer exports from the Pacific increased, and in some countries underwent something of a boom. Fiji in particular showed a major increase in production during 1986 and 1987. Production from Solomon Islands and Papua New Guinea also increased, although less markedly, during the same years. Much of the increase has been caused by increases in the price of traditionally low-valued species, which had previously not been worth collecting. One of these, *Actinopyga miliaris* (blackfish), made up the bulk of the increase in production from Fiji (T. Adams, *unpubl. ms.;* Preston *et al.*, 1988) and New Caledonia (B. Fao, *pers. comm.*) in the late 1980s.

The real reasons for the increase in demand may be attributed to a combination of factors. These include civil unrest and consequent production drops in bêche-de-mer producing areas outside the Pacific (especially the Philippines and Sri Lanka) and the growing use of low-value species as a barter currency between mainland China and overseas Chinese communities, following the tightening up of Chinese currency exchange regulations (L. Chui, *pers. comm.*).

Assuming a typical ratio between live sea cucumber weight and dried product of 10 to 1 (Conand, 1979; Preston, 1990b), Fiji's 1988 production of over 700 t converts to a total fresh weight of some 7,000 t. This exceeds the total quantity of all other forms of fishery production combined in Fiji that year, including the catch of the national tuna fishing corporation.

Markets: In the late 19th century, commercial statistics indicate the predominance of China as a bêche-de-mer importer, with about 1,000 t annually (Conand and Sloan, 1989). Today, the major markets for Pacific islands product are Hong Kong and, to a lesser extent, Singapore, with secondary markets in Beijing, Vancouver, Los Angeles and Sydney.

In each of the two principal markets, a good deal of repackaging and re-export takes place to smaller centres of consumption scattered throughout South-east Asia, mainland China and in Chinese communities worldwide. The two centres procure from and export to different hinterlands, with Singapore trading principally to the west, and Hong Kong having major links to neighbouring countries and those to the south (van Eys and Philipson, 1989). The functions of importers/exporters are not only limited to physical movement of product, but also include activities aimed at upgrading and adding value, such as grading, cleaning, drying and packing. The considerable transhipment of product that occurs among these markets complicates the interpretation of trade statistics.

Statistics on bêche-de-mer trade in Singapore are difficult to obtain because of the manner in which the product is classified by the Singaporean customs department (Van Eys and Philipson, 1989). The most recent available data from Singapore appear to be those presented by Conand (1986) and van Eys and Philipson (1989), both covering the period up to 1984. More recent data are available from Hong Kong, and these are shown in Table VIII.

It is notable that, while imports from Fiji in 1988 are noted as being over 1,000 t, Fiji export statistics indicate a production of only 717 t (Table VII). This underlines the difficulties in obtaining reliable information on the true extent of this complex trade.

Value: The recent production boom in the Pacific is a result of increasing prices generated by a growing demand for this product. In particular, the last decade has seen a marked increase in the price of traditionally low-valued species, attributed by McElroy (1990) to increasing demand in mainland China for inexpensive bêche-de-mer types. This has led to a change in the species

Table VIII. Hong Kong bêche-de-mer import and re-export statistics in tonnes, 1988 - 1989. (Data provided by INFOFISH).

Country	Imports 1988	Re-exports 1988	Imports 1989	Re-exports 1989
Australia	7.6	2.1	1.1	3.7
Canada	33.6	14.2	15.0	12.6
China	98.5	2,608.7	117.1	1,361.3
Fiji	1,067.5	0.0	242.9	0.0
Indonesia	3,131.5	0.0	1,785.6	11.6
Japan	34.2	0.6	39.4	0.9
Korea	42.9	0.0	22.4	9.6
Madagascar	86.6	0.0	57.7	0.0
Malaysia	19.5	10.9	0.0	11.4
Maldives	0.0	0.0	101.5	0.0
Mozambique	39.1	0.0	22.9	0.0
Papua New Guinea	202.0	0.0	71.5	0.0
Philippines	1,718.5	0.0	621.7	16.8
Singapore	797.7	123.5	1,067.9	55.4
Solomon Islands	139.6	0.0	91.5	0.0
South Africa	34.3	0.0	22.3	0.0
Sri Lanka	36.3	0.0	26.2	0.0
Tanzania	61.2	0.0	18.3	0.0
Thailand	0.0	0.0	15.5	0.5
Tonga	0.2	0.0	0.0	0.0
USA	12.1	41.9	24.4	63.2
Vanuatu	2.2	0	0.0	0.0
Other	151.8	501.2	161.7	299.8
Total	7,716.7	3,303.1	4,526.6	1,846.8

composition of exports, with greatly increased proportions of low-value types. McElroy (1990) presents data to show that, in Fiji and Solomon Islands, increases in bêche-de-mer production during the past decade have been accompanied by a marked decline in the average value per kg, attributed to increased proportions of low-value species.

In 1988 prices declined somewhat, especially for low-grade species, and this led to a levelling off in production. In addition, overexploitation and the subsequent introduction of management legislation combined to reduce overall production from Fiji (T. Adams, *pers. comm.*). Prices for high-grade species, however, have remained inflated or have increased in response to declining relative volumes of these types. As a result, in most countries production is still substantially higher than pre-1986 levels. This may justify concern over the long-term sustainability of some fisheries.

Although statistics are not available on the different types of bêche-de-mer, they are traded by species, and, within the species categories, by grade. The type of bêche-de-mer greatly influences the price, as shown in Table IX. Where a range of prices is shown, this reflects the value of the lowest and highest grades for that particular species.The sea cucumber fishery in Fiji generated foreign revenues of about US$3 million in 1986. If appropriately managed, these fisheries have significant potential to contribute regularly to the export earnings of small islands nations.

Table IX. Export prices of bêche-de-mer types in mid-1990 (from McElroy, 1990).

Product	Price (US$/kg)
White teatfish (*Holothuria fuscogilva*)	14 - 24
Black teatfish (*Holothuria nobilis*)	11 - 12
Sandfish (*Holothuria scabra*)	5 - 15
Prickly redfish (*Thelenota ananas*)	12
Greenfish (*Stichopus chloronotus*)	8
Surf redfish (*Actinopyga mauritiana*)	7 - 8
Curryfish (*Stichopus variegatus*)	6 - 7
Blackfish (*Actinopyga miliaris*)	6
Stonefish (*Actinopyga lecanora*)	4 - 6
Deep-water redfish (*Actinopyga echinites*)	4
Amberfish (*Thelenota anax*)	4
Elephant's trunk fish (*Holothuria fuscopunctata*)	3
Lolly fish (*Holothuria atra*)	2 - 4
Pinkfish (*Holothuria edulis*)	2
Chalkfish (*Bohadschia marmorata*)	10
Leopardfish (*Bohadschia argus*)	4
Brown sandfish (*Bohadschia vitiensis*)	2-3

IV. FISHERY MANAGEMENT

Historically, bêche-de-mer fisheries have been characterised by long cycles in which a period of heavy exploitation is followed by a resting period during which the resource is able to recover. These cycles have generally resulted from fluctuations in worldwide supply and demand caused by wars, economic recession, and other events that are beyond the control of producer countries.

This phenomenon also occurs on a smaller scale. Localised resource depletion has been observed in some countries, and this has usually resulted in a forced cessation of harvesting or in harvesters moving to other areas. In 1991 this led traditional resource owners in the north province of New Caledonia to develop a system of "crop rotation" in which areas are allowed to be harvested for three months, then lie fallow for the rest of the year (K. Poru, *pers. comm.*). In Fiji during the 1970s, the Fisheries Division's Fish Processing Unit travelled among Fijian outer islands, loaning smokesheds and providing a bêche-de-mer buying service that encouraged very intensive harvesting for periods of a few weeks at a time. The Unit would normally visit an island at 1-2 year intervals, in between which little or no harvesting took place, and the resource had time to recover.

Some species of sea cucumber have characteristics that tend to protect them from the more extreme forms of overexploitation. Juveniles may be cryptic and hard to find, and part of the population may exist in deep or turbid areas that are difficult to harvest effectively (although this may change with the increasing use of underwater breathing apparatus). In view of these characteristics, allowing the fishery to respond to market fluctuations and the logistical advantages of intensive short-term harvesting may be an easy and acceptable "management" option in some situations.

Most managers believe that a sustainable fishery is to be preferred over one that follows "boom-and-bust" market cycles. However, at the present time there are few fisheries for tropical holothurians that are subject to any form of management at all. The only formal management measure imposed at a national level in any Pacific islands country is a legal minimum size limit on dried sandfish *Holothuria scabra* in Fiji (T. Adams, *pers. comm.*) and an export limit of 40 t of dried product in Vanuatu (S. Roberts, *pers. comm.*). There is therefore little management experience on which to base broader suggestions or recommendations.

At present, we do not have the information needed to manage holothurian fisheries in order to produce maximum or optimum sustainable yields. For this, more detailed studies of the processes of recruitment, growth and mortality are needed. We do nevertheless have the basic biological information needed, and the research techniques available, at least to develop management systems that will protect the resources of most commercially important holothurians from the worst effects of overfishing, and to ensure that the resource is harvested in a sustainable way.

As an example, information on the size at first maturity, the ratio of dried to fresh size, and reproductive seasonality is available for many species, and this can be used to devise minimum size limits that will allow most animals to spawn at least once before being captured. Field survey work by fishery biologists to determine the size-frequency distributions both of the wild populations and of the finished product would enable prediction of the likely impacts of such measures on the fishery, and monitoring of actual impacts. Provided that they are workable and enforceable in the local social context, size limits would appear to be one of the most logical management tools for holothurians, given the relatively low value of the smaller sizes of any given species.

Other management approaches might include closed areas, closed seasons (such as the system of "crop rotation" mentioned above), quotas and gear restrictions. Preston and Lokani (1990) recommended that government efforts to develop a bêche-de-mer fishery in Ha'apai, Tonga, should include a ban on the use of SCUBA gear for the collection of sea cucumbers. The ban was proposed not only out of safety considerations, but because it was calculated that about half the estimated stock of 1 million exploitable bêche-de-mer in the area was in water deeper than 30 m, and this would be largely inaccessible to local divers without SCUBA. There is no technical obstacle to prevent fishery biologists from monitoring the results of this management measure, or any of the others mentioned above.

Holothurians have a reputation of being difficult animals to study, and in some ways this is deserved. Their plastic form makes measurement of live external dimensions unreliable, and the fact that they can contain variable quantities of water and sediment greatly affects live weight measurements. They are difficult to keep in captivity and typically show reduced feeding and negative growth when confined in aquaria, making *in vitro* growth studies difficult. They are able to shed most conventional types of tags through local necrosis of the body wall, rendering the results of tagging-based studies of mortality and even migration difficult to interpret. The study of growth and recruitment through analysis of modal progressions in size-frequencies is confounded by the occurrence of binary fission and the absence of small size classes in the population.

Sea cucumbers are nevertheless the basis of some of the most economically important small-scale fisheries in the Pacific islands region. There is enough basic information available to enable common-sense management approaches to be devised for these fisheries that will conserve resources and provide for sustainable exploitation. Holothurian populations are not immune to study by classic methods of invertebrate survey, and the effects of management approaches can be evaluated relatively easily and used to improve management. More basic studies on holothurian population characteristics are needed, and these are within the capacity of Pacific island fisheries departments to carry out. By promoting the study of sea cucumber fisheries, fisheries departments can contribute to the development of rational systems of management for their own national fisheries, and those of the region.

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