Commercially Valuable Sea Cucumbers of Guam

Results of a Stock Assessment

A Report Prepared for the Director, Department of Agriculture and Wildlife Resources, Territory of Guam, USA

Submitted by

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Saina Ma'åse!

EXECUTIVE SUMMARY

The island of Guam has an abundance of commercially valuable species of holothuroids (sea cucumbers) and is currently a target of interest to foreign buyers of the processed product, beche-de-mer. The Guam Territorial government has realized the danger of over-harvesting this valuable resource and is currently seeking to develop a management plan that will permit a sustainable level of harvesting. Towards this goal, we performed a survey of holothuroids and other echinoderms around the island's approximately 125 km of coastline to 1) assist in a stock assessment of commercially valuable species and 2) document Guam's echinoderms as part of a global survey of coral reef biodiversity. From July 2011 to May 2013, a total of 74 sites were visited during the day around the island, including reef flats, lagoons, channels, and forereef slopes to a depth of 25 m. Conservatively, a total of 6389 individual animals from 59 taxonomic units attributable to species of echinoderms were identified during the survey: 34 holothuroids, 12 echinoids, seven asteroids, 12 ophiuroids, and one crinoid. Numerous commercially valuable species of holothuroids were seen in Guam's waters, some in abundance. The most valuable species seen in reasonable abundance were *Holothuria* (*Microthele*) *whitmaei* (trade name: black teat fish), and *Actinopyga varians* (surf red fish), and *Actinopyga echinites* (deep-water red fish). Based on our survey, preliminary recommendations for a beche-de-mer management plan include: 1) Institute a moratorium on commercial fishing until a management plan is in place. 2) Institute minimum harvestable lengths for each species. 3) Institute temporary closures to increase stock size and value. 4) Increase public awareness and teach monitoring methods to Department of Agriculture personnel. 5) Continually assess the effectiveness of the management plan and modify it when necessary. We discuss all these measures at greater length in the report.

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INTRODUCTION

In late 2009, we submitted a proposal to the Guam Coral Reef Initiative (NOAA) expressing our interest in surveying and collecting holothuroids (sea cucumbers) on Guam. We were informed that our proposal was most timely, as some people had recently begun collecting in abundance commercially valuable species of holothuroids from local reefs for personal use. As well, foreign buyers had begun directing questions to one of us (AMK) about the possibility of commercial collection. In light of this revelation, we quickly refocussed our proposed surveys from a solely research-oriented format to one emphasising rapid, low-tech methods useful for island-level assessment of commercially valuable stocks.

Hence, we developed a survey the holothuroids and other echinoderms around the island of Guam. The following report primarily outlines a simple method for stock assessment and provides several suggestions for managing beche-de-mer based on our analysis of the data and the published literature. In sum, we

- surveyed reef sites around the island for their echinoderm fauna,
- assembled a checklist of the echinoderms encountered,
- collected and preserved voucher specimens of unusual species,
- photographed vouchers or representative specimens of each species,
- recorded the population size structure of commercially valuable species of holothuroids,
- calculated catch-per-unit effort of valuable species,
- provided interim reports to the Director of the Guam Coral Reef Initiative.
- put together an illustrated field guide to the island’s stock species,
- provided preliminary recommendations about developing a management plan for safeguarding Guam's holothuroid resources,

- published peer-reviewed scientific publications reporting on new distributional records of echinoderms for the island,
- presented this final report to the Guam Department of Agriculture.

METHODS

Site selection

Sites (Figure 1 and Appendix 1) were selected for their even distribution around the island and their presumed high diversity of echinoderms. On-site GPS or GoogleEarth coordinates of longitude and latitude for each site were recorded. Several sites where harvesting of holothuroids was known to have occurred (primarily along the west coast) were included, even though we knew these areas did not have virgin stocks of the harvested species.

Most major shallow-water marine habitats were investigated, including reef flats, fore-reef slopes to 25 m depth, seagrass beds, channels, lagoons, and areas adjacent to mangroves. Given the time constraints, we eschewed mangrove channels, river mouths, steep drop-offs and elsewhere with little accumulation of well-sorted sediment, since such areas, while in some cases having a possibly rich echinoderm fauna (e.g., crinoids and ophiuroids in the case of drop-offs), were likely to have few commercially valuable holothuroids, the focus of the survey. Most notably, Guam's rocky north-eastern coast was not sampled between Fadian Point and Pati Point, as it was known that this area had far fewer holothuroids, likely because of its poorly developed reefs and little sediment accumulation.

In the first subsection below, *Stock description*, we outline the species composition and ecology of commercially valuable species. In the second subsection, *Catch per unit effort*, we calculate catch per unit effort for abundant species. In the third subsection, *Minimum harvestable lengths*, we calculate minimum harvestable lengths for abundant species. In the fourth and final subsection, *Size frequency distribution*, we report on the population size structure at an island scale of the commercially valuable species. In the fifth and final subsection, *Site and depth distribution*, we report on the island-wide distribution of the commercially valuable species.

Stock survey

Divers performed counts of commercially valuable species of holothuroids using timed haphazard swims, usually between one or two hours. For SCUBA-aided surveys deeper than a few meters, surveys occurred at a constant depth, some dives to a maximum of 25 m. In addition, divers recorded the undisturbed lengths of all holothuroids *in situ*. This approach was reasoned superior to transects, quadrats or manta tows for several reasons. First, the usual methods are time intensive and our mandate was to perform a large-scale survey (of over 125 km of coastline) with fixed, albeit generous resources. Second, our approach also estimated an important quantity of interest to fisheries managers: catch per unit effort, the number of animals that a fisher might collect per unit time. Moreover, the method can easily be used by villages to monitor their own stocks. Finally, information on length can be translated into initial management recommendations about minimum harvestable size per species.

It was also convenient for divers to record all species of echinoderms that they observed at each site to a maximum of 25 m in depth. Collected specimens, or representatives thereof, from nearly all species were photographed *in situ*. One or two voucher specimens of unusual species were collected and preserved in 95% ethanol or 70% isopropanol. Before preservation, holothuroids were first relaxed in seawater laced with chlorobutanol and chilled to near freezing.

Material from these few species, including tissue samples for DNA extraction were deposited in the collections of the Florida Museum of Natural History. Divers looked through rubble and in crevices to find cryptic forms. However, no special methods were used to assess infaunal or nocturnal species, as the goal was to learn about CPUEs during normal harvesting, which usually occurs during the day.

Calculating minimum harvestable lengths

We calculated minimum harvestable lengths for each abundant species based on the mean length of the sampled individuals. The object of calculating this quantity is to preserve stock in proportion to a conservative percentage of its reproductive capacity. The latter phrase essentially refers to the total number of eggs produced by a stock. Amesbury (1996) suggests conserving 50% of the reproductive capacity of a beche-de-mer stock. However, calculating minimum harvestable lengths based on this level of conservation requires knowledge of target species' biology, which is currently unavailable for most of Guam's stocks. Relevant aspects of the biology include sex ratio and size class-specific proportion of reproductive females. Still, given the urgency of implementing a management plan and given what *is* known about the relationship between holothuroid length and the unavailable parameters (Amesbury 1996), mean length is probably a reasonable and conservative first estimate until such data can be incorporated.

Calculating catch per unit effort

We estimated catch per unit effort (CPUE) as person hours for each abundant species at a site during timed swims by three observers. These swims ranged from 40 minutes to 200 minutes. Particularly abundant species at a site were usually only counted for the first 10 to 30 minutes. Only using sites at which the species occurred was considered a more reasonable measure, as we sought to estimate conservative, but realistic estimates of likely CPUE during actual harvesting, which almost always only occur at sites where the species is known to occur. Had we measured CPUE based on all sites, we would have most accurately estimated the CPUE when harvesters selected collecting sites at random, a very unrealistic assumption.

CPUE was then calculated for a given species at an island level ("pooled CPUE") by summing over site abundances *n* of all observers for sites at which the species occurred, and dividing this by the sum of individual survey times *t* for these sites and all observers:

$$pooled \quad CPUE = \frac{\sum n_i}{\sum t_i}$$

We also calculated for each species the mean site CPUE over all observers and sites *k* at which the species occurred:

$$mean \quad CPUE = \frac{1}{k}\sum \frac{n_i}{t_i}$$

Population size structure

The size frequency distribution of a stock provides basic information on the status of a stock, such as age and reproductive structure. To examine the population structure of abundant species we recorded the in-situ undisturbed lengths of such species and then binned these by rounding lengths to the nearest centimeter.

Site and depth distribution

The spatial distribution of a stock provides information about the ecology of stocks by indicating the type of environment in which undiscovered stocks might most likely occur and the techniques used for economical harvesting. To examine the spatial distribution of abundant species we recorded the sites and depths of all species encountered.

RESULTS

A total of 74 sites were visited around the island (Fig. 1 and Appendix 1), equivalent to about one site on average per every 1.7 km of coastline. A total of 6389 individual echinoderms, including 5889 individual holothuroids were encountered. Table 1 lists these echinoderms, which came from 59 taxonomic units attributable to species: 34 holothuroids, 12 echinoids, seven asteroids, 12 ophiuroids, and one crinoid.

In 20 instances (0.31%), individuals of non-commercial holothuroids or other echinoderms were difficult to identify in the field and our method of photographing these for later identification could only place the specimens to genus or even family. We feel that eight of these (four holothuroids, one crinoid, one echinoid, two ophiuroids) in each case could be provisionally provided names of species already recorded. Another two small cryptic specimens of holothuroids belong to a poorly known genus *Labidodemas*, now under study by others (F. Michonneau, pers. comm.). Another echinoid most closely resembling a member of *Centrostephanus* after consultation with experts is an as yet taxonomically poorly known species perhaps not in this genus (G. Paulay, pers. comm.). The final nine unidentified echinoderms were all small, cryptic ophiuroids whose taxonomy is in general poorly known or in flux. Because of these

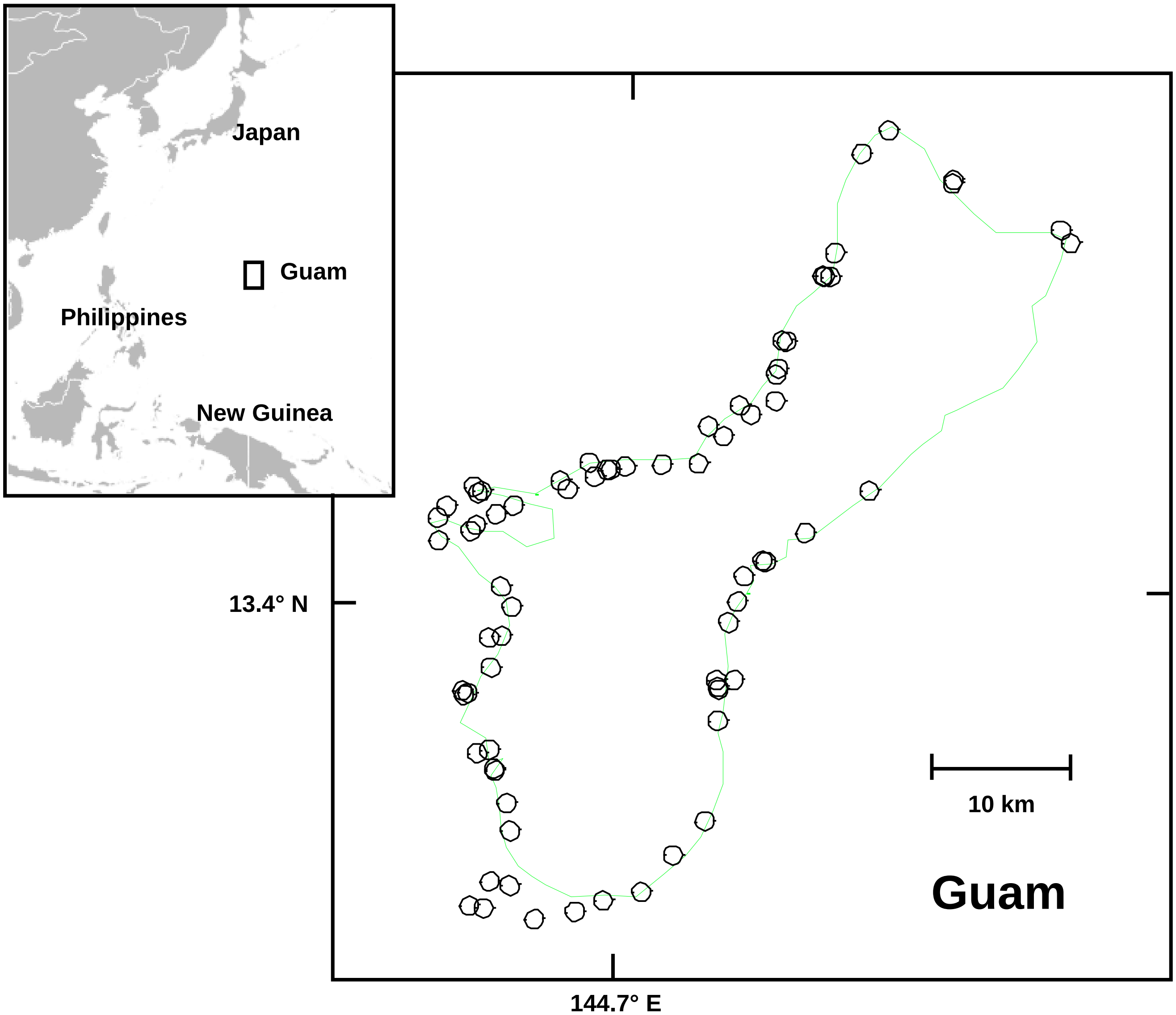

Figure 1. Map of Guam, showing study sites. Outline of Guam includes the sometimes wide (to 1 km) reef-flat margin.

taxonomic difficulties, the aforementioned 19 species were not included in the above species tallies. However, their identifications are included in the full list of species in Table 1.

Stock description

Guam has about 22 species of holothuroids regarded as commercially valuable. They are arrayed in six genera among two families. This is out of a total of about 60 species of holothuroids known from the Mariana Islands (Michonneau et al. 2013). The high number of holothuroids collected here as compared to other echinoderms is undoubtedly due to an outsized collection effort for these species on our part, rather than a true representation of their proportional richness in the island's echinoderm fauna.

Several species we surveyed have only been seen at most a few times as single individuals over the course of decades of studying and collecting by zoologists, e.g., *Holothuria* (*Lessonothuria*) *verrucosa*. A couple of others 'species' may turn out to be colour variants of more common species. For example, *Bohadschia ocellata* may be covered with large red dots with white margins or be completely dark brown (Kim et al. 2013). One species, *Holothuria* (*Cystipus*) *rigida*, however, is a new record for the island and has been reported by one of us (AKM) in Michonneau et al. (2013).

Only one of the holothuroids could be new to science and formally undescribed. *Stichopus* sp. cf. *horrens* is a small (about 12 cm undisturbed length) light to deep brown animal often with black blotches dorsally that was found in seaweed (*Sargassum* sp.) at the Agat reef-flat site. This contrasted with the normal colour the other and often larger morph of *S. horrens* island-wide, which tended to be blotched in several shades of grey, as well as possess a cryptic habit during the day, hiding under rocks.

Table 1. Echinoderms encountered and their spatial distributions.

Taxa	Number of sites	Minimum Depth (m)	Maximum Depth (m)
HOLOTHUROIDEA			
Actinopyga echinites	42	0	3.35
Actinopyga palauensis	6	0	10
Actinopyga varians	39	0	9
Afrocucumis africana	3	0	0
Bohadschia argus	35	0	23
Bohadschia koellikeri	1	0	0
Bohadschia marmorata	2	0	0
Bohadschia sp	1	9	9
Bohadschia vitiensis	8	0	10
Chiridota hawaiiensis	3	0	0
Holothuria atra	49	0	18
Holothuria cinerascens	5	0	0
Holothuria difficilis	3	0	7.6
Holothuria edulis	10	0	20
Holothuria fuscocinerea	2	0	0
Holothuria fuscopunctata	4	0	10
Holothuria hilla	23	0	7.6
Holothuria impatiens	5	0	1.3
Holothuria leucospilota	29	0	20
Holothuria lineata	6	0	0.15
Holothuria pervicax	3	0	0
Holothuria rigida	2	0	0.15
Holothuria rigida?	1	0	0
Holothuria verrucosa	1	0	0
Holothuria whitmaei	23	0	20
Labidodemas sp	2	6	10.6

Table 1. Echinoderms encountered and their spatial distributions.

Taxa	**Number of sites**	**Minimum Depth (m)**	**Maximum Depth (m)**
Opheodesoma grisea	1	0	0
Pearsonothuria graeffei	3	7.62	16.8
Stichopus chloronotus	39	0	20
Stichopus horrens	5	0	0
Synapta maculata	25	0	25
Synaptidae gen et sp	2	0	0
Thelenota ananas	8	0	18.3
Thelenota anax	1	16.2	16.2
ASTEROIDEA			
Acanthaster planci	18	0	25
Choriaster granulatus	2	9.14	16.2
Culcita novaguineae	21	0	18.3
Echinaster luzonicus	4	4.57	20
Linckia guildingi	10	0	20
Linckia laevigata	41	0	20
Linckia multifora	14	0	20
CRINOIDEA			
Phanogenia gracilis	1	9.1	9.1
Phanogenia sp	1	2.7	2.7
ECHINOIDEA			
Centrostephanus sp	1	0	0
Diadema savignyi	15	0	6.4
Echinometra aciculatus	1	0	0
Echinometra diadema	6	0	9
Echinometra mathaei	32	0	9
Echinometra oblonga	1	2.7	2.7
Echinometra sp	1	0	0

Table 1. Echinoderms encountered and their spatial distributions.

Taxa	Number of sites	Minimum Depth (m)	Maximum Depth (m)
Echinometra sp A	16	0	9.14
Echinostrephus aciculatus	36	0	9
Echinothrix calamaris	12	0	9
Echinothrix diadema	29	0	7.6
Parasalenia gratiosa	2	20	22.8
Toxopneustes pileolus	1	7.6	7.6
Tripneustes gratilla	6	0	3.35
OPHIUROIDEA			
Macrophiothrix longipeda	2	0	0
Macrophiothrix sp	2	0	2.7
Ophiactis savignyi	3	0.15	9.1
Ophiarachnella gorgonia	2	7.6	30
Ophiarthum elegans	3	0	30
Ophiarthum pictum	1	6	6
Ophiocoma anaglyptica	1	0	0
Ophiocoma dentata	3	0	0
Ophiocoma erinaceus	4	0	9.1
Ophiocoma scolopendrina	15	0	16.8
Ophiocomella sexradiata	1	3.05	3.05
Ophiolepis cincta	1	10.6	10.6
Ophiomastix caryophyllata	2	3.05	18.3
Ophiomastix mixta	4	0.15	9.1
Ophionereis sp	1	10.6	10.6
Ophiuroidea sp	9	0	0

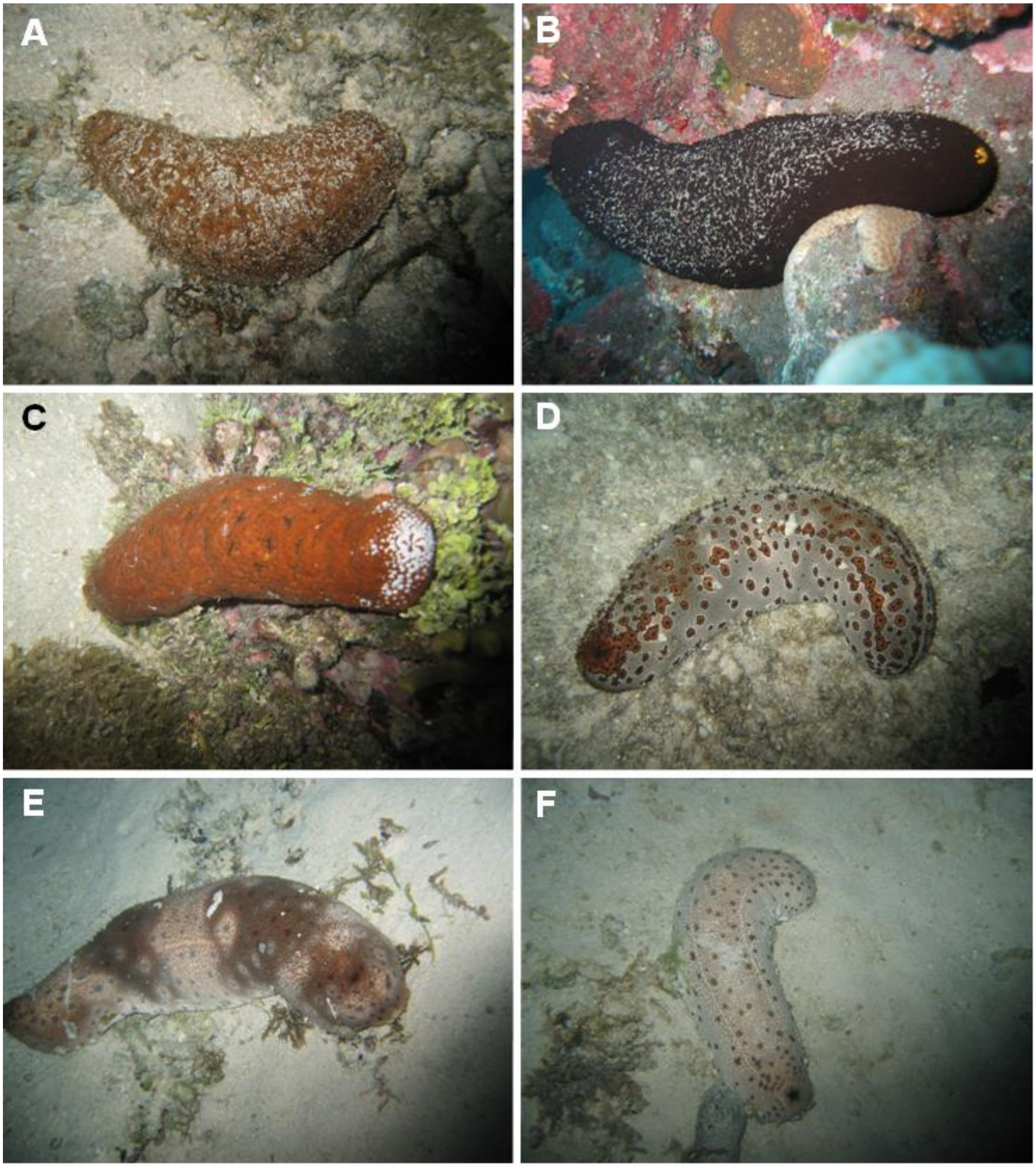

Figure 2. Commercially valuable holothuroids of Guam. A) *Actinopyga echinites*. B) *A. palauensis*. C) *A. varians*. D) *Bohadschia argus*. E) *B. argus* X *B. vitiensis* hybrid, blotched morph. F) *B. argus* X *B. vitiensis* hybrid, spotted morph.

In sum, Guam appears to have numerous commercially important species of holothuroids that could be harvested in large numbers. How much of these resources can be sustainably harvested is, however, a separate question and will be addressed later in this report under the section *Recommendations*.

Figure 2 illustrates 17 of the most abundant and distinctive species or species hybrids of commercially valuable forms found on Guam. These forms are described below, while similar-looking, but much less common forms are mentioned under the more common species. Below, we describe in detail Guam's most valuable or abundant species.

HOLOTHURIIDAE

Actinopyga echinites (Jäger, 1833)

Fig. 2A

A medium-sized species, to 30 cm in length, with a thick muscular, usually bumpy to slightly wrinkled body wall, noticeably flattened ventrally and somewhat dorsally. Anus surrounded by five calcified papillae or "teeth." Body color dorsally and ventrally, light to dark brown with darker to black inside dorsal and lateral wrinkles. Specimens less than 15 cm in length often lighter in color and with a single row of widely spaced ventrolateral enlarged papillae or "teats." Usually entirely covered in sand. The trade name, "deep red fish", implies its habit in deep water. However, on Guam, as well as elsewhere in Micronesia, this species only occurs in abundance only on the shallow (0 - 2 m depth) reef flats. Otherwise, found during the day and night near sandy rubble from less than 1 to more than 10 m. Common throughout the western Indo-Pacific. Found throughout Micronesia.

HOLOTHURIIDAE

Actinopyga palauensis Panning, 1944

Fig. 2C

A large species, to 40 cm in length, with a thick muscular, smooth body wall, flattened ventrally less so dorsally, often wrinkled laterally and covered with a fine, net-like, partial covering of sand. Anus surrounded by five calcified papillae or "teeth". Body color dorsally and ventrally a solid, deep blackish brown. Found during the day and night in the open on the reef slope associated with live corals to at least 30 m depth. Found in the islands of the western tropical Pacific. In Micronesia, *A. palauensis* is known from the Mariana and Caroline archipelagos.

HOLOTHURIIDAE

Actinopyga varians (Selenka, 1867)

Fig. 2B

A large species, to 30 cm in length, with a thick muscular, smooth body wall, noticeably flattened ventrally. Anus surrounded by five calcified papillae or "teeth." Body color dorsally a chestnut either free of, to almost entirely covered by, white blotches tending to form irregular transverse bands. Body color ventrally a lighter, almost rose brown. Found during the day and night exposed on the wave-washed outer reef-flat margin. In this survey, it was commonly seen in the surf zone near the outer reef-flat margin and surge channels to 2 m depth. In older literature, this species goes by the name of *A. mauritiana*, a name soon to be reserved for the closely related species from the Indian Ocean (Michonneau et al. 2013). The red surf fish occurred at nearly all surveyed locales. Common throughout the western Indo-Pacific. Found throughout Micronesia.

HOLOTHURIIDAE

Bohadschia argus Jäger, 1833

Fig. 2D

A large species, to 40 cm in length, with a thick, smooth body wall, flattened ventrally, and occasionally covered with pieces of shell or algae. Body color pattern dorsally distinctive but quite variable, usually a background of gray with few to many scattered orange-brown ocelli. Body color ventrally often yellowish. Elsewhere in Micronesia some specimens nearly all white with gray spots or all black with dark brown spots. Ejects many long sticky, milky white Cuvierian tubules from its anus when disturbed. Found during the day and night in the open on sandy to rubble bottoms on the shallow mid- to outer reef flat to 20 m depth of the reef slope. Found throughout the tropical Indo-west Pacific region, including Micronesia.

HOLOTHURIIDAE

Bohadschia argus X *B. vitiensis* hybrid

Fig. 2E-F

A large form, to 35 cm in length, with a thick body wall, flattened ventrally. Color pattern dorsally quite variable, from white with scattered dark brown polka dots to as above or with gray spots. These varied forms all appear to be F1 reciprocal hybrids between *B. argus* and *B. vitiensis* (see Kim et al. 2013). Ejects many long sticky, milky white Cuvierian tubules from its anus when disturbed. Burrows in sand during the day, but active at night in the open on sandy to rubble bottoms on the reef flats and lagoons to at least 10 m depth. Found throughout the tropical west Pacific, including Micronesia.

HOLOTHURIIDAE

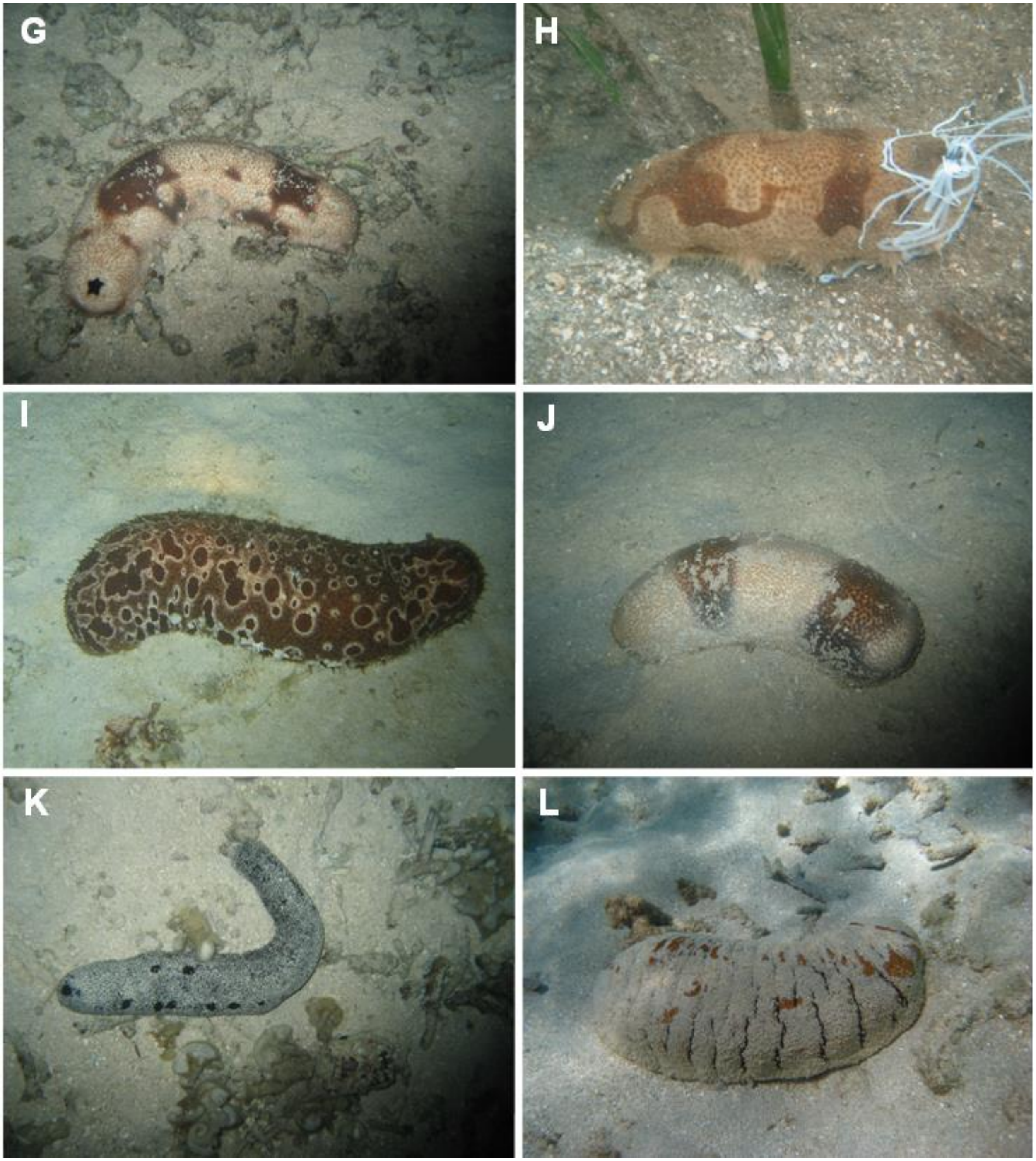

Figure 2 (cont'd.). Commercially valuable holothuroids of Guam. G) *Bohadschia koellikeri*. H) *B. marmorata*. I) *B. ocellata*. J) *B. vitiensis*, banded form. K) *Holothuria* (*Halodeima*) *atra*. L) *H.* (*Microthele*) *fuscopunctata*.

Bohadschia koellikeri (Semper, 1868)

Fig. 2G

A medium-sized species, to 30 cm in length, with a thick body wall, flattened ventrally. Color pattern variable dorsally, a cream background with purplish brown transverse "eroded" bands having the appearance of small circular pieces removed. Close-up, the colours are comprised of many fine lines. Ejects many long sticky, milky white Cuvierian tubules from its anus when disturbed. Burrows in sand during the day, but active at night in the open on sandy to rubble bottoms, sometimes with seagrass, on the reef flats and lagoons to at least 5 m depth. Found throughout the tropical west Pacific to the eastern Indian Ocean. Found throughout Micronesia.

HOLOTHURIIDAE

Bohadschia marmorata Jäger, 1833

Fig. 2H

A medium-sized species, to 25 cm in length, with thick, smooth body wall, flattened ventrally, sometimes with shaggy, enlarged ventrolateral papillae. Often coated in sand. Background color dorsally cream to tan, usually with irregular caramel blotches dorsolaterally. Lighter cream ventrally. Ejects many long sticky, milky white Cuvierian tubules from its anus when disturbed. Burrowed in sand or silt during the day, active at night in the open on sandy to rubble bottoms on the shallow mid- to outer reef flat to 20 m depth of the reef slope. Also, on silty inner reef flats and seagrass beds near mangroves. Found throughout the tropical Indo-west Pacific region. Found throughout Micronesia.

HOLOTHURIIDAE

Bohadschia ocellata (Jaeger, 1833)

Fig. 2I

A medium-sized species, to 25 cm in length, with thick body wall, flattened ventrally. Color variable, either uniformly dark brown with yellow-brown papillae dorsally, or also overlain with a few to many yellowish to reddish brown spots outlined in white when large. Ventral color dark when there are few or no spots dorsally, white otherwise. Ejects milky white Cuvierian tubules from its anus when disturbed. Burrows in sand during the day, but active at night in the open on sandy to rubble bottoms, sometimes with seagrass, on the reef flats and lagoons to at least 5 m depth. Found throughout the tropical west Pacific region and Micronesia.

HOLOTHURIIDAE

Bohadschia vitiensis (Semper, 1867)

Fig. 2J

A large species, to 35 cm in length, with a thick body wall, flattened ventrally. Color pattern dorsally quite variable, from banded as above to uniformly dark brown or even pure white, but never purplish brown eroded bands as in *Bohadschia koellikeri*. Ejects many long sticky, milky white Cuvierian tubules from its anus when disturbed. Burrows in sand during the day, but active at night in the open on sandy to rubble bottoms, sometimes with seagrass, on the reef flats and lagoons to at least 10 m depth. Found throughout the tropical Indo-west Pacific. Found throughout Micronesia.

HOLOTHURIIDAE

Holothuria (*Halodeima*) *atra* Jäger, 1833

Fig. 2K

A medium-sized species, to 25 cm in length, with a soft, smooth body wall, rounded in cross section. Body completely black, usually covered in sand dorsally with characteristic double longitudinal rows of spots lacking sand. Lies in the open on sandy bottoms of the reef flats and reef slope to at least 10 m depth. Larger specimens, more often without sand, occur in deeper water. Reef-flat forms often reproduce by transverse binary fission, resulting in dense populations of short, stubby specimens. Found throughout the Indo-west Pacific. Occurs throughout Micronesia. A closely related, but less common species, *Holothuria* (*Halodeima*) *edulis* Lesson, 1830, to 25 cm in length, also with a smooth, pliable body wall, rounded in cross section. On Guam, it is only found on the western coast from PIti Bay to Merizo. In the Mariana Islands, the colors are usually reddish brown to black dorsally, pink ventrally. Elsewhere in the Pacific, it may also be entirely pink or gray. Exposed during the day and night on sand to sand-and-rubble bottoms on the reef flat and lagoons to at least 10 m depth, often where there is at least a fraction of finer terrigenous sediment. Found throughout the tropical western Pacific. Occurs throughout Micronesia.

HOLOTHURIIDAE

Holothuria (*Microthele*) *fuscopunctata* Jäger, 1833

Fig. 2L

A very large species, to 60 cm in length, with a thick, wrinkled body wall, flattened ventrally. Dorsally white to yellowish, with many small scattered brown dots, black within wrinkles. White ventrally. Lies exposed day and night on sandy bottoms on reef slopes and lagoons from 2 m to at least 30 m depth. Found throughout the tropical western Pacific. Occurs throughout Micronesia.

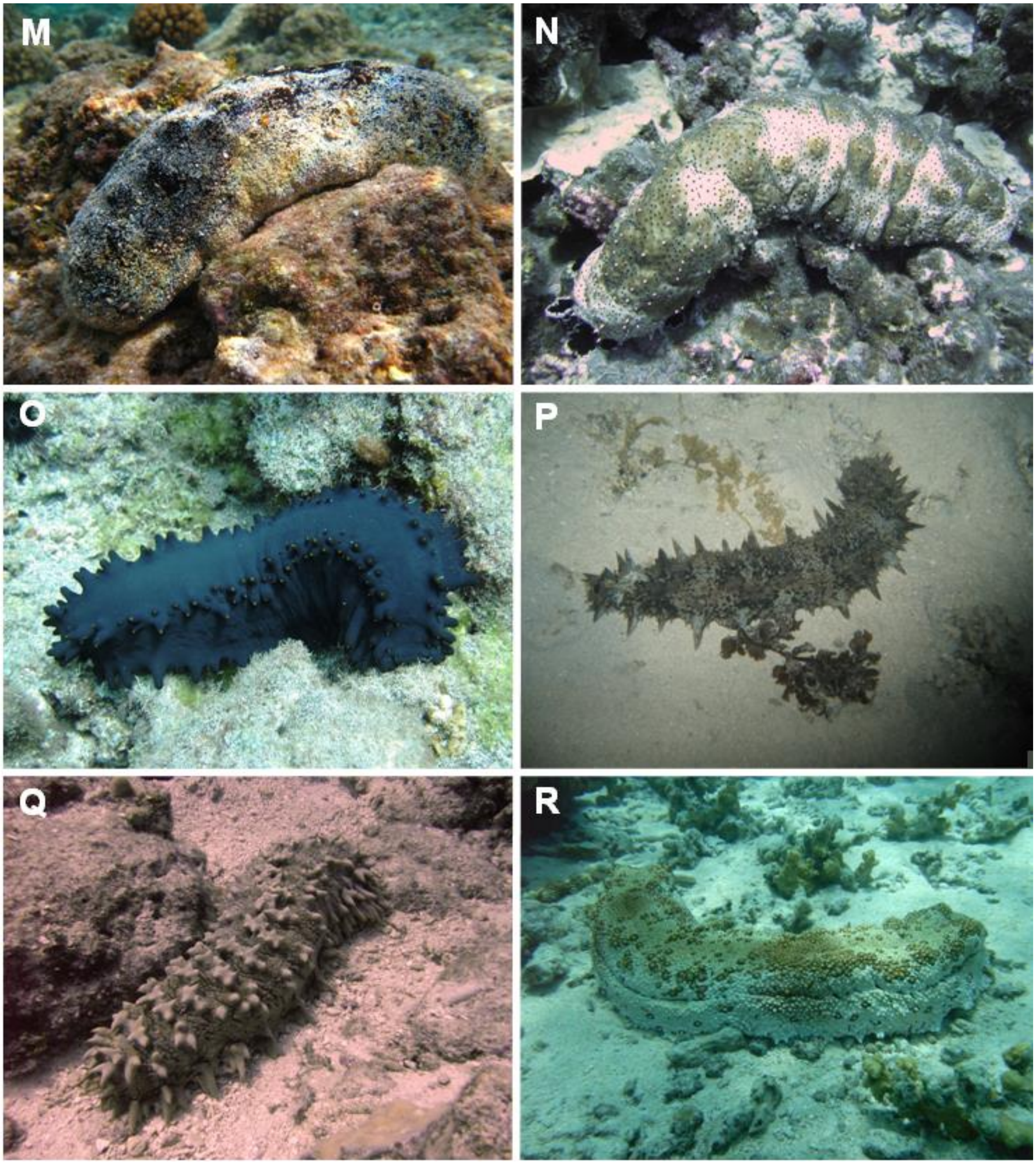

Figure 2 (cont'd.). Commercially valuable holothuroids of Guam. M) *Holothuria* (*Microthele*) *whitmaei*. N) *Pearsonothuria godeffroyi*. O) *Stichopus chloronotus*. P) *S. horrens*. Q) *Thelenota ananas*. R) *T. anax*.

HOLOTHURIIDAE

Holothuria (*Microthele*) *whitmaei* Bell, 1887

Fig. 2M

A large species, to 50 cm in length, with a thick, rigid, smooth body wall, flattened ventrally. Adults with enlarged ventrolateral papillae, juveniles also with dorsal papillae. Adults completely black dorsally, grayish black ventrally. Often covered with a thin layer of fine sand. Very small specimens white, increasingly larger juveniles with more black blotches dorsally. Lies exposed day and night on sandy bottoms on reef slopes and lagoons from 0 to 25 m depth. Smaller specimens more often found on the outer reef flat from 0 to 1 m depth. This species occurred infrequently (approximately two to six animals were observed per one-hour swim) on mid- to outer reef flats islandwide. In other parts of Micronesia, this species also is found on the forereef slope to a maximum depth of about 23 m. In older literature, this species goes by the name of *H.* (*M.*) *nobilis*, a name now reserved for a closely related species from the western Indian Ocean.Found throughout the tropical western Pacific. Occurs throughout Micronesia. Guam also has a similar, closely related, but quite rare species, *Holothuria* (*Microthele*) *fuscogilva* Cherbonnier, 1980, to 60 cm in length. Background color dorsally and ventrally, tan to light brown overlain dorsally with variable amounts of mottling in dark brown to black. Usually with enlarged ventrolateral papillae or "teats". Lies exposed day and night on sandy bottoms on reef slopes and lagoons. A relatively deepwater species, occurring from 5 m to at least 30 m depth. Found throughout the tropical western Pacific, but may be reduced by commercial over-harvesting. Occurs in the Marianas and western Caroline Islands in Micronesia.

HOLOTHURIIDAE

Pearsonothuria graeffei (Semper, 1867)

Fig. 2N

A large species, to 35 cm in length, with a firm, bumpy body wall, slightly flattened ventrally, numerous, large ventral tubefeet. Adult dorsal colors distinctive, blotchy, brown and white with numerous speckles and short streaks of black, tentacles black, edged in white. Small juveniles black with yellow-tipped white papillae, resembling a *Phyllidia* nudibranch. Rarely ejects many long, milky white Cuvierian tubules from anus. Lives exposed during day and night near live coral on the reef slope from 2 to at least 20 m depth. Found throughout the tropical western Pacific. Occurs throughout Micronesia.

STICHOPODIDAE

Stichopus chloronotus Brandt, 1835

Fig. 2O

Medium-sized species, to 35 cm in length, with a soft, thick body wall, trapezoidal in cross section. Color distinctive: dark green, almost black dorsally, lighter ventrally with large, orange-tipped dorsal and lateral papillae. Exposed day and night on rock, rubble, or sand of the outer reef flat and reef slope from 0 to at least 30 m depth. Smaller animals may reproduce via transverse binary fission. Found throughout the tropical Indo-western Pacific. Occurs throughout Micronesia.

STICHOPODIDAE

Stichopus horrens Selenka, 1867

Fig. 2P

Medium-sized species, to 35 cm in length, with a soft, thick body wall, trapezoidal in cross section. Color is mottled in dark gray blotches over a background of cream. Sometimes with a greenish, pinkish or yellowish background. Numerous large dorsal and lateral papillae. Hidden during day in crevices or under rubble, exposed at night on rock, rubble, or sand of the outer reef flat and reef slope from 0 to at least 30 m depth. A smaller, brown, diurnally active, fissioning form from seagrass (see inset) may prove to be a distinct species. Found throughout the tropical Indo-western Pacific. Occurs throughout Micronesia. Guam also has a simlar, but much rarer species, Stichopus noctivagus Cherbonnier, 1980. It is medium-sized, to 25 cm in length, with a soft, thick body wall, trapezoidal in cross section. Color is mottled red to rust blotches over a background of white. Numerous small scattered papillae. Hidden during day in crevices or under rubble, exposed at night on rock, rubble, or sand of the reef slope from 2 to at least 30 m depth. Found in the tropical western Pacific. Occurs at least in the Mariana and western Caroline Islands in Micronesia.

STICHOPODIDAE

Thelenota ananas (Jäger, 1833)

Fig. 2Q

Very large species, to 70 cm in length, with a firm, smooth, thick body wall, trapezoidal in cross section with numerous, sometimes well-developed, multi-pronged papillae dorsally and many large tubefeet ventrally. Small juveniles extremely irregular in shape, resembling a small pink alcyonacean coral. Color is reddish brown dorsally, pinkish ventrally, pink in juveniles. Exposed during day and night on sand near live coral on the reef slope from 2 to at least 30 m depth. Found in the tropical Indo-western Pacific. Occurs throughout Micronesia. Guam also has a similar, but much rarer species, the striking *Thelenota rubralineata*, only seen once at great depth (Kerr et al. 1992). Large species, to 50 cm in length, Thelenota rubralineata Massin & Lane, 1991, with numerous uneven papillae dorsally and many large tubefeet ventrally. Color is characteristic: a herringbone-like pattern of crimson and white fine lines, papillae tipped in yellow. Juvenile form unknown. Exposed during day and night on sand near live coral on the reef slope from 8 to at least 65 m depth. Found across the tropical western Pacific, including Micronesia where it occurs below 20 m depth.

STICHOPODIDAE

Thelenota anax H.L. Clark, 1921

Fig. 2R

Very large species, to 1 m in length, with a firm, bumpy, thick body wall, trapezoidal in cross section with numerous warty papillae scattered dorsally and many large tubefeet ventrally. Color is tan to reddish blotches dorsally over a beige background, whitish ventrally. Juvenile form unknown. Exposed during day and night on sand near live coral in lagoons and on the reef slope from 2 to at least 30 m depth. Found in the tropical Indo-western Pacific. Occurs throughout Micronesia.

Catch per unit effort

Table 2 shows catch per unit effort of the 15 most abundant or valuable commercially valuable species for which at least three individuals were measured. The pooled CPUE values in Table 1 estimate island-wide CPUE for the species. While this was calculated using only sites at which a given species occurred, the values are probably conservative, since we sampled haphazardly, while fishers will target areas of highest abundance of a species. The mean CPUE is an average catch per unit effort calculated over sites at which a given species occurred. The minimum and maximum site CPUE are often quite different, indicating wide variability in abundances of a species among sites.

Table 2. Catch per unit effort (CPUE) of the 15 largest and commercially most valuable species of holothuroids on Guam. *n* = number of sites with the species; Pooled = CPUE based on pooling all sites for a species; Mean = mean site CPUE; Min = minimum site CPUE; Max = maximum site CPUE.

Species	***n***	**Pooled**	**Mean**	**Min**	**Max**
Actinopyga echinites	42	16.6	47.4	0.3	507.7
Actinopyga palauensis	6	0.9	1.3	0.3	3.3
Actinopyga varians	39	8.7	29.6	0.2	327.3
Bohadschia argus	35	1.6	2.1	0.4	18.0
Bohadschia marmorata	2	1.7	3.4	0.7	6.0
Bohadschia vitiensis	8	7.1	25.3	0.7	156.0
Holothuria atra	49	27.9	93.7	20.2	162.0
Holothuria edulis	10	16.4	69.6	1.2	440
Holothuria fuscopunctata	4	0.5	0.6	0.2	1.3
Holothuria whitmaei	23	2.4	2.6	0.2	9.6
Pearsonothuria graeffei	3	2.9	3	2.2	3.6
Stichopus chloronotus	39	9.6	13.3	0.5	72.7
Stichopus horrens	5	10.7	7.0	0.5	31.0
Thelenota ananas	8	0.9	1.1	0.3	1.9
Thelenota anax	1	10.7	10.7	10.7	10.7

Species found at only a few of the 74 sites surveyed, probably indicate species with more patchy distributions around Guam (e.g., *Actinopyga palauensis* and *Thelenota anax*). Conversely, species such as *Bohadschia argus*, *Holothuria* (*Halodeima*) *atra* and *Stichopus chloronotus* appear to be both locally abundant – as evidenced by relatively high CPUE – and widely distributed – as evidenced by similar minimum and maximum CPUEs.

Table 3. Mean *in situ* lengths, pooled across sites at which the species was present, of the 15 largest and most commercially valuable holothuroids in Guam. *n* = sample size; C.I. = confidence interval around sample mean. Lengths in centimeters.

Species	*n*	Mean Length	Lower 95% C.I.	Upper 95% C.I.
Actinopyga echinites	1361	14.7	14.7	14.7
Actinopyga palauensis	10	27.6	27.3	27.9
Actinopyga varians	631	16.5	16.5	16.5
Bohadschia argus	116	25.9	25.8	26.0
Bohadschia marmorata	3	16.0	14.9	17.1
Bohadschia vitiensis	98	23.7	23.6	23.8
Holothuria atra	1924	15.0	15.0	15.0
Holothuria edulis	196	15.8	15.7	15.9
Holothuria fuscopunctata	5	36.4	36.2	36.6
Holothuria whitmaei	111	27.8	27.7	27.9
Pearsonothuria graeffei	11	30.0	29.7	30.3
Stichopus chloronotus	749	18.3	18.3	18.3
Stichopus horrens	145	7.0	7.0	7.0
Thelenota ananas	12	38.8	38.5	39.1
Thelenota anax	5	55.6	55.0	56.2

Minimum harvestable lengths

Table 3 shows mean *in situ* lengths of commercially valuable species for which at least three individuals and upwards of 1924 individuals, were measured. The upper and lower 95% confidence intervals indicate the range of lengths over which we can be most confident the true mean length of the entire population of a species occurs. All species appear to be similar in size to those found elsewhere in the Pacific (Conand 1989), including Micronesia (Kerr et al. 2007, 2008).

Population size structure

Figure 3 shows the frequency histograms of *in situ* lengths of the 10 commercially valuable species for which at least 100 individuals were measured islandwide. Most distributions are unimodal and slightly right skewed about their presumed modal size, hence appear to be log normally distributed. This is a commonly seen feature of tropical organisms that possess slow and constant recruitment and have long lives. This in turn suggests that the size distributions are equilibrial and have been so over many life times of the animal. Commercially valuable species as seen in Figure 3 tend to be long-lived. For example, *Holothuria* (*Microthele*) *whitmaei* (Figure 2M) has been estimated to live for 20 to 30 years, while smaller, thinner walled species such as *H*. (*Halodeima*) *atra* (Figure 2E) may live to seven years (Conand 1989). Hence, these holothuroids constitute virgin stocks of all the figured species. One species' size distribution, however, appears to be bimodal, *Stichopus horrens* (Figure 2P). The lower mode appears to consist mostly of the small brown morph commonly seen in Agat, while the upper mode primarily of the more widely seen grey morph.

Site and depth distribution

Table 1 shows the number of sites at which all holothuroids were found, as well as the minimum and maximum depths at which they were seen. These depths appear typical for these species seen elsewhere in their geographic ranges (Conand 1989). The only exception appears to be *Actinopyga echinites* (Figure 2A), which is a shallow-water, primarily reef-flat inhabitant in Guam and elsewhere in Micronesia (Kerr et al. 2006, 2008), but can occur deeper in the

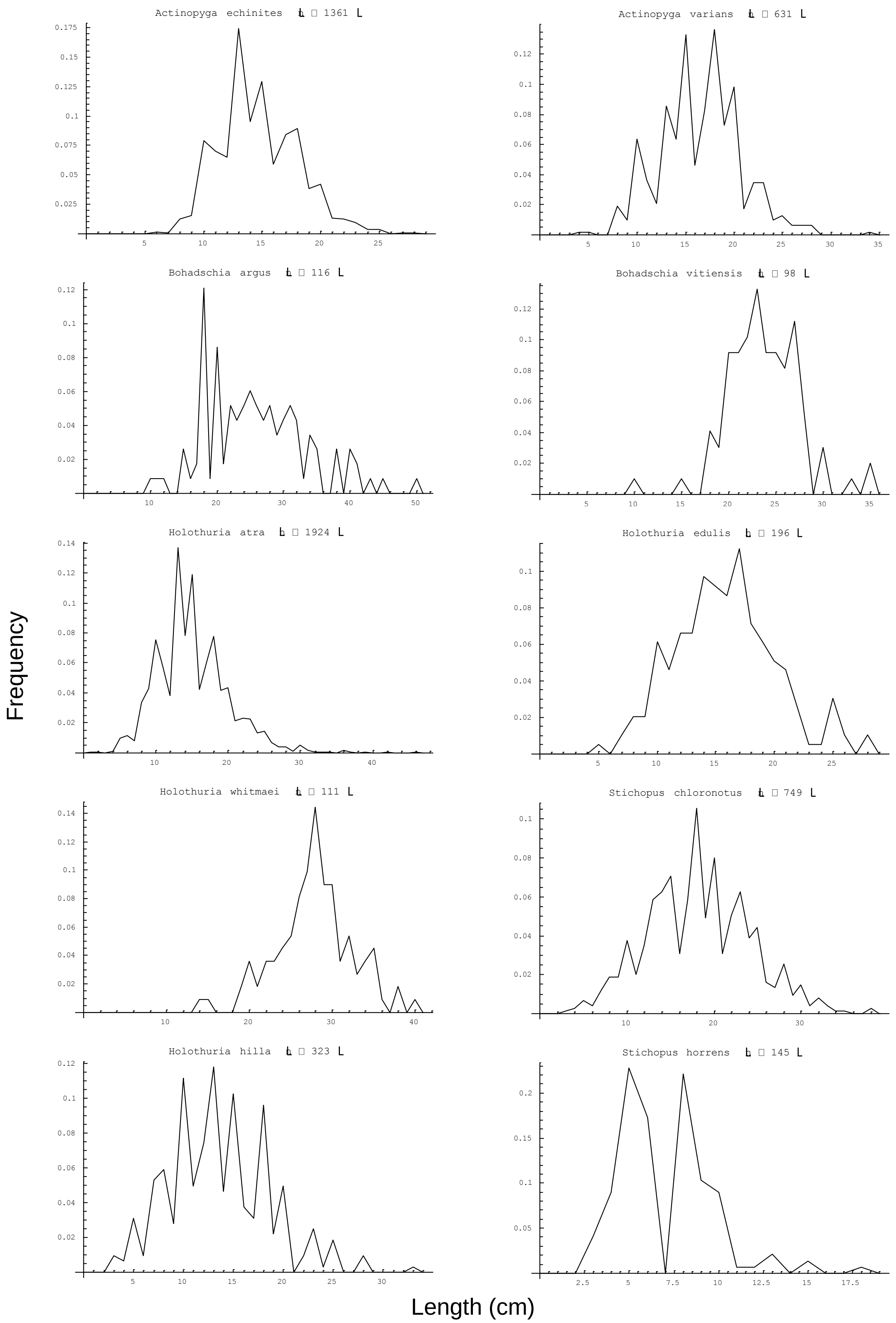

Figure 3. Population size structure of commercially valuable holothuroids of Guam.

western-most Pacific (Conand 1989). One species occurring at several sites, *Holothuria* (*Halodeima*) *edulis*, nevertheless appears restricted to the southwestern shores of Guam from Piti Bay to the western flank of Cocos lagoon. Species found at several sites whose minimum and maximum depths were less than 3 m were strictly reef-flat inhabitants. Only a few widely occurring species were essentially habitat generalists in that they occurred in quite shallow to the deepest parts of the forereef slopes that we surveyed (to 25 m).

DISCUSSION

Prospects for a Sustainable Beche-de-mer Fishery

Guam has an abundance of commercially valuable species of holothuroids. We observed populations of some of the most desirable commercial species, occurring at all of the sites we visited around the island. Many of these species occur at the high population densities sometimes seen elsewhere in Micronesia, and, hence, constitute an important and valuable marine resource for the island.

Conversations with stakeholders have made it clear that Guam is currently being targeted by at least one foreign buyer of beche-de-mer. In this industry at other locations in Micronesia, local fishers are paid for fresh, unprocessed holothuroids by an island-based intermediary, who processes the animals into the dried product, which is then sold to the foreign buyers, who ship the beche-de-mer to Asian markets, including Korea, China and the United States. At other islands in Micronesia, local processors have expressed a wish to reduce the number of foreign buyers (presumably to the buyer that they alone supply!). We suggest, however, that market competition among foreign buyers for Guam product would appear to be beneficial for the price received by the local fishers and thus encouraged (should a legal fishery arise in a sustainable manner). A more detailed market analysis is required to ensure what strategy Guam should adopt when licensing foreign buyers of beche-de-mer.

Guam has been targeted by buyers from China during at least as early as the mid-nineteenth century, during the Spanish colonial period (Driver 1984). Guam is now once again one of many areas that are being heavily targeted by the beche-de-mer industry, whose ships now ply tropical and temperate waters worldwide. The increasing demand for beche-de-mer (and other products, such as shark fin and live reef fish) is fueled in large part by the rapidly expanding cash economies in Asia. Global trade in beche-de-mer is a multimillion dollar industry and profits are high enough, and the industry largely unregulated, that the practice of a “boom and bust” fishery has become commonplace. Quality product (e.g., white teat fish) in Hong Kong markets can retail for over US$100 per kilogram. Exporters *preferentially* move into countries where regulation is non-existent and offer low prices for a resource that is easily harvested and is often not being used otherwise. Because of the cost of, and lag in developing, legislating and implementing a management plan, as well as the difficulty of enforcement and education, the local fishery often collapses before the management plan, if one is put in place at all, can take effect. Exporters know this and exploit this.

Foreign buyers are fully aware that regulations take time to implement and thus, they specifically target small, often young, cash-strapped nations, because there, profits are highest. Buyers often work ”under the radar” of the government by enlisting local intermediaries who encourage collecting and transit of product for export. Foreign buyers often speak in terms of sustainability, such as performing a “demonstration fishery” or an “experimental fishery;” they also speak of the viability of “reseeding,” “aquaculture,” etc. to create an impression that this is the beginning of a long-term relationship. However, and most tellingly, they make *no* commitment, *no* monetary investment to such endeavors, and *no* data are ever methodically collected during the “experiments,” much less analysed or made available in published form, or otherwise, to stakeholders. Alas, the goal of foreign exporters is always the same: obtain as much high-quality product in as short a time as possible and absent any consideration of the sustainability of the fishery, and then move on to the next naive fishery. The list of countries lured into this boom-and-bust practice is both long and growing: Fiji, Solomon Islands, Cook Islands, Galapagos Islands, Egypt, etc. This list includes islands in Micronesia, e.g., Kosrae and Chuuk. Given this sad history of repeated over-exploitation, the prospects for Guam’s beche-de-mer fishery at first glance seem grim indeed.

Still, despite the generally cheerless prospects for beche-de-mer fisheries worldwide, there are solid reasons for hope with Guam. First, there *are* indeed examples of sustainable, long-term fisheries involving beche-de-mer, including those in California (USA), Newfoundland (Canada), Queensland (Australia) and elsewhere. Moreover, Guam brings several distinctive strengths to the table: 1) A recent leadership that increasingly values marine resources for their cultural as well as economic value. 2) Experience in marine-resource policy and management. 3) The ability to enforce conservation legislation. 4) A system of marine protected areas.

In the section *Recommendations* that follows, we submit our suggestions to begin managing Guam’s beche-de-mer. For further recommendations on the issue, we highly recommend the detailed report from a workshop that brought together considerable Micronesian-based expertise in the form of fisheries scientists, economists and governmental marine-resource officers: *Suggestions for the Management of Sea Cucumber Resources in Micronesia* (Richmond 1996). This report makes numerous helpful recommendations concerning the management of beche-de-mer fisheries in Micronesia. It has sections covering the biology of holothuroids as they relate to fisheries, management strategies, economic analyses and recommendations for a Micronesian-wide plan to develop beche-de-mer fisheries. Another font of advice and information on beche de mer is available at the website of the South Pacific Commission, http://www.spc.int. Here, on their Coastal Fisheries pages, is a wealth of contact information with fisheries scientists and publications about the latest information on beche de mer, including the long-running publication, *The Beche-De-Mer Bulletin*.

Guam's Diverse Echinoderm Fauna

Guam now has 60 species of holothuroids recorded from its waters (Michonneau et al 2013), including the 34 provisional species found during this survey (Table 1). By comparison, over 202 species of echinoderms are known from the well-sampled coasts of Guam (Paulay 2003; AKM, unpubl.). This compares well with what is known about the diversity of other Micronesian islands. However, many of these islands have not been as well investigated as Guam. Palau, for example, because of its much larger areal extent of reefs and increased proximity to the global epicentre of marine diversity, likely has even more.

RECOMMENDATIONS

We make some initial recommendations for initiating a beche-de-mer management plan on Guam. The following approach constitutes only one of several possible starting points, but may prove expedient as extraction under current legislation, as well as apparent illegal fishing, increases in the near future.

Institute a moratorium on fishing until a management plan is in place. This might initiate as a referendum before the legislature. Note that a moratorium of fixed period is more likely to be violated towards the end of its duration, as poachers and buyers may stockpile product in anticipation of the reinstatement of harvesting. Enforcement at such time should be especially vigilant.

Conduct an inventory of the island's commercially valuable species. We have performed a preliminary inventory. An inventory of unharvested (in fisheries parlance, "virgin") stocks provides baseline data to assess the status of the fishery and to estimate the minimum harvestable length (see below). We suggest a quick method for the initial inventory: record the lengths of all commercially exploitable species in timed swims of about an hour per person. This provides two valuable pieces of information: 1) population data on animal size used for calculating minimum harvestable length and 2) an estimate of an important quantity in fisheries management, the catch per unit effort, i.e., how much effort must be expended to harvest a given amount of beche de mer. While a centrally conducted inventory by the government may be desirable, it may also be preferable to ensure that each village performs their own inventory.

Institute island-wide minimum harvestable lengths for each species. Using minimum size is only of one many options for regulating harvesting (See Amesbury 1996 for other techniques). Minimum length, though, is the simplest measure to implement in the absence of more detailed information on biology and is also the simplest to enforce. The minimum harvestable size of a stock can be roughly calculated for most holothuroids as the average length of a species *before* harvesting has begun. This ensures that close to 50% of the reproductive capacity (50% of all eggs produced) is preserved. For a virgin stock, one not having previously experienced harvesting, this approach to management quickly results in a "fish down," an initial period of large catches of large animals. After

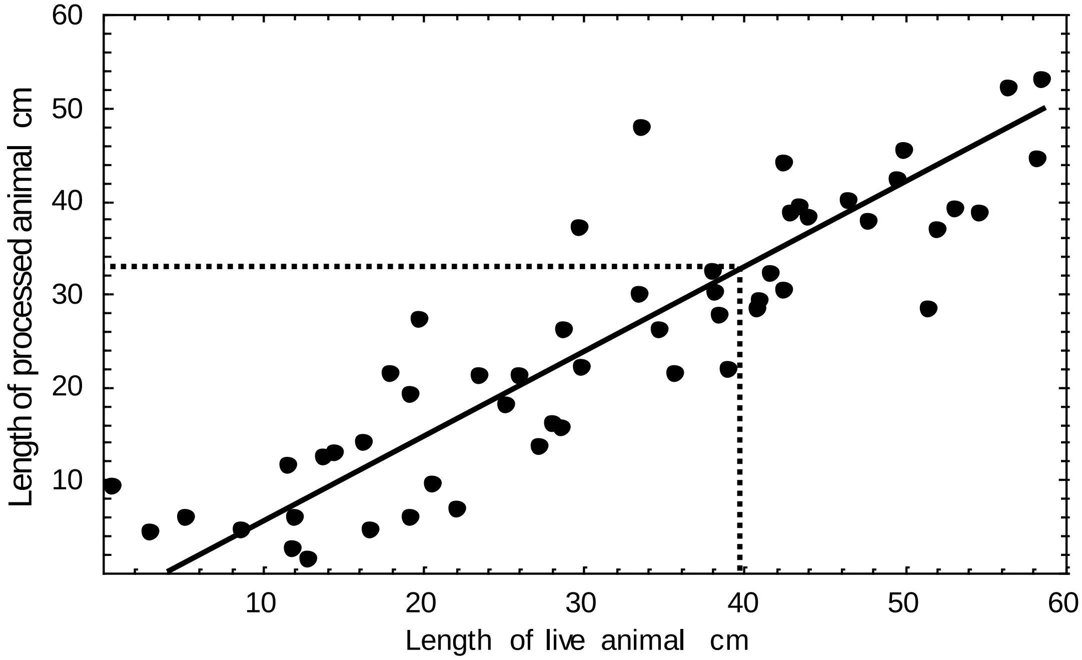

Figure 4. Calculating the minimum legal length of processed beche de mer from the minimum harvestable length of live animals. The points represent the live and dried lengths measured for 30 or more individual holothuroids. The solid line is the best-fit regression line through these points (as implemented in, say, *Microsoft Office Excel*). The dotted lines show how the minimum processed length is related to minimum harvestable length (40 cm in this example). This calculation must be done for each species.

this period, catch per unit effort drops considerably as fishers must wait for smaller animals to grow to harvestable size.

Institute temporary closures on heavily fished reefs to increase stock size and value. MPAs (marine protected areas) are an additional method by which to preserve the reproductive capacity of a stock. Additionally, "spill over" of animals to areas outside the MPA allows more and larger animals to be harvested. Regulating harvesting by instituting a minimum harvestable size rapidly removes the largest and most valuable stock from the reefs. However, the value of beche de mer rapidly plummets with decreasing product size. Hence, to more quickly grow out the remaining animals to the most valuable lengths, may require seasonal or rotating closures of areas to harvesting. The length of closure will depend on trade offs between economic concerns (e.g., maintaining catch per unit effort) and the growth rates of individual species. Closures might, for example, coincide with the onset of spawning to permit stocks to preserve population size. Determining when spawning occurs can be done as suggested in Richmond, Hopper and Martinez (1996). When closing the reefs to permit regrowth to harvestable size, periodic monitoring of length via timed swims should be performed to learn when reefs can be reopened.

Regulate harvesting and export at the level of local processors. We recommend mandatory (i.e., legislated) reporting of harvests and percentages of undersized product. The intermediaries' dried product can be periodically assessed for lengths and amounts. Lengths will differ from the minimum harvestable lengths mentioned above, because the animal shrinks considerably with processing. Therefore, it will be necessary to know the relationship between minimum harvestable length and its processed length. This in turn requires information for each species on both these lengths for at least 30 or so animals. Then, the relation is determined via the best-fit regression line through the data as shown in Figure 4.

Continually assess the effectiveness of the management plan and modify it when necessary. A management plan, especially after it is first implemented, will likely require some fine tuning or, even, a major retool. As more data from monitoring of both stocks and exports collects, it may become clear that modification to harvesting regulations is needed to maintain the goal of the fishery (e.g., continue a reasonable catch per unit effort or level of income). For example, average length is only a very rough guide to estimating 50% reproductive capacity. In fact, average length will usually underestimate 50%

reproductive capacity somewhat in most situations. Still, given the biology of holothuroids, it is a reasonable starting point for a beginning fishery. A more refined approach measures gonad weight of females and calculates a minimum length based on reproductive maturity of females. This analysis might suggest that a larger (or smaller) minimum harvestable size is preferable. We also recommend that after a year or two that a fisheries scientist and a fisheries economist (e.g., from the South Pacific Commission or University of Guam) be invited to learn about Guam and its experiences, then have them examine the fisheries at length to suggest other possible refinements.

Uncertainties and potential problems. The above recommendations are made in the absence of much information usually needed to form a fisheries management plan. We, therefore, foresee several issues needing consideration:

1) The main unanswered question is how much money can be sustainably received by a fisher after the initial fish-down of virgin stocks? Will the density and growth rates of the holothuroids permit a continuous harvest, even at some low level, to sustain at least a trickle of cash into the local economy? These questions concern scale of sustainability and holothuroid life-history traits. The answers should become apparent with increasing data on the status of the fishery, such as interviews with, or surveys of, fishers and their satisfaction with catch size.

2) After fish-down, fishers may become dissatisfied with small catches and insist that management has been a failure. It is important that they understand, perhaps via stakeholder meetings, that ultimately, the amount of harvesting that is sustainable is determined not simply by even the best management, but by the number of fishers and how fast holothuroid reproduce and grow. Alas, tropical holothuroids both reproduce and grow rather slowly. They should be prepared

well ahead of time for the possible need for temporary closures to allow stocks to recover.

3) Another important issue is what to do with undersized catch. Because enforcement must occur after processing, the local buyers must incur this risk. This has the beneficial effect them becoming an ally in enforcement at the level of the fisher. Nevertheless, even given these inducements, some portion of the processed product – potentially valuable – will be undersized. Amesbury (1996) cautions against the temptation to sell under-sized product, as it creates a demand for under-sized product that will be met by fishers, effectively undermining the management plan.

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Appendix 1. Survey sites.

Site	Latitude (°N)	Longitude (°E)	Minimum depth (m)	Maximum depth (m)
Achang "reef flat"	13.2475	144.7109	0	1
Achang "North of Manell Channel"	13.2417	144.6960	6	12
Babi Island	13.2378	144.6746	5	15
Agana Bay "Cindy's Pub"	13.4787	144.7614	0	1
Agana Bay "south of Boat Basin"	13.4780	144.7421	0	0
Agat "in front of cemetery"	13.3866	144.6507	6	15
Agat "North of marina"	13.3709	144.6515	0	2
Anae Island "Dive one"	13.3586	144.6365	7	14
Anae Island "Dive two"	13.3563	144.6375	3	9
Anae Island "reef flat"	13.3574	144.6394	1	2
Apaka Point	13.4029	144.6626	0	2
Asan Bay "near river mouth"	13.4753	144.7132	0	0
Asan Cut "north of river"	13.4754	144.7150	3	11
Adelup "south of point"	13.4771	144.7227	0	0
Blue Hole	13.4381	144.6240	16	26
Cetti Bay "Dive 1"	13.3163	144.6538	9	13
Cetti Bay "Dive 2"	13.3173	144.6533	9	20
Cocos Lagoon	13.2555	144.6614	2	3
Cocos Lagoon "western reef front "	13.2577	144.6510	6	7
Cocos "West Dive 1"	13.2448	144.6403	9	24
Cocos "West Dive 2"	13.2437	144.6476	1	4
Dadi Beach	13.4135	144.6569	0	2
Dog Leg Reef	13.4631	144.6447	3	18
Double Reef	13.5900	144.8336	10	24
East Hagåtña "Sleepy Lagoon"	13.4930	144.7747	0	0
Fadian Point	13.4419	144.8179	0	0
Faifai Beach	13.5289	144.8035	0	0
Family Beach	13.4641	144.6468	0	2

Site	Latitude (°N)	Longitude (°E)	Minimum depth (m)	Maximum depth (m)
First Beach	13.3427	144.7715	0	1
Ga'an Point	13.3874	144.6573	0	2
Gabgab I, Apra Harbor	13.4430	144.6409	0	1
Gabgab II, Apra Harbor	13.4461	144.6439	6	17
Glass Breakwater "Seabee Junk Yard"	13.4562	144.6281	5	15
Gun Beach	13.5254	144.8024	5	17
Haputo "Dive 1"	13.5777	144.8270	9	17
Haputo "Dive 2"	13.5776	144.8281	3	6
Haputo "reef flat"	13.5774	144.8311	0	1
Inalåhan "reef flat"	13.2522	144.7311	0	2
Inalåhan Pools	13.2716	144.7478	0	2
Ipan "north end of Beach Park"	13.3605	144.7717	0	0
Ipan "in front of cemetery"	13.3592	144.7720	0	0
Ipan, "Jeff's Pirates Cove reef flat"	13.3642	144.7707	0	1
Ipan, "Jeff's Pirates Cove Dive"	13.3715	144.8101	9	13
Jade Shoals, Apra Harbor	13.4565	144.6637	3	11
Luminao Reef	13.4664	144.6426	0	2
Nongsa, Malojloj	13.2896	144.7647	8	15
Oka Point "Sheraton Hotel"	13.4983	144.7666	7	18
Orote Point	13.4501	144.6235	8	17
Pago Bay "east end reef flat"	13.4273	144.7953	0	1
Pago Bay "east end reef front"	13.4266	144.7969	0	1
Pago Bay "west end"	13.4189	144.7853	0	1
Pati Point "southeast end"	13.5950	144.9582	11	21
Pati Point "northwest end"	13.6020	144.9530	9	14
Piti Bay "Bomb holes"	13.4792	144.7037	5	11
Piti Bay "north end"	13.4718	144.7065	0	2
Piti "outside reef crest"	13.4695	144.6883	12	17
Ritidian Point	13.6546	144.8620	0	2

Site	Latitude (°N)	Longitude (°E)	Minimum depth (m)	Maximum depth (m)
Sella Bay "reef slope"	13.3256	144.6443	6	12
Sella Bay "reef flat"	13.3273	144.6507	0	2
Tagachang "reef flat"	13.4057	144.7820	0	1
Tanguisson "in front of power plant"	13.5436	144.8057	9	22
Tanguisson "north of power plant"	13.5431	144.8081	0	2
Tarague Beach "reef flat"	13.6267	144.8958	0	1
Tarague Beach "dive"	13.6284	144.8963	4	14
Tepungan Channel, Piti Bay	13.4651	144.6922	0	1
Thousand Steps, Mangilao	13.4641	144.8517	0	1
Toguan Bay	13.2844	144.6616	2	14
Tumon Bay "near Hilton"	13.5094	144.7832	4	11
Tumon "near former Fujita Hotel"	13.5116	144.802	0	1
Umatac Bay "reef flat"	13.2990	144.6599	0	1
Urunao "Uncle Carl's house"	13.6424	144.8477	6	12
Western Shoals, Apra Harbor	13.4519	144.6544	3	23
Ylig Bay, Turtle Cove	13.3945	144.7771	0	1
Ypao Beach, Tumon Bay	13.5045	144.7891	0	2

Appendix 2: Authors' contact information

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