

Sea Cucumbers 2013-2020

Bibliography

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Background & Scope

This bibliography focuses on sea cucumber literature published since 2013. Sea cucumbers live on the sea floor around the world and many species are fished or farmed for human consumption. This bibliography is intended as a reference resource when compiling and summarizing any relevant new (i.e. 2013-present) information for sea cucumbers. It is organized into five sections: Biology, Conservation, Ecology, Fisheries & Aquaculture, and Population Abundance and Trends.

Section I – Biology

Section one is intended to provide an overview of the biology and life history of a variety of sea cucumber species.

Section II – Ecology

Section two is intended to provide an overview of how sea cucumbers interact with the environment, including the impact of pollutants on sea cucumbers.

Section III – Fisheries & Aquaculture

Section three is intended to provide an overview of the latest fisheries and aquaculture research on sea cucumbers.

Section IV – Population Abundance and Trends

Section four is intended to provide an overview of the latest population estimates and trends for sea cucumbers.

Section V – Conservation

Section five is intended to provide an overview of conservation research for sea cucumbers, including information on sustainable fishing practices.

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics Web of Science: Science Citation Index Expanded and Social Science Index; Science.gov; ProQuest Science and Technology including Aquatic Science Fisheries Abstracts; Elsevier ScienceDirect; JSTOR; ProQuest ABI/INFORM; the NOAA Institutional Repository; the Biodiversity Heritage Library; BioOne Complete; LexisAdvance, and Wiley Online.

Section I: Biology

Bello, S. A., Torres-Gutierrez, V., Rodriguez-Flores, E. J., Toledo-Roman, E. J., Rodriguez, N., Diaz-Diaz, L. M., . . . Garcia-Arraras, J. E. (2020). Insights into intestinal regeneration signaling mechanisms. *Developmental Biology*, 458(1), 12-31 <https://doi.org/10.1016/j.ydbio.2019.10.005>.

The cellular mechanisms underlying the amazing ability of sea cucumbers to regenerate their autotomized intestines have been widely described by us and others. However, the signaling pathways that control these mechanisms are unknown. Previous studies have shown that Wnt homologs are upregulated during early intestinal regenerative stages, suggesting that the Wnt/beta-catenin pathway is active during this process. Here, we used small molecules, putative disruptors of the Wnt pathway, to determine the potential role of the canonical Wnt pathway on intestine regeneration in the sea cucumber *Holothuria glaberrima*. We evaluated their effects *in vivo* by using histological analyses for cell dedifferentiation, cell proliferation and apoptosis. We found that iCRT14, an alleged Wnt pathway inhibitor, decreased the size of the regenerating intestine, while LiCl, a presumed Wnt pathway activator, increased its size. The possible cellular mechanisms by which signaling pathway disruptors affect the gut rudiment size were further studied *in vitro*, using cultures of tissue explants and additional pharmacological agents. Among the tested signaling activators, those that act through GSK-3 inhibition, LiCl, 1-Azakenpaullone, and CHIR99021 were found to increase muscle cell dedifferentiation, while the inhibitor iCRT14 blocked cell dedifferentiation. Differently, cell proliferation was reduced by all GSK-3 inhibitors, as well as by iCRT14 and C59, which interferes with Wnt ligand secretion. The *in vivo* temporal and spatial pattern of beta-catenin activity was determined using an antibody against phosphorylated beta-catenin and shown to correlate with cell proliferative activity. *In vitro* treatment using C59 decreased the number of cells immunostained for nuclear phosphorylated beta-catenin. Our results showed that the cell dedifferentiation observed during intestinal regeneration can be decoupled from the cell proliferation event and that these cellular processes can be modulated by particular signaling pathway inhibitors and activators. These results open the door for future studies where the cellular signaling pathways involved at each regeneration stage can be determined.

Borrero-Perez, G. H., & Vanegas-Gonzalez, M. J. (2019). *Holothuria* (Mertensiothuria) *viridiaurantia* sp. nov. (Holothuriida, Holothuriidae), a new sea cucumber from the Eastern Pacific Ocean revealed by morphology and DNA barcoding. *Zookeys*, (893), 1-19 <https://doi.org/10.3897/zookeys.893.36013>.

Holothuria (Mertensiothuria) *viridiourantia* sp. nov. is described based on specimens from rocky reefs of northern Choco in the Colombian Pacific Ocean; however, it also occurs along the Eastern Pacific Ocean from Mexico and Panama. Although specimens from Mexico and Panama were previously identified as *Holothuria* (Mertensiothuria) *bilk* Lesson, 1830 the new species is easily distinguished morphologically and via mtDNA. In terms of morphology, the species can be identified by its olive-green background and white-orange papillae and tentacles, larger tentacles with deep indentations and also by larger buttons on the dorsal and ventral body wall, papillae and tube feet; large, thick and rough tentacle rods, and the absence of ossicles in the longitudinal muscles. The new species is included in the subgenus *Mertensiothuria* considering molecular evidence.

Brown, N. A. W., Wilson, D. R., & Gagnon, P. (2019). Plasticity in the antipredator behavior of the orange-footed sea cucumber under shifting hydrodynamic forces. *Current Zoology*, 65(6), 685-695 <https://doi.org/10.1093/cz/zoy100>.

Marine invertebrates that move too slowly to evade unfavorable environmental change may instead exhibit phenotypic plasticity, allowing them to adjust to varying conditions. The orange-footed sea cucumber *Cucumaria frondosa* is a slow-moving suspension feeder that is preyed on by the purple sunstar *Solaster endeca*. The sea cucumber's antipredator behavior involves changing shape and detaching from the substratum, which might increase its probability of being displaced by water motion into an unsuitable environment. We hypothesized that sea cucumbers' antipredator responses would be diminished under stronger hydrodynamic forces, and that behavioral strategies would be flexible so that individuals could adjust to frequent changes in water flows. In a natural orange-footed sea cucumber habitat, individuals lived along a pronounced hydrodynamic gradient, allowing us to measure antipredator behavior under different water flow strengths. We placed purple sunstars in physical contact with sea cucumbers living at various points along the gradient to elicit antipredator responses. We then repeated this procedure in a laboratory mesocosm that generated weak and strong hydrodynamic forces similar to those observed at the field site. Subjects in the mesocosm experiment were tested in both wave conditions to determine if their antipredator behavior would change in response to sudden environmental change, as would be experienced under deteriorating sea conditions. Antipredator responses did not covary with hydrodynamic forces in the field. However, antipredator responses in the mesocosm experiment increased when individuals were transplanted from strong to weak forces and decreased when transplanted from weak to strong forces. Overall, our results indicate environmentally induced plasticity in the antipredator behavior of the orange-footed sea cucumber.

Eckelbarger, K. J., & Riser, N. W. (2013). Derived sperm morphology in the interstitial sea cucumber *Rhabdomolgus ruber*, with observations on oogenesis and spawning behavior. *Invertebrate Biology*, 132(3), 270-281 <https://doi.org/10.1111/ivb.12030>.

Some life history features of the interstitial sea cucumber *Rhabdomolgus ruber* are described from intertidal specimens collected from the northern coast of Maine. Histological studies suggest that the population consists of hermaphrodites with gametogenesis being initiated in April and reproduction beginning in May and continuing through the summer months. Sexually mature adults possess a single, blind-ended gonadal tubule that functions as an ovotestis by producing both eggs and sperm. The ovotestis wall consists of an outer peritoneum composed of flagellated epithelial cells and muscles; an inner germinal epithelium of germ and somatic cells; and a middle connective tissue (hemal) compartment bounded by the basal laminae of the peritoneum and germinal epithelium. During the reproductive season, the gonadal tubule contains all stages of oocyte development. Vitellogenesis appears to involve the biosynthetic activities of the Golgi complex and rough endoplasmic reticulum. A few specimens had transitional ovotestes with mature sperm in the gonad lumen and asynchronously developing oocytes and a small number of spermatocytes within the germinal epithelium. The mature spermatozoon is an ent-aquasperm with ultrastructural features significantly different from those described from other echinoderm classes including a highly elongated acrosome, a large periacrosomal region between the acrosome and nucleus, numerous unfused mitochondria in the midpiece, and a cytoplasmic sleeve or collar extending posteriorly along the proximal portion of the flagellum. The sperm head reaches 11.5 μm in length (combined midpiece, nucleus, periacrosomal region, acrosome), making it the longest yet reported from the Holothuroidea and among the longest in the Echinodermata. Some elements of this derived morphology could be attributed to fertilization biology,

but others may have phylogenetic significance. Spawning behavior was observed in which two individuals appeared to pseudocopulate by intertwining their oral tentacles for several minutes before one of them abruptly secreted an egg mass containing three eggs.

Emlet, R. B. (2016). The nonfeeding auricularia of *Holothuria mexicana* (Echinodermata, Holothuroidea). *Invertebrate Biology*, 135(3), 245-251 <https://doi.org/10.1111/ivb.12136>.

Among echinoderms, nonfeeding larvae usually are simplified in body shape, have uniform ciliation, and have lost the larval gut. A few species have nonfeeding larvae that express some remnant features of feeding larvae like ciliated bands and larval skeleton or larval arms, but typically their larval mouth never opens and their gut does not function. Still other species have retained the feeding larval form, a functional gut, and can feed, but they do not require food to metamorphose. The present note describes the development of a tropical holothurian, *Holothuria mexicana*, which hatches as a gastrula that is already generating coelomic structures. A translucent auricularia forms with a mouth that opens but becomes reduced soon thereafter. In form and ciliation this auricularia resembles a feeding larva, but it does not respond to food. A doliolaria forms on day 4 and the pentactula on day 6 post-fertilization. Further study of this larva and that of its closely related congener, *Holothuria floridana*, is warranted.

Eriksson, H., Conand, C., Lovatelli, A., Muthiga, N. A., & Purcell, S. W. (2015). Governance structures and sustainability in indian ocean sea cucumber fisheries. *Marine Policy*, 56, 16-22 <https://doi.org/10.1016/j.marpol.2015.02.005>.

Good governance is paramount to the sustainability of fisheries, and inclusiveness of stakeholder groups has become the centerpiece in the ethos of managing small-scale fisheries. Understanding the effect of governance network structures on fishery sustainability can help guide governance to achieve desired outcomes. Data on resource users, fishing methods, governance networks and classifications of stock health were compiled for 17 sea cucumber fisheries in the Indian Ocean. The subjective influence of the actors and the complexity of governance networks on the health of wild stocks were analyzed. The fisheries differed widely in their resource users, fishing methods and governance networks. Little correspondence was found between the number of nodes in the governance networks and the health (exploitation status) of wild stocks. Government entities dominated the networks but neither their relative influence in the networks nor their proportionate contribution to the number of entities in the networks greatly affected stock health. These findings do not refute the benefits of inclusive governance, but rather suggest that multiple other factors (e.g. inadequate regulations, weak enforcement, high number of fishers) are also likely to play a role in influencing sea cucumber fishery sustainability. These factors must be tackled in tandem with good governance.

Fitch, A. J., Leeworthy, G., Li, X., Bowman, W., Turner, L., & Gardner, M. G. (2013). Isolation and characterisation of eighteen microsatellite markers from the sea cucumber *Holothuria scabra* (Echinodermata : Holothuriidae). *Australian Journal of Zoology*, 60(6), 368-371, 364 <https://doi.org/10.1071/ZO12114>.

We isolated 18 new, polymorphic, microsatellite markers from *Holothuria scabra*, a commercially important species of sea cucumber found throughout the Asia-Pacific region. Next-generation sequencing was used to identify 206 unique loci for which primers were designed. Of these unique loci,

we trialled 65 primer pairs in the target species, and 48 (74%) amplified a product of the expected size. Eighteen loci were found to be polymorphic and reliable, and were screened for variation in 50 individuals, from a single population from Croker Island, Northern Territory, Australia. Observed heterozygosity ranged from 0.00 to 0.96 (mean = 0.46) and the number of alleles per locus from 2 to 28 (mean = 9.61). These loci will be useful for the investigation of population structure and mating systems in *H. scabra* and may also be of use in other holothurian species.

Garcia-Ararras, J. E., Bello, S. A., & Malavez, S. (2019). The mesentery as the epicenter for intestinal regeneration. *Seminars in Cell & Developmental Biology*, 92, 45-54
<https://doi.org/10.1016/j.semcd.2018.09.001>.

The mesentery, a newly minted organ, plays various anatomical and physiological roles during animal development. In echinoderms, and particularly in members of the class Holothuroidea (sea cucumbers) the mesentery plays an additional unique role: it is crucial for the process of intestinal regeneration. In these organisms, a complete intestine can form from cells that originate in the mesentery. In this review, we focus on what is known about the changes that take place in the mesentery and what has been documented on the cellular and molecular mechanisms involved. We describe how the events that unfold in the mesentery result in the formation of a new intestine.

Gebruk, A. V., Kremenetskaia, A., & Rouse, G. W. (2020). A group of species "Psychropotes longicauda" (Psychropotidae, Elasipodida, Holothuroidea) from the Kuril-Kamchatka Trench area (North-West Pacific). *Progress in Oceanography*, 180, 17
<https://doi.org/10.1016/j.pocean.2019.102222>.

Collections of holothurians taken in 2012-2016 by three German-Russian deep-sea expeditions to the Kuril-Kamchatka Trench area (KuramBio, SokhoBio and KuramBio II) were examined. Here we present data on the genus *Psychropotes* (Psychropotidae, Elasipodida). Based on new material and some additional (mainly old) material from the North-West and East Pacific, we re-describe the species *Psychropotes longicauda* Theel, 1882, describe two varieties, *P. longicauda* var. *monstrosa* Theel, 1882 and *P. longicauda* var. *fuscopurpurea* Theel, 1882, as separate species, re-establish the species *P. rariopes* Ludwig, 1893, *P. dubiosa* Ludwig, 1893 and *P. dyscrita* (Clark, 1920), and describe two new species: *P. moskalevi* sp. nov. and *P. pawsoni* sp. nov.

Gianasi, B. L., Hamel, J.-F., & Mercier, A. (2018). Morphometric and behavioural changes in the early life stages of the sea cucumber *Cucumaria frondosa*. *Aquaculture*, 490, 5-18
<https://doi.org/10.1016/j.aquaculture.2018.02.017>.

The present study examined morphological and behavioural development in post-settled juveniles of the commercial sea cucumber *Cucumaria frondosa*, in an effort to assist captive breeding and conservation initiatives. Juveniles developed all 10 tentacles within 16 months; they had 9 podia and measured 4.6 mm in length after 21 months. Scaling between body length and number of podia was isometric, whereas dorsal tentacle metrics showed negative allometric scaling, indicating that growth was accompanied by a decreasing tentacle to body size ratio. Dorsally-oriented tentacles developed and ramified faster, showing 6 ramifications after 21 months, when ventrally-oriented tentacles only displayed one. This asynchrony underlines the distinctive roles of dorsal vs. ventral tentacles during the

early months. The former were strictly used to capture plankton from the water column; whereas the latter were used for anchorage and feeding on deposited material. Ossicles of the body wall increased in length and thickness, and became slightly curved and rounded in older juveniles. Light intensity and water flow tolerance increased with age; from 25 lx and 5 cm s⁻¹ in 1-month-old individuals, to >50 lx and 10 cm s⁻¹ in 6, 12, and 21-month-old individuals, consistent with migration from sheltered to more exposed locations. Moreover, 1 and 6-month-old juveniles preferred rock substrates and black or red background colours; whereas 12 and 21-month-old individuals favoured substrates of coralline algae and a red background, also indicative of increasing affinity with sunlit environments and a shift from benthic to planktonic feeding. Juveniles of all age classes were feeding (i.e. had deployed tentacles) 24 h a day and commonly sought vertical surfaces. Together, the findings shed light on the early juvenile ecology of this cold-water suspension-feeding sea cucumber. Considering the expansion of sea cucumber fisheries and growing interest in the aquaculture of *C. frondosa*, this work also provides a framework for improved stock management and culture protocols.

González-Wangüemert, M., Valente, S., Henriques, F., Domínguez-Godino, J. A., & Serrão, E. A. (2016). Setting preliminary biometric baselines for new target sea cucumbers species of the NE Atlantic and Mediterranean fisheries. *Fisheries Research*, 179, 57-66
<https://doi.org/10.1016/j.fishres.2016.02.008>.

Commercial interest on sea cucumber species from the NE Atlantic and the Mediterranean is increasing. *Holothuria polii*, *Holothuria tubulosa*, *Holothuria mammata* and *Holothuria arguinensis* are the new target species. The scarce biological and ecological knowledge on these species along their geographical distribution, is a major problem for their fisheries management. To address it, we carried out a morphometric study to describe the baseline population size structure, focused on the length–weight relationship and size–weight distribution. In the NE Atlantic, the largest mean size and heaviest mean weight of *H. mammata* and *H. arguinensis* were found in localities with upwelling, but another factors could be influencing on these results. In the Mediterranean, Girona and Mallorca showed the heaviest specimens of *H. polii*, *H. tubulosa* and *H. mammata*, and the smallest were registered in Crete and Kusadasi. Significant differences in length and weight between populations were found for each species. These results could be linked with local environmental conditions. Size frequency distribution was multimodal for all species except for *H. mammata*; the weight frequency distribution was only unimodal for *H. polii* and *H. mammata*. This study provides novel data, helpful for stock and population assessment which could support the implementation of effective management for the European sea cucumber target species.

Grael-Sabido, M. J., Miron-Lopez, G., Leon-Deniz, L. V., Moo-Puc, R. E., Quintal-Novelo, C. J., Quijano, L., & Mena-Rejon, G. J. (2016). Total NMR assignment of a new antiproliferative triterpene oligoglycoside from the sea cucumber *Astichopus multifidus*. *Tetrahedron Letters*, 57(39), 4375-4378 <https://doi.org/10.1016/j.tetlet.2016.08.051>.

Astichoposide D, a new oligoglycosidic triterpene of the holostan-type was isolated from *Astichopus multifidus* together with the known astichoposide C and Sticholoroside B-2. The structure elucidation and the complete assignment of all signals of the compounds were accomplished based on 1D and 2D, H-1, and C-13 NMR experiments, mainly on the 1D TOCSY experiment with different mixed times. The antiproliferative activity of isolated compounds against two breast cancer cell lines (MCF-7 and MDA-

MB-231) was investigated. All compounds exhibited antiproliferative activity against both breast cancer cells ranging from 5.53 to 1.38 μ M.

Gunay, D., Emiroglu, D., & Suzer, C. (2020). Seasonal variations of digestive enzymes in sea cucumbers (*Holothuria tubulosa*, G. 1788) under culture conditions. *Journal of Experimental Zoology Part A- Ecological and Integrative Physiology*, 333(3), 144-150 <https://doi.org/10.1002/jez.2336>.

Sea cucumber, *Holothuria tubulosa* (Gmelin, 1788), is an economically valuable species due to its rich nutrients content that being exported in Turkey. However, culture of this species is difficult due to a lack of knowledge. The main objective of this study is to investigate seasonal activities of main digestive enzymes (protease, lipase, and amylase) for nutritional requirements. In this sense, sea cucumbers were stocked in the glass aquarium and sediment was 10 cm. It was replaced monthly and enriched (1% of the living individual weight) by dried *Sargassum* sp. Total protease and amylase enzymes have shown higher activity compared to lipase. All three enzyme activities were maximum in the summer and minimum in the winter. In summer, the highest measured total protease, amylase, and lipase activity values were 6.45 +/- 0.66, 6.77 +/- 0.72, and 2.78 +/- 0.32 U/mg per protein, respectively. In winter, the lowest total protease, amylase, and lipase activity values were measured as 2.03 +/- 0.16, 1.14 +/- 0.14, and 0.12 +/- 0.01 U/mg per protein, respectively. As a conclusion of the study, seasonal expression of the main digestive enzymes was strictly dependent on water temperatures and food abundance and also it was ideal to feed this species with food containing high protein and carbohydrate under appropriate temperatures for commercial culture.

Hernandez-Pasos, J., Valentin-Tirado, G., & Garcia-Arraras, J. E. (2017). Melanotransferrin: New Homolog Genes and Their Differential Expression during Intestinal Regeneration in the Sea Cucumber *Holothuria glaberrima*. *Journal of Experimental Zoology Part B-Molecular and Developmental Evolution*, 328(3), 259-274 <https://doi.org/10.1002/jez.b.22731>.

Melanotransferrin (MTf) is a protein associated with oncogenetic, developmental, and immune processes which function remains unclear. The MTf gene has been reported in numerous vertebrate and invertebrate species, including echinoderms. We now report the finding of four different MTfs in the transcriptome of the sea cucumber *Holothuria glaberrima*. Sequence studies and phylogenetic analyses were done to ascertain the similarities among the putative proteins and their relationship with other transferrin family members. The genes were shown to be differentially expressed in various holothurian organs and to respond differently when the animals were challenged with the immune system activator lipopolysaccharide (LPS). Moreover, the four genes were found to be highly overexpressed during the early stages of intestinal regeneration. The finding of four different genes in the holothurian is particularly surprising, because only one MTf gene has been reported in all other animal species sequenced to date. This finding, combined with the increase expression during intestinal regeneration, suggests a new possible function of MTf in organ regenerative processes.

Huo, D., Sun, L. N., Storey, K. B., Zhang, L. B., Liu, S. L., Sun, J. C., & Yang, H. S. (2020). The regulation mechanism of lncRNAs and mRNAs in sea cucumbers under global climate changes: Defense against thermal and hypoxic stresses. *Science of the Total Environment*, 709, 15 <https://doi.org/10.1016/j.scitotenv.2019.136045>.

The aquatic environment can be greatly impacted by thermal and hypoxic stresses, particularly caused by intensified global warming. Hence, there is an urgency to understand the response mechanisms of marine organisms to adverse environment. Although long non-coding RNAs (lncRNAs) are involved in many biological processes, their roles in stress responses still remain unclear. Here, differentially expressed (DE) lncRNAs and mRNAs were identified as responses to environmental stresses in the economically important sea cucumber, *Apostichopus japonicus*, and their potential roles were explored. Based on a total of 159, 355 and 495 significantly upregulated genes and 230, 518 and 647 significantly downregulated genes identified in the thermal, hypoxic and combination thermal + hypoxic stress treatments, respectively, we constructed DE-lncRNA-mRNA coexpression networks. Among the networks, eight shared pairs were identified from the three treatments, and based on the connectivity degree, MSTRG.27265, MSTRG.19729 and MSTRG.95524 were shown to be crucial lncRNAs. Among all the significantly changed lncRNAs identified by RT-qPCR and sequencing data, binding sites were found in four other lncRNAs (MSTRG.34610, MSTRG.10941, MSTRG.81281 and MSTRG.93731) with Aja-miR-2013-3p, a key miRNA that responds to hypoxia in sea cucumbers. The hypoxia-inducible factor (HIF-1 alpha) was also shown as the possible targeted mRNA of Aja-miR-2013-3p. As indicated by a dual-luciferase reporter assay system, "HIF-1 alpha gene/Aja-miR-2013-3p/MSTRG.34610" network and the "HIF-1 alpha gene/Aja-miR-20133p/MSTRG.10941" network may play important roles in sea cucumbers under environmental stresses. Moreover, environmental stress altered the expression of multiple lncRNAs and mRNAs, thus affecting various biological processes in *A. japonicus*, including immunity, energy metabolism and the cell cycle. At the molecular level, more comprehensive responses were elicited by the combined thermal/hypoxic stress treatment than by individual stresses alone in sea cucumbers. This study lays the groundwork for future research on molecular mechanisms of echinoderm responses to thermal and hypoxic stress in the context of global climate changes.

Iwalaye, O. A., Moodley, G. K., & Robertson-Andersson, D. V. (2020). The possible routes of microplastics uptake in sea cucumber *Holothuria cinerascens* (Brandt, 1835). *Environmental Pollution*, 264, 114644 <https://doi.org/10.1016/j.envpol.2020.114644>.

Investigating the routes of microplastic uptake in sea cucumber is crucial in this plastics pollution age considering their non-selective feeding process, nutritional, biomedical and ecological importance. The guts, respiratory trees and coelomic fluids of *Holothuria cinerascens* were sampled and examined for microplastic after exposure to fluorescent microplastic fragments and microfibres. The madreporite pore size was also determined. 90% of the animals sampled ingested microplastic fragments via their feeding tentacles. Microplastic ingested ranged from 0 to 24 fragments intestine-1 (8.7 ± 2.11). All (100%) the animals sampled had microfibre in their coelomic fluid ranging from 32 to 227 microfibrils coelom-1 (79.58 ± 10.53). Microfibrils were found attached to all undigested respiratory trees examined. Microfibrils were also found in 57.8% of digested respiratory trees with a range of 0–12 microfibrils respiratory tree-1 (1.74 ± 0.66). Notably, there was no fluorescent microplastic fragments/microfibrils found in the gut, coelomic fluid, and respiratory trees of animals in the control group. The madreporite pore size ranged from 0.59 to 2.90 μm ($1.22 \pm 0.03 \mu\text{m}$). Microfibrils found in the coelomic fluid were transferred from the respiratory trees because the size of microfibre used for this experiment was assumed larger for it to have passed through the gut into the coelom. Although the madreporite pore size is smaller than microfibre used in this study, madreporite can act as another channel to transport nanoplastics from the coelom into the animal tissue. This study showed that sea cucumber uptake microplastics from the environment using the feeding tentacles and the respiratory trees. Chemicals desorption from microplastics into *H. cinerascens* when ingested may pose a risk to the animals and

their consumers. Further study is required to determine if microfibrils transfer from the respiratory trees to the coelomic fluid is dependent on microfibril concentration and water temperature.

Jaekle, W. B., & Strathmann, R. R. (2013). The anus as a second mouth: anal suspension feeding by an oral deposit-feeding sea cucumber. *Invertebrate Biology*, 132(1), 62-68
<https://doi.org/10.1111/ivb.12009>.

Respiratory trees of holothurians are blind-ended evaginations of the posterior digestive system that are rhythmically inflated with seawater via the anus, and are considered to have respiratory and excretory functions. We tested the assimilatory capability of the respiratory tree epithelium by exposing adults of the oral deposit-feeding aspidochirotid sea cucumber *Parastichopus californicus* to (1) ¹⁴C-labeled unicellular algae and (2) iron-containing macromolecules, and then following the distribution of the labels in various body regions. The abundance of the ¹⁴C (nmol ¹⁴C g wet weight⁻¹) varied among body regions. The majority of the label was associated with the respiratory trees. The next greatest concentration was in the rete mirabile of the hemal system. The amount of ¹⁴C within samples of the anterior digestive system, posterior digestive system, and body wall muscle at each sampling time was lower than that of the respiratory trees. The presence and abundance of the ¹⁴C label in samples of the hemal system and the physical association between the respiratory tree and the rete mirabile suggest initial uptake by the respiratory tree and subsequent transfer to the hemal system. The iron label from the protein ferritin and the polysaccharide iron dextran entered cells of the respiratory tree luminal epithelium. The presence of the iron label in mesenchyme cells within the connective tissue compartment of the respiratory trees exposed to ferritin further suggests directional transfer of materials. Holothurians with respiratory trees are nutritionally bipolar; the anus serves as a second mouth.

Kang, X. M., Zhao, Y. F., Shang, D. R., Zhai, Y. X., Ning, J. S., Ding, H. Y., & Sheng, X. F. (2020). Identification of the geographical origins of sea cucumbers in China: The application of stable isotope ratios and compositions of C, N, O and H. *Food Control*, 111, 7
<https://doi.org/10.1016/j.foodcont.2019.107036>.

The determination of the geographical origins of seafood is significant for food safety and health of consumers. It is necessary to develop a feasible method of identifying the geographical origins of sea cucumbers in China. In this study, 76 sea cucumbers collected from five different regions in China were analyzed for the stable isotope ratios and compositions of carbon (C), nitrogen (N), oxygen (O) and hydrogen (H). One way analysis of variance was adopted for the study of the differences in the stable isotope ratios and compositions of C, N, O and H in these sea cucumbers. The principal component analysis (PCA) and linear discriminant analysis (LDA) were used as exploratory techniques and classification procedures, respectively. The one way analysis of variance showed that there was a significant difference ($p < 0.05$) in the stable isotope ratios and compositions of C, N, O and H in the sea cucumbers, which proved that the stable isotope ratios and compositions of C, N, O and H were useful in the identification of the origins of sea cucumbers. Based on the PCA, there was no clear distinction between the sea cucumbers from different regions. High recognition (93.4%) and satisfactory predictive ability (89.5%) were achieved with the LDA. The present findings suggest that the analysis of the stable isotope ratios and compositions of C, N, O and H combined with the statistical analysis could be potentially applied in the discrimination of the geographical origins of sea cucumbers.

Kim, S. W., Miller, A. K., Brunson, C., Netchy, K., Clouse, R. M., Janies, D., . . . Kerr, A. M. (2014). Shallow-Water Holothuroids (Echinodermata) of Yap, Federated States of Micronesia. *Pacific Science*, 68(3), 397-420, 324 <https://doi.org/10.2984/68.3.8>.

In December 2002, July 2007, and December 2009, we surveyed the sea cucumber fauna of the western Caroline Island of Yap (Federated States of Micronesia). We collected 37 species of holothuroids, including 32 species of aspidochirotetes and five species of apodans. We found all 13 of the previously reported species and 24 new records for the Islands: 19 aspidochirotetes and five apodans. At least two of the new records appear to be previously undescribed species. Types of microhabitats and reef zonation were closely correlated with the species distributions of Yapese holothuroids.

Kremenetskaia, A., Ezhova, O., Drozdov, A. L., Rybakova, E., & Gebruk, A. (2020). On the reproduction of two deep-sea Arctic holothurians, *Elpidia heckeri* and *Kolga hyalina* (Holothuroidea:Elpidiidae). *Invertebrate Reproduction & Development*, 15 <https://doi.org/10.1080/07924259.2019.1692915>.

Internal gonad morphology was examined in two species of elpidiid holothurians, *Elpidia heckeri* and *Kolga hyalina*, commonly occurring in the Central Arctic Ocean. The holothurians were sampled in August - September 2012 and in August 2018, at several locations in the Nansen and Amundsen Basins, in areas under the constant ice cover and in areas free of ice. Both species were observed at different reproductive stages and both are presumed to reproduce periodically. In 2012, spawning occurred at the beginning of September in *Elpidia heckeri* and from late August to early September in *Kolga hyalina*. There are reasons to believe that gametogenesis in *K. hyalina* depends on the availability of freshly deposited phytodetritus. The maximum oocyte size in *Kolga hyalina* (240 μm) was smaller than in *Elpidia heckeri* (390 μm).

Li, J., Xu, C., Jiang, L. X., Xiao, Y., Deng, L. M., & Han, Z. Z. (2020). Detection and Analysis of Behavior Trajectory for Sea Cucumbers Based on Deep Learning. *IEEE Access*, 8, 18832-18840 <https://doi.org/10.1109/access.2019.2962823>.

The motion trajectory of sea cucumbers reflects the behavior of sea cucumbers, and the behavior of sea cucumbers reflects the status of the feeding and individual health, which provides the important information for the culture, status detection and early disease warning. Different from the traditional manual observation and sensor-based automatic detection methods, this paper proposes a detection, location and analysis approach of behavior trajectory based on Faster R-CNN for sea cucumbers under the deep learning framework. The designed detection system consists of a RGB camera to collect the sea cucumbers images and a corresponding sea cucumber identification software. The experimental results show that the proposed approach can accurately detect and locate sea cucumbers. According to the experimental results, the following conclusions are drawn: (1) Sea cucumbers have an adaptation time for the new environment. When sea cucumbers enter a new environment, the adaptation time is about 30 minutes. Sea cucumbers hardly move within 30 minutes and begin to move after about 30 minutes. (2) Sea cucumbers have the negative phototaxis and prefers to move in the shadows. (3) Sea cucumbers have a tendency to the edge. They like to move along the edge of the aquarium. When the sea cucumber is in the middle of the aquarium, the sea cucumber will look for the edge of the aquarium. (4) Sea cucumbers have unidirectional topotaxis. They move along the same direction with the initial

motion direction. The proposed approach will be extended to the detection and behavioral analysis of the other marine organisms in the marine ranching.

Li, Y., Yang, Y. Y., Ji, Q. Q., Song, J. X., Wang, L., Liu, B. K., . . . Li, C. (2020). The function of *Apostichopus japonicas* catalase in sea cucumber intestinal immunity. *Aquaculture*, 521, 10 <https://doi.org/10.1016/j.aquaculture.2020.735103>.

Catalase is an important oxidoreductase enzyme that catalyzes the conversion of hydrogen peroxide molecules into water and oxygen and regulates the homeostasis of ROS in animals and humans. Catalase functions in host immune defense, cellular apoptosis, aging, inflammation, and tumor formation. The intestine is not only an important site of nutrient digestion and absorption but also an important site of innate immunity against microbial infection in invertebrates. Catalase can participate in intestinal immune responses. However, the role of catalase in intestinal immunity in the sea cucumber (*Aj-catalase*) has not been elucidated. In this study, we showed that *Aj-catalase* plays a key role in intestinal immunity and microbiota homeostasis. The expression level of *Aj-catalase* was upregulated, and its enzymatic activity was increased in the *Apostichopus japonicas* intestine after challenge with *Vibrio splendidus* via oral infection. When *Aj-catalase* was knocked down by RNA interference (RNAi), the survival rate of sea cucumbers declined; microbiota homeostasis was disturbed in the intestine compared with that in the control group, and the intestinal villi protruding from the epithelial lining of the intestinal wall were damaged. Further study results demonstrated that the ROS level was increased for a long period in *Aj-catalase*-knockdown sea cucumbers, which is likely the main mechanism by which catalase is involved in regulating intestinal immunity. These results suggest that *Aj-catalase* participates in intestinal immunity and microbiota homeostasis by regulating ROS levels.

Lim, A. Y. H., Chan, I. Z. W., Carrasco, L. R., & Todd, P. A. (2019). Aposematism in pink warty sea cucumbers: independent effects of chromatic and achromatic cues. *Marine Ecology Progress Series*, 631, 157-164 <https://doi.org/10.3354/meps13159>.

The importance of chromatic and achromatic cues in aposematism is well established, but in situ experiments investigating their comparative roles within a single warning signal remain rare. In a predation experiment, we examined their relative importance in pink warty sea cucumbers *Cercodemas anceps* Selenka, 1867, by asking (1) Do chromatic and achromatic cues have significant effects on attack rate? (2) Are their effects independent? (3) Does one have more influence on attack rate than the other? Using a multispectral imaging-based technique, we fabricated 4 types of clay models based on the hues, chroma and luminance levels of the animals and the background. Models were deployed in sets of 4 at 2 sites (n = 65 sets) for 3 days, and the number of imprints from predation attempts was recorded. A generalised linear mixed model analysis showed that both types of cues had significant but independent effects on attack rates and that chromatic cues had a greater effect compared to achromatic ones. This study, the first manipulative investigation into holothurian aposematism, demonstrates the potential for chromatic and achromatic cues to play distinct roles in animal signalling, and highlights the importance of accurate experimental models.

Marquet, N., Conand, C., Power, D. M., Canário, A. V. M., & González-Wangüemert, M. (2017). Sea cucumbers, *Holothuria arguinensis* and *H. mammata*, from the southern Iberian Peninsula:

Variation in reproductive activity between populations from different habitats. *Fisheries Research*, 191, 120-130 <https://doi.org/10.1016/j.fishres.2017.03.007>.

New fisheries in the western Mediterranean and north eastern Atlantic target the sea cucumbers *Holothuria arguinensis* and *H. mammata*; however, lack of biological information hinders management decisions. Here, the reproductive biology of populations the two species was investigated in the southern Iberian Peninsula. Different populations located along a narrow latitudinal range displayed the same general reproductive pattern of summer-autumn spawning. However, significant differences in size, gonadal production and maturity profile between locations suggests the influence of site-specific factors. In Sagres and Ria Formosa *H. arguinensis* individuals were larger and had larger gonads than in Olhos de Água, which had relatively more immature animals. The spawning and active gametogenesis periods were also longer in Sagres, possibly linked to specificity of food availability and tidal conditions. Ria Formosa also had larger *H. mammata* individuals with larger gonads than in Murcia and Olhos de Água, possibly reflecting differences in feeding activity in different substrates (muddy/sandy vs rocky). Gametogenesis in *H. arguinensis* may be triggered by decreasing photoperiod and temperature, and spawning by increasing temperature. Altogether, these results, which include fecundity and size at first maturity, provide an important basis for the scientific management of sea cucumber fisheries in the region.

Mashanov, V., Zueva, O., & García-Arrarás, J. (2015). Expression of pluripotency factors in echinoderm regeneration. *Cell & Tissue Research*, 359(2), 521-536 <https://doi.org/10.1007/s00441-014-2040-4>.

Cell dedifferentiation is an integral component of post-traumatic regeneration in echinoderms. As dedifferentiated cells become multipotent, we asked if this spontaneous broadening of developmental potential is associated with the action of the same pluripotency factors (known as Yamanaka factors) that were used to induce pluripotency in specialized mammalian cells. In this study, we investigate the expression of orthologs of the four Yamanaka factors in regeneration of two different organs, the radial nerve cord and the digestive tube, in the sea cucumber *Holothuria glaberrima*. All four pluripotency factors are expressed in uninjured animals, although their expression domains do not always overlap. In regeneration, the expression levels of the four genes were not regulated in a coordinated way, but instead showed different dynamics for individual genes and also were different between the radial nerve and the gut. SoxB1, the ortholog of the mammalian Sox2, was drastically downregulated in the regenerating intestine, suggesting that this factor is not required for dedifferentiation/regeneration in this organ. On the other hand, during the early post-injury stage, Myc, the sea cucumber ortholog of c-Myc, was significantly upregulated in both the intestine and the radial nerve cord and is therefore hypothesized to play a central role in dedifferentiation/regeneration of various tissue types.

Mashanov, V. S., Zueva, O. R., & Garcia-Arraras, J. E. (2017). Inhibition of cell proliferation does not slow down echinoderm neural regeneration. *Frontiers in Zoology*, 14, <https://doi.org/10.1186/s12983-017-0196-y>.

Regeneration of the damaged central nervous system is one of the most interesting post-embryonic developmental phenomena. Two distinct cellular events have been implicated in supplying regenerative neurogenesis with cellular material - generation of new cells through cell proliferation and recruitment of already existing cells through cell migration. The relative contribution and importance of these two

mechanisms is often unknown. Methods: Here, we use the regenerating radial nerve cord (RNC) of the echinoderm *Holothuria glaberrima* as a model of extensive post-traumatic neurogenesis in the deuterostome central nervous system. To uncouple the effects of cell proliferation from those of cell migration, we treated regenerating animals with aphidicolin, a specific inhibitor of S-phase DNA replication. To monitor the effect of aphidicolin on DNA synthesis, we used BrdU immunocytochemistry. The specific radial glial marker ERG1 was used to label the regenerating RNC. Cell migration was tracked with vital staining with the lipophilic dye Dil. Results: Aphidicolin treatment resulted in a significant 2.1-fold decrease in cell proliferation. In spite of this, the regenerating RNC in the treated animals did not differ in histological architecture, size and cell number from its counterpart in the control vehicle-treated animals. Dil labeling showed extensive cell migration in the RNC. Some cells migrated from as far as 2 mm away from the injury plane to contribute to the neural outgrowth. Conclusions: We suggest that inhibition of cell division in the regenerating RNC of *H. glaberrima* is compensated for by recruitment of cells, which migrate into the RNC outgrowth from deeper regions of the neuroepithelium. Neural regeneration in echinoderms is thus a highly regulative developmental phenomenon, in which the size of the cell pool can be controlled either by cell proliferation or cell migration, and the latter can neutralize perturbations in the former.

Mashjoor, S., & Yousefzadi, M. (2019). Cytotoxic effects of three Persian Gulf species of Holothurians. *Iranian Journal of Veterinary Research*, 20(1), 19-26. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6509911/pdf/ijvr-20-019.pdf>.

Pharmaceutical industries around the world are struggling for finding new approaches to fight cancer and many researchers are involved in this process to find new drug candidates. Aims: The current study aimed at investigating the new marine natural products with anticancer potential from the three Persian Gulf *Holothuria* sea cucumbers. Methods: We evaluated the cytotoxic activity of different organs of three *Holothuria* sea cucumbers species (*H. scabra*, *H. parva*, and *H. leucospilota*) using organic extract (OE): n-Hexane (nH), ethyl acetate (E), and methanol (M). Cytotoxicity potential of three fractions was estimated using two toxicity models: brine shrimp (*Artemia salina*) lethality assay (BSA) and tetrazolium-based colorimetric assay (MTT) assay in human cancer cell lines (MCF-7) and normal cell lines (HeLa). Results: The data illustrated that toxicity depends on concentration but BSA was highest for the M extracts of cuvierian tubules (CT) organs of *H. leucospilota* (up to 95% at 1000 $\mu\text{g/ml}$, $\text{LC}_{50} = 616.4 \mu\text{g/ml}$) and respiratory tree (RT) organs of *H. parva* (up to 86% at 1000 $\mu\text{g/ml}$, $\text{LC}_{50} = 607.2 \mu\text{g/ml}$). Based on cell lines, the more effective extracts were noticed for E fractions of CT organs of *H. leucospilota* (up to 85% at 250 $\mu\text{g/ml}$, $\text{LC}_{50} = 37.25 \mu\text{g/ml}$) against MCF-7 and for E extracts of intestine tract (IT) organs of *H. parva* (up to 80% at 250 $\mu\text{g/ml}$, $\text{LC}_{50} = 46.25 \mu\text{g/ml}$) against HeLa cells. This variation indicates that the possible cytotoxic compounds in fractions are selective toxicity toward cell lines. Conclusion: The data demonstrated that *Holothuria* species are an interesting source for discovery of drugs.

Montgomery, E. M., Small, T., Hamel, J. -, & Mercier, A. (2019). Albinism in orange-footed sea cucumber (*Cucumaria frondosa*) in newfoundland. *The Canadian Field-Naturalist*, 133(2), 113-117 <https://doi.org/10.22621/cfn.v133i2.2047>.

Orange-footed Sea Cucumber (*Cucumaria frondosa*; Echinodermata: Holothuroidea) is a dark-brown species that is broadly distributed in North Atlantic and Arctic waters. Here, we document the rare occurrence of colour morphs showing various degrees of albinism, from totally white to faint orange

pigmentation. These unusually coloured individuals were found across a broad distribution range in eastern Canada and northeastern United States, with their occurrence in Newfoundland samples ranging from 0.2% to 0.5%. Two fully albino individuals were noticeably smaller than other colour morphs. The occurrence of rare, unusually coloured sea cucumbers is important from an ecological standpoint and may also have commercial implications.

Morrone, L., Rakaj, A., Grosso, L., Fianchini, A., Pellegrini, D., & Regoli, F. (2020). Sea cucumber *Holothuria polii* (Delle Chiaje, 1823) as new model for embryo bioassays in ecotoxicological studies. *Chemosphere*, 240, 7 <https://doi.org/10.1016/j.chemosphere.2019.124819>.

The sea cucumbers are common members of marine benthic communities, widespread distributed, easily available and handled. Nevertheless, no data are available on embryo toxicity assays using sea cucumbers, despite some of these species could fully meet the requirements for model test organisms. *Holothuria polii* is a key species in soft sediments and seagrass meadows; the aim of the present study was the standardization of a new embryo bioassay with this species, as an ecologically relevant test to evaluate the effects of environmental stressors. Sequential experiments were carried out, allowing to define the test acceptability, and a minimum sample size of 240 embryos. Temperature of 26 degrees C, salinity at 36 parts per thousand and a density of 60 eggs/ml were identified as optimum experimental conditions for performing the bioassay. The EC50 calculated for Cd²⁺ and Cu²⁺ in dose-response experiments indicated a good sensitivity of *H. polii*, with comparable values with those obtained in embryo toxicity bioassays of other marine invertebrates. An Integrative Toxicity Index (ITI) was calculated by integrating the frequency of abnormal embryos with the severity of observed abnormalities. The index allows to better discriminate different levels of toxicity, appearing particularly relevant for validating the usefulness of *H. polii* in embryo assays and ecotoxicological studies on environmental quality.

Mou, J. J., Wang, C., Li, W. J., & Yang, J. (2017). Purification, structural characterization and anticoagulant properties of fucosylated chondroitin sulfate isolated from *Holothuria mexicana*. *International Journal of Biological Macromolecules*, 98, 208-215 <https://doi.org/10.1016/j.ijbiomac.2017.01.123>.

A novel fucosylated chondroitin sulfate (HmG) was isolated from sea cucumber *Holothuria mexicana*, the structure of which was characterized by monosaccharide composition, disaccharide composition, IR, H-1 and C-13 NMR spectrum, additionally with two dimensional NMR spectrum of degraded HmG (DHmG). The backbone of HmG was identified as chondroitin 6-O sulfate, while the major O-4 sulfated fucose branches linked to O-3 position of glucuronic acid in almost every disaccharide unit. The anticoagulant activities of HmG and DHmG were assessed and compared with heparin and low molecular weight heparin. The results indicated that HmG and DHmG both could significantly prolong the activated partial thrombo-plastin time, and the properties were well related to its molecular weight. DHmG showed similar anticoagulant properties to low molecular weight heparin with less bleeding risks, making it a safer anticoagulant drug.

Mu, C., Wang, R. J., Li, T. Q., Li, Y. Q., Tian, M. L., Jiao, W. Q., . . . Bao, Z. M. (2016). Long Non-Coding RNAs (lncRNAs) of Sea Cucumber: Large-Scale Prediction, Expression Profiling, Non-Coding Network Construction, and lncRNA-microRNA-Gene Interaction Analysis of lncRNAs in

Apostichopus japonicus and Holothuria glaberrima During LPS Challenge and Radial Organ Complex Regeneration. *Marine Biotechnology*, 18(4), 485-499 <https://doi.org/10.1007/s10126-016-9711-y>.

Long non-coding RNA (lncRNA) structurally resembles mRNA but cannot be translated into protein. Although the systematic identification and characterization of lncRNAs have been increasingly reported in model species, information concerning non-model species is still lacking. Here, we report the first systematic identification and characterization of lncRNAs in two sea cucumber species: (1) *Apostichopus japonicus* during lipopolysaccharide (LPS) challenge and in healthy tissues and (2) *Holothuria glaberrima* during radial organ complex regeneration, using RNA-seq datasets and bioinformatics analysis. We identified *A. japonicus* and *H. glaberrima* lncRNAs that were differentially expressed during LPS challenge and radial organ complex regeneration, respectively. Notably, the predicted lncRNA-microRNA-gene trinities revealed that, in addition to targeting protein-coding transcripts, miRNAs might also target lncRNAs, thereby participating in a potential novel layer of regulatory interactions among non-coding RNA classes in echinoderms. Furthermore, the constructed coding-non-coding network implied the potential involvement of lncRNA-gene interactions during the regulation of several important genes (e.g., Toll-like receptor 1 [TLR1] and transglutaminase-1 [TGM1]) in response to LPS challenge and radial organ complex regeneration in sea cucumbers. Overall, this pioneer systematic identification, annotation, and characterization of lncRNAs in echinoderm pave the way for similar studies and future genetic, genomic, and evolutionary research in non-model species.

Nieves-Rios, C., Alvarez-Falcon, S., Malavez, S., Rodriguez-Otero, J., & Garcia-Ararras, J. E. (2020). The nervous system component of the mesentery of the sea cucumber *Holothuria glaberrima* in normal and regenerating animals. *Cell and Tissue Research*, 380(1), 67-77 <https://doi.org/10.1007/s00441-019-03142-3>.

The mesenterial tissues play important roles in the interactions between the viscera and the rest of the organism. Among these roles, they serve as the physical substrate for nerves connecting the visceral nervous components to the central nervous system. Although the mesenterial nervous system component has been described in vertebrates, particularly in mammals, a description in other deuterostomes is lacking. Using immunohistochemistry in tissue sections and whole mounts, we describe here the nervous component of the intestinal mesentery in the sea cucumber *Holothuria glaberrima*. This echinoderm has the ability to regenerate its internal organs in a process that depends on the mesentery. Therefore, we have also explored changes in the mesenterial nervous component during intestinal regeneration. Extensive fiber bundles with associated neurons are found in the mesothelial layer, extending from the body wall to the intestine. Neuron-like cells are also found within a plexus in the connective tissue layer. We also show that most of the cells and nerve fibers within the mesentery remain during the regenerative process, with only minor changes: a general disorganization of the fiber bundles and a retraction of nerve fibers near the tip of the mesentery during the first days of regeneration. Our results provide a basic description of mesenterial nervous component that can be of importance for comparative studies as well as for the analyses of visceral regeneration.

O'Loughlin, P. M., Mackenzie, M., & VandenSpiegel, D. (2013). New sea cucumber species from the seamounts on the Southwest Indian Ocean Ridge (Echinodermata: Holothuroidea: Aspidochirotida, Elaspodida, Dendrochirotida). *Memoirs of Museum Victoria*, 70, 37-50 <https://doi.org/10.24199/j.mmv.2013.70.04>.

Marine research program JC066 (JC067) in the southwest Indian Ocean on the RRS James Cook in November and December 2011 collected sea cucumbers with an ROV from the Atlantis Bank and Coral Seamount. Three new species are described: *Amphigymnas staplesi* O'Loughlin sp. nov.; *Pannychia taylorae* O'Loughlin sp. nov.; *Psolus atlantis* O'Loughlin sp. nov. Genera *Amphigymnas* Walsh and *Pannychia* Théel are reviewed. A lectotype for *Pannychia moseleyi* Théel is designated.

Omar, H. A., Abdel Razek, F. A., Abdel Rahman, S. H., & El Shimy, N. A. (2013). Reproductive periodicity of sea cucumber *Bohadschia vitiensis* (Echinodermata: Holothuroidea) in Hurghada area, Red Sea, Egypt. *The Egyptian Journal of Aquatic Research*, 39(2), 115-123
<https://doi.org/10.1016/j.ejar.2013.06.002>.

Sea cucumbers form an important part of multispecies fisheries existing for over 1000 years along the Indo-Pacific region. The "beche-de-mer", is considered as a good source of income for fishermen and has an important role in the benthic community. A small scale sea cucumber fishery began on Red Sea Coast, by the year 2000. This fishery had expanded dramatically, leading to over exploitation. The sea cucumber *Bohadschia vitiensis* is currently one of the most valuable species recorded in Egyptian Red Sea Water especially in Hurghada area. The present study is concerned with reproduction of this species. Samples were collected monthly, between March, 2003 and February 2004, at Hurghada area. Gonad index and macroscopic examination were estimated for each individual gonad. Gametogenesis began in May and peak of spawning occurred in June and July in males and females. The gonad index correlated significantly with gonad tubule length and diameter. This is considered a good predictor of sexual maturity and reproduction. The gonad index showed a significant correlation with temperature which may play a role in controlling reproduction. The minimum biological size was 24.5cm and 26.1cm for males and females, respectively. There was a shift in sex ratio from 1:1 to a significant rise in number of males throughout the sampling period. This species is considered as a summer spawner as most of Egyptian tropical sea cucumber species of Red Sea.

Pagan-Jimenez, M., Ruiz-Calderon, J. F., Dominguez-Bello, M. G., & Garcia-Ararras, J. E. (2019). Characterization of the intestinal microbiota of the sea cucumber *Holothuria glaberrima*. *Plos One*, 14(1), <https://doi.org/10.1371/journal.pone.0208011>.

High-throughput 16S rRNA gene sequencing has been used to identify the intestinal microbiota of many animal species, but that of marine invertebrate organisms remains largely unknown. There are only a few high-throughput sequencing studies on the intestinal microbiota of echinoderms (non-vertebrate Deuterostomes). Here we describe the intestinal microbiota of the sea cucumber *Holothuria glaberrima*, an echinoderm, well-known for its remarkable power of regeneration. We characterized the microbiota from the anterior descending intestine, the medial intestine (these two comprise the small intestine) and the posterior descending intestine (or large intestine), using pyrosequencing to sequence the V4 region of the 16S rRNA gene. We compared animals in their natural marine environment and in sea-water aquaria. A total of 8,172 OTU's were grouped in 10 bacterial phyla, 23 classes, 44 orders, 83 families, 127 genera and 1 group of unknown bacteria, present across the digestive tract of 10 specimens. The results showed that the anterior intestine is dominated by Proteobacteria (61%) and Bacteroidetes (22%), the medium intestine is similar but with lower Bacteroidetes (4%), and the posterior intestine was remarkably different, dominated by Firmicutes (48%) and Bacteroidetes (35%). The structure of the community changed in animals kept in aquaria, which had a general dominance of

Firmicutes and Bacteroidetes, regardless the intestinal segment. Our results evidence that in the natural sea environment, there is intestinal segment differentiation in the microbiota of *H. glaberrima*, which is lost in artificial conditions. This is relevant for physiological studies, such as mechanisms of digestive regeneration, which might be affected by the microbiota.

Pereira, T., Mattar, L., Pereira, E., Merçon, J., Silva, A., & Cruz, Z. (2017). Effects of Tin on Enzyme Activity in *Holothuria grisea* (Echinodermata: Holothuroidea). *Bulletin of Environmental Contamination & Toxicology*, 98(5), 607-611 <https://doi.org/10.1007/s00128-016-1992-3>.

This study evaluated the effect of tin exposure on enzyme activity in the sea cucumber (*Holothuria grisea* Selenka, 1867). After exposure to 0 (control), 0.04, 0.08, or 0.12 mg L tin, we tested the activities of total cholinesterase in longitudinal muscles, acid phosphatase in gonads and the respiratory tree, as well as alkaline phosphatase in the intestines during a 96-h bioassay. Regression analyses showed that all enzyme activities declined with increasing tin concentrations, except for acid phosphatase in the respiratory tree, which were similarly, inhibited at all tin concentrations. These results indicate that *H. grisea* is a potential bioindicator for seascape habitat monitoring programs, as its biochemical markers show sensitivity to trace elements that can indicate a rise in pollution levels.

Prompoon, Y., Weerachayanukul, W., Withyachumnarnkul, B., Vanichviriyakit, R., Wongprasert, K., & Asuvapongpatana, S. (2015). Lectin-Based Profiling of Coelomocytes in *Holothuria scabra* and Expression of Superoxide Dismutase in Purified Coelomocytes. *Zoological Science*, 32(4), 345-351, 347 <https://doi.org/10.2108/zs140285>.

Coelomocytes are the first line of immune defense in marine animals. Their distributions are greatly variable even in the close animal species. In this study, we used lectin staining to aid in the classification and purification of these cells for further investigation of SOD distribution among coelomocytes of *H. scabra*. We classified coelomocytes into four types: type 1, lymphocytes; type 2, phagocytes; type 3, spherulocytes; and type 4, giant cells. Among four lectins used, Con A appeared to give a broad reactivity against most coelomocytes, except for giant cells. In addition, phagocytes usually engaged the highest fluorescent intensity with most lectins, with the exception of PNA, for which spherulocytes possessed the highest fluorescent intensity. Using FACS for fraction collection, it was found that F1 fraction contained the purest phagocyte population (> 95%), which was highly reactive with anti-superoxide dismutase (SOD) as revealed by immunoblotting and immunofluorescence staining, although some minor staining was also detected in spherulocytes. Our results thus provide a fundamental platform for comparing alterations that may happen to the population and SOD contents of coelomocytes when the sea cucumber is subjected to environmental changes that would activate their immune responses.

Rafalowski, S., & Plante, C. (2013). Non-equilibrium processes structuring benthic bacterial communities following deposit feeding by a sea cucumber. *Marine Ecology Progress Series*, 478, 115-126 <https://doi.org/10.3354/meps10162>.

Non-equilibrium models of community structure focus on the role of disturbance, recovery, and succession. We examined the disturbance effect of *Isostichopus badionotus* (Selenka, 1867) deposit feeding on the physical habitat and benthic bacterial communities. Physical sediment characteristics

were compared between ingesta and egesta, and bacterial community structure was compared among ingesta, egesta, fore-, mid-, and hind-gut samples using epifluorescence microscopy and DGGE analysis of 16S rDNA. When compared with ambient sediments, fresh egesta were significantly higher in organic content and algal pigments, suggesting that these animals fed selectively. In contrast, total and metabolically active bacterial densities were significantly reduced by 33 and 60%, respectively, as sediment passed through the gut, producing disturbance patches of reduced abundance. We also compared different modes of bacterial recovery by experimentally isolating egesta from underlying sediment or overlying waters. Numerical recovery occurred between 1 and 6 h, depending on which mode of recovery (migration, recruitment, or regrowth) was precluded. In contrast to previous studies performed in intertidal settings, all forms of recolonization were significant, in the following order of importance: migration \approx recruitment $>$ regrowth. Species richness did not change significantly through time under any recolonization regime nor was species turnover evident; thus, bacterial communities in this subtidal habitat appear to be founder-controlled. Yet the mode of recovery did influence community structure, as reflected by a significant treatment effect. The pool of potential recruits can be restricted by the mode of recolonization; thus, patchiness in community structure and high species diversity can result even in a competitive lottery situation.

Ramón, M., Simarro, G., Galimany, E., & Lleonart, J. (2019). Evaluation of sediment particle size selection during feeding by the holothurian *Parastichopus regalis* (Cuvier, 1817). *Regional Studies in Marine Science*, 31, 100763 <https://doi.org/10.1016/j.rsma.2019.100763>.

Parastichopus regalis is an epibenthic holothurian common in the Mediterranean Sea and the NE Atlantic, which feeds on the upper layer of the sediment playing a significant role on soft-bottom dynamics. Whether or not *P. regalis* is able to select the sediment ingested by size is the question of this study. For this purpose, a comparison between grain size distributions of the seabed sediments and the digestive contents of sea cucumbers were carried out. We performed the comparisons among sediment distributions through the median diameter D50 and the granulometric dispersion D84/D16. The results showed that the size of the sediment within the holothurians was significantly smaller and more uniform than the ones in the seabed. Evidence showed that *P. regalis* select sediment by particle size during feeding, choosing the smaller particles. This finding reports novel information on the feeding behavior of this species, a fishery resource of local interest and importance in the Western Mediterranean region.

Ramos-miranda, J., Del Río-Rodríguez, R., Flores-hernández, D., Rojas-González, R. I., Gómez-Solano, M., Cu-Escamilla, A. D., . . . Juárez-Camargo, P. (2017). Reproductive cycle of the sea cucumber *Holothuria floridana* in the littorals of Campeche, Mexico. *Fisheries Science*, 83(5), 699-714 <https://doi.org/10.1007/s12562-017-1100-6>.

The reproduction of *Holothuria floridana* in Campeche bay, southern Gulf of Mexico, was investigated over a period of 12 months by macroscopic and histological examination of the gonad and gametogenesis. A total of 1938 specimens were collected. Their body gutted weight and body gutted length ranged from 15 to 225 g and 5 to 21 cm, respectively. Percentage of the gonad weight to the gutted body weight (gonad index, GI) increased steadily from December to April, rapidly declined in May, and remained low during the following months. GI displayed a negative correlation with temperature of the habitat and no correlation with salinity. The gonad maturity scale with five stages was developed from macroscopic and microscopic observations; I, recovery; II, growing; III, early mature; IV, mature and V, spent. Stages III to V were observed all around the year, suggesting that this

species displays continuous reproduction with two peaks of spawning events; from March to April and in September. The presence of viscera regurgitated individuals caused high variability in GI. The sex-ratio varied from 1:1 (December 2013 to June 2014), to 1.37:1 (November 2013); we suggest that this may be the consequence of unintentional selective fishing. The body length and body weight at the first maturity were calculated to be 13.4 cm and 87.0 g, respectively. For resource management it will be necessary to address some reference points like harvest season and avoidance of catches shorter than length at first maturity.

Ren, J. S., Stenton-Dozey, J., & Zhang, J. (2017). Parameterisation and application of dynamic energy budget model to sea cucumber *Apostichopus japonicus*. *Aquaculture Environment Interactions*, 9, 1-8. Retrieved from <https://www.int-res.com/abstracts/aei/v9/p1-8/>.

The sea cucumber *Apostichopus japonicus* is an important aquaculture species in China. As global interest in sustainable aquaculture grows, the species has increasingly been used for co-culture in integrated multitrophic aquaculture (IMTA). To provide a basis for optimising stocking density in IMTA systems, we parameterised and validated a standard dynamic energy budget (DEB) model for the sea cucumber. The covariation method was used to estimate parameters of the model with the DEBtool package. The method is based on minimisation of the weighted sum of squared deviation for datasets and model predictions in one single-step procedure. Implementation of the package requires meaningful initial values of parameters, which were estimated using non-linear regression. Parameterisation of the model suggested that the accuracy of the lower and upper boundaries of tolerance temperatures are particularly important, as these would trigger the unique behaviour of the sea cucumber for hibernation and aestivation. After parameterisation, the model was validated with datasets from a shellfish aquaculture environment in which sea cucumbers were co-cultured with the scallop *Chlamys farreri* and Pacific oyster *Crassostrea gigas* at various combinations of density. The model was also applied to a land-based pond culture environment where the sea cucumber underwent a fast growth period in spring and non-growth periods during winter hibernation and summer aestivation. Application of the model to datasets showed that the model is capable of simulating the physiological behaviour of the sea cucumber and responds adequately to the wide range of environmental and culture conditions.

Rosado-Olivieri, E. A., Ramos-Ortiz, G. A., Hernandez-Pasos, J., Diaz-Balzac, C. A., Vazquez-Rosa, E., Valentin-Tirado, G., . . . Garcia-Arraras, J. E. (2017). A START-domain-containing protein is a novel marker of nervous system components of the sea cucumber *Holothuria glaberrima*. *Comparative Biochemistry and Physiology B-Biochemistry & Molecular Biology*, 214, 57-65 <https://doi.org/10.1016/j.cbpb.2017.08.004>.

One of the main challenges faced by investigators studying the nervous system of members of the phylum Echinodermata is the lack of markers to identify nerve cells and plexi. Previous studies have utilized an antibody, RN1, that labels most of the nervous system structures of the sea cucumber *Holothuria glaberrima* and other echinoderms. However, the antigen recognized by RN1 remained unknown. In the present work, the antigen has been characterized by immunoprecipitation, tandem mass spectrometry, and cDNA cloning. The RN1 antigen contains a START lipid-binding domain found in Steroidogenic Acute Regulatory (StAR) proteins and other lipid binding proteins. Phylogenetic tree assembly showed that the START domain is highly conserved among echinoderms. We have named this antigen HgSTARD10 for its high sequence similarity to the vertebrate orthologs. Gene and protein

expression analyses revealed an abundance of HgSTARD10 in most *H. glaberrima* tissues including radial nerve, intestine, muscle, esophagus, mesentery, hemal system, gonads and respiratory tree. Molecular cloning of HgSTARD10, consequent protein expression and polyclonal antibody production revealed the STARD10 ortholog as the antigen recognized by the RN1 antibody. Further characterization into this START domain-containing protein will provide important insights for the biochemistry, physiology and evolution of deuterostomes.

Salari-Aliabadi, M. A., & Monjezi-Veysi, M. (2020). Application of Calcareous Spicules for the Identification of Sea Cucumbers in the Rocky Shores of Northern Persian Gulf. *Indian Journal of Geo-Marine Sciences*, 49(2), 281-286. Retrieved from <http://nopr.niscair.res.in/handle/123456789/54073>.

Sea cucumbers as a large group of marine invertebrates have traditionally been demanded as a food with high nutritional value and for medicinal aims in Asia and the Middle East for many years. To identify and compare sea cucumber species in the tidal rocky northern coast of the Persian Gulf, samples were collected from six stations in the four seasons. Based on the results of morphological and microscopic aspects, two sea cucumber species were identified including, *Holothuria parva* and *Holothuria arenicola* from *Holothuriidea*, *Echinodermata*. Comparison based on the calcareous structures (spicules or calcareous ossicles), is an important key in the identification, as it displays obvious differences between both species. The most common type of spicule of *H. parva* was various forms of rod shape, and for *H. arenicola* was related to Buttony spicules. Overall, our results indicated that skeletal microscopic structure can be used in the taxonomy of sea cucumbers, and also established the important role of calcareous spicules as an identification key to distinguish sea cucumber species.

Samyn, Y., Massin, C., & Vandenspiegel, D. (2019). The sea cucumber *Holothuria lineata* Ludwig, 1875 (*Holothuroidea*, *Aspidochirotida*, *Holothuriidae*) re-described from the newly found type. *Zookeys*, 836, 81-91 <https://doi.org/10.3897/zookeys.836.29932>.

A re-description of the little-known holothurian species *Holothuria* (*Lessonothuria*) *lineata* Ludwig, 1875 is given. It is based on the single recovered type specimen and an individual recently collected on Glorioso Islands, near Madagascar. A key to separate three closely related and commonly confused species, i.e., *Holothuria* (*Lessonothuria*) *pardalis* Selenka, 1867, *Holothuria* (*Lessonothuria*) *verrucosa* Selenka, 1867 and *Holothuria* (*Lessonothuria*) *insignis* Ludwig, 1875, is presented.

Slater, M., Chen, J. (2015). Sea Cucumber Biology and Ecology. In *Echinoderm Aquaculture* (pp. 47-55) <https://doi.org/10.1002/9781119005810.ch3>.

Sea cucumbers are frequently among the largest and most diverse classes of benthic invertebrate in the intertidal and subtidal and constitute the vast majority of total biomass in slope and abyssal benthic systems. While most sea cucumbers are either sedentary or at the least comparatively slow-moving, a number of species move periodically by swimming and a few are primarily bathypelagic free swimmers. Holothurians have a calcareous ring at the anterior surrounding the esophagus, the ring consists of calcareous plates and serves as attachment for tentacle complexes and longitudinal muscles which extend along the body. The class differs from other echinoderms in its possession of a comparatively well-developed hemal system. Current commercial and experimental aquaculture of sea cucumbers,

presumably as a result of accessibility and commercial value, is limited to high-value intertidal and subtidal aspidochirotetes, primarily the temperate species *A. japonicus* and the tropical species *Holothuria scabra*.

Solís-Marín, F. A., Conejeros-Vargas, C. A., Caballero-Ochoa, A. A., & Arriaga-Ochoa, J. A. (2019). *Epitomapta simentalae* sp. n., a new species of apodous sea cucumber from the Central Eastern Pacific coast of Mexico (Echinodermata, Holothuroidea, Apodida). *Zookeys*, 817, 1-9
<https://doi.org/10.3897/zookeys.817.29406>.

Epitomapta simentalae sp. n. occurs in depths of 4–10 m off the Mexican Central Pacific coast. It is distinctive in having twelve tentacles, each tentacle with two or three pairs of digits and four to six sensory cups, lacking papillae or oval bumps and in reaching a maximum length of 50 mm in life.

Solis-Marin, F. A., Komatsu, M., Soliman, T., Uchida, K., Shimotani, T., & Nozaki, M. (2014). *Scoliorhapis dianthus*, a new species of sea cucumber (Apodida: Chiridotidae) from the Sea of Japan. *Proceedings of the Biological Society of Washington*, 127(2), 323-327, 325
<https://doi.org/10.2988/0006-324X-127.2.323>.

Scoliorhapis dianthus, new species, was collected from depths of 0.20–1 m in the Sea of Japan. It is distinctive in having ten tentacles with six pairs of digits of equal size. Ossicles in the body wall have a sigmoid shape and average $75 \pm 5 \mu\text{m}$ in length. An identification key to all species of the genus is provided.

Sun, J., Hamel, J.-F., Stuckless, B., Small, T. J., & Mercier, A. (2020). Effect of light, phytoplankton, substrate types and colour on locomotion, feeding behaviour and microhabitat selection in the sea cucumber *Cucumaria frondosa*. *Aquaculture*, 526, 735369
<https://doi.org/10.1016/j.aquaculture.2020.735369>.

While the suspension-feeding sea cucumber *Cucumaria frondosa* is commercially exploited in the North Atlantic and is considered to have potential for integrated aquaculture, the impact of environmental conditions on its behaviour and population structure remains incompletely understood. The present study showed that adults are not photosensitive; they do not exhibit any preference for either illuminated or shaded areas. Within each photoperiod treatment, analyses of the daily activity cycle revealed that the proportion of individuals with feeding tentacles deployed did not change over time; however, the proportion of moving individuals increased in the dark phase under the 12 h light/12 dark regime, but remained constant under continuous light or darkness. Hence, from an aquaculture perspective, long days (i.e. summer photoperiod) might decrease the time spent moving in favour of feeding, potentially shifting the energy budget toward faster growth. Variations in phytoplankton concentration modulated the deployment of tentacles but did not trigger any displacement toward the food source, indicating that feeding responds directly to the presence of food. Moreover, *C. frondosa* exhibited a clear preference for substrates composed of bare rocks and rocks with coralline algae and displayed a weak preference for darker substrate backgrounds. Together, these findings highlight how some key environmental factors can govern the feeding, locomotor activities, and eventual distribution of cold-water suspension-feeding sea cucumbers.

Sun, J., Zhang, L., Pan, Y., Lin, C., Wang, F., Kan, R., & Yang, H. (2015). Feeding behavior and digestive physiology in sea cucumber *Apostichopus japonicus*. *Physiology & Behavior*, 139, 336-343
<https://doi.org/10.1016/j.physbeh.2014.11.051>.

The feeding behavior and digestive physiology of the sea cucumber, *Apostichopus japonicus* are not well understood. A better understanding may provide useful information for the development of the aquaculture of this species. In this article the tentacle locomotion, feeding rhythms, ingestion rate (IR), feces production rate (FPR) and digestive enzyme activities were studied in three size groups (small, medium and large) of sea cucumber under a 12 h light/12 h dark cycle. Frame-by-frame video analysis revealed that all size groups had similar feeding strategies using a grasping motion to pick up sediment particles. The tentacle insertion rates of the large size group were significantly faster than those of the small and medium-sized groups ($P < 0.05$). Feeding activities investigated by charge coupled device cameras with infrared systems indicated that all size groups of sea cucumber were nocturnal and their feeding peaks occurred at 02:00–04:00. The medium and large-sized groups also had a second feeding peak during the day. Both IR and FPR in all groups were significantly higher at night than those during the daytime ($P < 0.05$). Additionally, the peak activities of digestive enzymes were 2–4 h earlier than the peak of feeding. Taken together, these results demonstrated that the light/dark cycle was a powerful environment factor that influenced biological rhythms of *A. japonicus*, which had the ability to optimize the digestive processes for a forthcoming ingestion.

Sun, L. N., Lin, C. G., Li, X. N., Xing, L., Huo, D. C., Sun, J. C., . . . Yang, H. S. (2018). Comparative Phospho- and Acetyl Proteomics Analysis of Posttranslational Modifications Regulating Intestine Regeneration in Sea Cucumbers. *Frontiers in Physiology*, 9,
<https://doi.org/10.3389/fphys.2018.00836>.

Sea cucumbers exposed to stressful circumstances eviscerate most internal organs, and then regenerate them rapidly under favorable environments. Reversible protein phosphorylation and acetylation are major modifications regulating protein function. Herein, for the first time, we perform quantitative phospho- and acetyl proteomics analyses of intestine regeneration in a sea cucumber species *Apostichopus japonicus*. We identified 1,862 phosphorylation sites in 1,169 proteins, and 712 acetylation sites in 470 proteins. Of the 147 and 251 proteins differentially modified by phosphorylation and acetylation, respectively, most were related to cytoskeleton biogenesis, protein synthesis and modification, signal recognition and transduction, energy production and conversion, or substance transport and metabolism. Phosphorylation appears to play a more important role in signal recognition and transduction than acetylation, while acetylation is of greater importance in posttranslational modification, protein turnover, chaperones; energy production and conversion; amino acid and lipid transport and metabolism. These results expanded our understanding of the regulatory mechanisms of posttranslational modifications in intestine regeneration of sea cucumbers after evisceration.

Viera-Vera, J., & Garcia-Arraras, J. E. (2019). Retinoic Acid Signaling Is Associated with Cell Proliferation, Muscle Cell Dedifferentiation, and Overall Rudiment Size during Intestinal Regeneration in the Sea Cucumber, *Holothuria glaberrima*. *Biomolecules*, 9(12),
<https://doi.org/10.3390/biom9120873>.

Almost every organism has the ability of repairing damaged tissues or replacing lost and worn out body parts, nevertheless the degree of the response substantially differs between each species. Adult sea cucumbers from the *Holothuria glaberrima* species can eviscerate various organs and the intestinal system is the first one to regenerate. This process involves the formation of a blastema-like structure that derives from the torn mesentery edges by the intervention of specific cellular processes (e.g., cell dedifferentiation and division). Still, the genetic networks controlling the regenerative response in this model system are just starting to be unraveled. In this work we examined if and how the retinoic acid (RA) signaling pathway is involved in the regenerative response of this deuterostome. We first identified and characterized the holothurian orthologs for short chain dehydrogenase/reductase 7 (SDR7) and aldehyde dehydrogenase family 8A1 (ALDH8A1), two enzymes respectively associated with retinaldehyde and RA anabolism. We then showed that the SDR7 transcript was differentially expressed during specific stages of intestinal regeneration while ALDH8A1 did not show significant differences in regenerating tissues when compared to those of normal (non-eviscerated) organisms. Finally, we investigated the consequences of modulating RA signaling during intestinal regeneration using pharmacological tools. We showed that application of an inhibitor (citrinal) of the enzyme synthesizing RA or a retinoic acid receptor (RAR) antagonist (LE135) resulted in organisms with a significantly smaller intestinal rudiment when compared to those treated with DMSO (vehicle). The two inhibitors caused a reduction in cell division and cell dedifferentiation in the new regenerate when compared to organisms treated with DMSO. Results of treatment with tazarotene (an RAR agonist) were not significantly different from the control. Taken together, these results suggest that the RA signaling pathway is regulating the cellular processes that are crucial for intestinal regeneration to occur. Thus, RA might be playing a role in echinoderm regeneration that is similar to what has been described in other animal systems.

Viera-Vera, J., & García-Arrarás, J. E. (2018). Molecular characterization and gene expression patterns of retinoid receptors, in normal and regenerating tissues of the sea cucumber, *Holothuria glaberrima*. *Gene*, 654, 23-35 <https://doi.org/10.1016/j.gene.2018.01.102>.

Retinoic acid receptors (RAR) and retinoid X receptors (RXR) are ligand-mediated transcription factors that synchronize intricate signaling networks in metazoans. Dimer formation between these two nuclear receptors mediates the recruitment of co-regulatory complexes coordinating the progression of signaling cascades during developmental and regenerative events. In the present study we identified and characterized the receptors for retinoic acid in the sea cucumber *Holothuria glaberrima*; a model system capable of regenerative organogenesis during adulthood. Molecular characterizations revealed the presence of three isoforms of RAR and two of RXR as a consequence of alternative splicing events. Various analyses including: primary structure sequencing, phylogenetic analysis, protein domain prediction, and multiple sequence alignment further confirmed their identity. Semiquantitative reverse transcription PCR analysis of each receptor isoform herein identified showed that the retinoid receptors are expressed in all tissues sampled: the mesenteries, respiratory trees, muscles, gonads, and the digestive tract. During regenerative organogenesis two of the receptors (RAR-L and RXR-T) showed differential expression in the posterior segment while RAR-S is differentially expressed in the anterior segment of the intestine. This work presents the first description of the components relaying the signaling for retinoic acid within this model system.

Wang, Z., Cui, J., Song, J., Wang, H., Gao, K., Qiu, X., . . . Wang, X. (2018). Comparative transcriptome analysis reveals growth-related genes in juvenile Chinese sea cucumber, Russian sea cucumber,

and their hybrids. *Marine Biotechnology*, 20(2), 193-205 <https://doi.org/10.1007/s10126-018-9796-6>.

Heterosis is important for sea cucumber breeding, but its molecular mechanism remains largely unexplored. In this study, parental lines of *Apostichopus japonicus* from Russia (R) and China (C) were used to construct hybrids (CR and RC) by reciprocal crossing. We examined the transcriptional profiles of the hybrids (CR and RC) and the purebreds (CC and RR) at different developmental times. A total of 60.27 Gb of clean data was obtained, and 176,649 unigenes were identified, of which 50,312 unigenes were annotated. A total of 414,536 SNPs were identified. A total of 7011 differentially expressed genes (DEGs) were obtained between the purebreds and hybrids at 45 days after fertilization (DAF), and a total of 8218 DEGs were obtained between the purebreds and hybrids at 75 DAF. In addition, a total of 7652 DEGs were obtained between 45 DAF and 75 DAF. The significant DEGs were mainly involved in the MAPK and FOXO signaling pathways, especially in the Ras-Raf-MEK1/2-ERK module, which may be a key regulator of development and growth in juvenile *A. japonicus*. In addition, we also identified key growth-related genes, such as fgfs, igfs, megfs and hgfs, which were upregulated in the hybrids (RC and CR); these genes may play important roles in heterosis in *A. japonicus*. Our study provides fundamental information on the molecular mechanisms underlying heterosis in sea cucumber and might suggest strategies for the selection of rapidly growing strains of sea cucumber in aquaculture.

Weinrauch, A. M., & Blewett, T. A. (2019). Anoxia tolerance in the sea cucumbers *Parastichopus californicus* and *Cucumaria miniata* reflects habitat use. *Journal of Experimental Marine Biology and Ecology*, 520, 6 <https://doi.org/10.1016/j.jembe.2019.151203>.

Natural fluctuations in dissolved oxygen are an important physiological challenge faced by marine organisms. This is particularly true of intertidal species that may become trapped in bodies of water where oxygen becomes rapidly depleted, or which may be emersed and exposed to elevated oxygen, but without respiratory organs adapted for uptake of oxygen from air. We sought to determine whether oxygen handling approaches differ in two species of sea cucumber, *Cucumaria miniata* and *Parastichopus californicus*, which inhabit distinct niches that vary in dissolved oxygen profiles. *C. miniata* occupies the rocky intertidal zone and thus experiences daily oscillations in oxygen content, whereas *P. californicus* inhabits the more oxygen stable, subtidal zone. Using closed chamber respirometry, our data showed that *C. miniata* have a higher basal metabolic rate than *P. californicus*, attributed to continuous filter-feeding, a phenomenon that contrasts with the sporadic feeding habits of the sediment-feeding *P. californicus*. Exposure to 6-h of anoxia or 6-h of emersion had no effect on coelomic fluid glucose concentrations in either species, however *P. californicus* body wall glucose concentrations increased similar to 6-fold relative to immersed normoxic controls under both treatments. Lactate production, a marker of anaerobic metabolism, was unaltered in both species under both anoxia and emersion conditions. These data demonstrate that habitat influences anoxia tolerance in sea cucumbers, with the intertidal *C. miniata* displaying a higher tolerance to both low dissolved oxygen and emersion, than the subtidal species, *P. californicus*.

Wolfe, K., & Davey, M. (2020). Localised high-density population of a sea cucumber on a Malaysian coral reef. *Coral Reefs*, 39(1), 33-38 <https://doi.org/10.1007/s00338-019-01877-7>.

While tropical sea cucumbers are among the most conspicuous mobile invertebrates on coral reefs, information on their population biology and ecology is limited, particularly for dendrochirotids

(suspension feeders). Here, we characterised a localised high-density population of the small and poorly described dendrochirotid, *Colochirus quadrangularis*, on a coral reef around Pom Pom Island, Malaysia. The high-density population was restricted to one site (Lobster Wall) on the south-eastern edge of Pom Pom Reef, with only 16 individuals found across all other sites. Average densities of this species were 669 +/- 76 ind m⁻² in the population epicentre, with a maximum of 1444 ind m⁻², and mean body length across the population of 2.78 cm (SD +/- 0.87). *Colochirus quadrangularis* showed preference for consolidated dead coral substrate while avoiding live corals. Asexual reproduction (transverse fission) was observed for the first time in this species along with cases of novel species interactions. There are no prior data for this species around Pom Pom Island, or elsewhere, to determine the drivers and impacts of this high-density *Colochirus* population, but these holothuroids may be an indication of the shifts in community states that can be expected for future coral reefs.

Woo, S. P., Kajihara, H., Byrne, M., & Fujita, T. (2019). Description and phylogenetic relationships of a new genus of sea cucumbers from Australia, with two new combinations (Holothuroidea, Stichopodidae). *Marine Biodiversity*, 49(6), 2499-2518 <https://doi.org/10.1007/s12526-019-00974-8>.

A new genus of Holothuroidea, *Notostichopus*, from Australia is described and its phylogenetic relationship examined. The new genus is based on two species within the family Stichopodidae, previously attributed to *Stichopus*. *Notostichopus* is characterized by the absence of rosette ossicles and the presence of table ossicles with at most one crossbeam in dorsal body wall. The two species revised here (*N. ludwigi* and *N. ellipes*) are distributed in the shallow, tropical, and temperate waters of Australia. Phylogenetic analyses indicate that this genus is closely related to the genera *Isostichopus* and *Stichopus* but is distinct based on ossicles and phylogenetic analyses. We describe the ossicle assemblages of both species.

Woo, S. P., Yasin, Z., Tan, S. H., Kajihara, H., & Fujita, T. (2015). Sea cucumbers of the genus *Stichopus* Brandt, 1835 (Holothuroidea, Stichopodidae) in Straits of Malacca with description of a new species. *Zookeys*, 545, 1-26 <https://doi.org/10.3897/zookeys.545.6415>.

Five sea cucumber species including one new species of the genus *Stichopus* are reported from the shallow coral reefs of Straits of Malacca. The new species *Stichopus fusiformiossa* has unusual fusiform spicules in the tentacles, which are not found in the other species of the genus. Pseudo-tables and large perforated plates are newly recorded for *Stichopus hermanni* Semper, 1868 and *Stichopus vastus* Sluiter, 1887, respectively.

Xia, B., Ren, Y., Wang, F., Yu, D., Cui, G., & Chen, J. (2017). A comparative study on growth, protein turnover and energy budget of green and white color morphs of sea cucumber *Apostichopus japonicus* (Selenka). *Aquaculture Environment Interactions*, 9, 405-414 <https://doi.org/10.3354/aei00241>.

A 98 d experiment was conducted to compare the growth performance, protein turnover and energy budget between green and white color morphs of the sea cucumber *Apostichopus japonicus*. During the experiment, sea cucumbers were fed a single natural diet of *Sargassum thunbergii* and a premixed artificial diet. Results showed that there was no significant interaction of diet, species or experimental

time on growth performance and feed utilization of *A. japonicus*. Specific growth rate (SGR) of green sea cucumber was significantly higher than that of white sea cucumber. Green sea cucumber fed *S. thunbergii* exhibited much higher food conversion efficiency (FCE) and protein efficiency ratio (PER) compared to those on the artificial diet, indicating preferential absorption of *S. thunbergii*. There were also significant discrepancies in body wall production rate (BWPR), crude protein and ash content between green and white sea cucumber. The observed $\delta^{15}\text{N}$ values gradually increased owing to the assimilation of the diets containing higher nitrogen stable isotope ratios. Green sea cucumber reflected and approached $\delta^{15}\text{N}$ values of the experimental diets much more quickly and with shorter half-lives than white sea cucumber. The relatively constant metabolic contributions in intestine (71 to 78%) and body wall (46 to 52%) of sea cucumber indicated a stable bioenergetic distribution strategy of tissue. According to the time-based turnover model, the estimated fractionation ($\Delta^{15}\text{N}$) ranged from 2.37 to 3.30‰. The average formulas of energy allocation for green and white sea cucumber were: $100\text{C} = 7.8\text{G} + 53.1\text{F} + 6.2\text{U} + 32.8\text{R}$, $100\text{C} = 6.3\text{G} + 57.9\text{F} + 8.9\text{U} + 27.0\text{R}$, respectively. Taken together, our results suggest that white sea cucumber may have higher dietary quality requirements for growth and metabolism than green sea cucumber.

Yamana, Y., & Hamano, T. (2006). New size measurement for the Japanese sea cucumber *Apostichopus japonicus* (Stichopodidae) estimated from the body length and body breadth. *Fisheries Science*, 72(3), 585-589 <https://doi.org/10.1111/j.1444-2906.2006.01187.x>.

Anesthetized body length (L_a), an accurate measurement of body size of Japanese sea cucumber *Apostichopus japonicus*, is measured by using l-menthol anesthetizer but it is difficult to apply L_a in the field. An estimation method of L_a from only one simultaneous measurement of body length (L) and body breadth (B), regardless of the degree of contraction or extension of the body, is proposed. In simultaneous measurement of L and B for each of 150 animals of both the green and the black types of *A. japonicus*, there were significant negative correlations between L and B in all animals. Further, \sqrt{LB} was approximately constant regardless of the animals body form (coefficient of variance: 0.01-0.06). Thus, the regression equations for L_e , estimated L_a , were calculated: the green type, $L_e = 2.32 + 2.02\sqrt{L \cdot B}$; and the black type, $L_e = 1.34 + 2.12\sqrt{L \cdot B}$. The error values between L_e from these equations and L_a were small. The variances of L_e were approximately one-quarter of those of L and half of B . From these, the equations can be used for body size measurements taken in the field.

Section II: Ecology

Boncagni, P., Rakaj, A., Fianchini, A., & Vizzini, S. (2019). Preferential assimilation of seagrass detritus by two coexisting Mediterranean sea cucumbers: *Holothuria polii* and *Holothuria tubulosa*. *Estuarine, Coastal and Shelf Science*, 231, 106464 <https://doi.org/10.1016/j.ecss.2019.106464>.

Holothuria polii and *Holothuria tubulosa* are two of the most commercially exploited sea cucumbers of the Mediterranean Sea. As deposit-feeders, they represent an important component of the benthic community. Hence, knowledge of their feeding behaviour is crucial for understanding their function in terms of benthic ecology and sediment dynamics. Using information obtained from stable isotope analysis, the food selectivity/assimilation, temporal variations in diet and trophic niche of *H. polii* and *H. tubulosa* were investigated. Analysis of carbon and nitrogen isotopic ratios in body wall tissue showed a preferential assimilation of seagrass detritus among multiple food sources, with a total contribution to the diet ranging from 63% to 74%. The temporal changes in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values followed the seagrass isotopic dynamics with depleted values in winter and enriched values in summer. Additionally, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements were used to outline the species' trophic niche width. The two species coexist, showing an overlap on the $\delta^{13}\text{C}$ axis and a partial degree of niche segregation on the $\delta^{15}\text{N}$ axis. Our results provide an overview on the feeding activity of *H. polii* and *H. tubulosa*, providing evidence of their crucial role on the seagrass detrital pathways for Mediterranean coastal ecosystems.

Minami, K., Masuda, R., Takahashi, K., Sawada, H., Shirakawa, H., & Yamashita, Y. (2019). Seasonal and interannual variation in the density of visible *Apostichopus japonicus* (Japanese sea cucumber) in relation to sea water temperature. *Estuarine, Coastal and Shelf Science*, 229, 106384 <https://doi.org/10.1016/j.ecss.2019.106384>.

Apostichopus japonicus (Japanese sea cucumber) is of ecological and economic importance in the coastal waters of Japan. To assess the apparent abundance of *A. japonicus*, density data of visible *A. japonicus* are required; however, the activity of this species on the sea floor changes with variations in sea water temperature. For example, at high sea water temperatures, *A. japonicus* takes shelter in the gaps of rocks or oyster shells. This change in its visibility on the sea floor makes it difficult to determine the apparent abundance of this species. In the present study, we aimed to clarify the optimal survey timing to assess the apparent abundance of *A. japonicus* based on the relationship between the density of visible *A. japonicus* and sea water temperature. Between 2010 and 2013, we evaluated how the density (ind. 100 m⁻²) of visible *A. japonicus* changes with sea water temperature in an area preferred by these organisms, Maizuru Bay, Kyoto, Japan, every 2 weeks. Seasonal changes in the density were consistent with seasonal variations in sea water temperature. Density increased when sea water temperature decreased and was at a maximum at minimum sea water temperatures. In addition, the density tended to change significantly over a short period. In some cases, the density after the lowest sea water temperature in March 2011 declined by half from 65 to 27 in just 2 weeks. Owing to considerable variations in the density of visible *A. japonicus*, we believe it is important to establish the appropriate survey timing to quantify the apparent abundance of this species, with our data suggesting that surveys should be performed during the season with the lowest sea water temperatures. Furthermore, at the lowest sea water temperatures in 2010, 2011, 2012, and 2013, the maximum densities were 99.0 (9.1 °C), 65.0 (9.7 °C), 41.3 (9.8 °C), and 8.7 (8.9 °C), respectively. Over 4 years, the density decreased to approximately 10% of that in the year with the peak density. Considering this decrease, it is suggested that *A. japonicus* in Maizuru Bay is overfished. Therefore, it is possible that the

density of visible *A. japonicus* at the lowest sea water temperatures provides useful information for assessing the apparent abundance of this species.

Mohsen, M., Wang, Q., Zhang, L., Sun, L., Lin, C., & Yang, H. (2019a). Heavy metals in sediment, microplastic and sea cucumber *Apostichopus japonicus* from farms in China. *Marine Pollution Bulletin*, 143, 42-49 <https://doi.org/10.1016/j.marpolbul.2019.04.025>.

The concentrations of eight heavy metals (As, Cd, Cr, Cu, Mn, Ni, Pb and Zn) were measured in the sediment, the isolated microplastics from the sediment and the body wall of sea cucumbers from farms in China. Accordingly, the heavy metal concentrations in the sediment were below the class I upper limit of Chinese sediment quality guidelines. Among heavy metals, the median concentrations of Cd and As were higher in the body wall than in the corresponding sediment. Additionally, the median concentrations of Cd, Pb, and Zn were higher on the microplastics than in the corresponding sediment. Furthermore, there was no significant correlation among heavy metals in sediment, sea cucumber and microplastics. This study contributes to the understanding of the heavy metal accumulation in the sediment, the microplastics and the body wall of the sea cucumber.

Mohsen, M., Wang, Q., Zhang, L., Sun, L., Lin, C., & Yang, H. (2019b). Microplastic ingestion by the farmed sea cucumber *Apostichopus japonicus* in China. *Environmental Pollution*, 245, 1071-1078 <https://doi.org/10.1016/j.envpol.2018.11.083>.

Microplastic ingestion by the farmed sea cucumber is undocumented. Microplastics were isolated from the sea cucumber *Apostichopus japonicus* that was collected from eight farms along the Bohai Sea and the Yellow Sea in China. To examine microplastic ingestion, the intestines were isolated, digested and then subjected to the floatation test. The microplastic abundance in the sediment ranged from 20 to 1040 particles kg⁻¹ of dry sediment, while the ingested microplastics ranged from 0 to 30 particles intestine⁻¹. After filtering the coelomic fluid, the extracted microplastics from the coelomic fluid ranged from 0 to 19 particles animal⁻¹. Thus, we speculated that microplastics may transfer to the coelomic fluid of sea cucumber. The ingested microplastics did not correlate with the animal body weight but was site dependent, suggesting that sea cucumber may serve as sentinel for microplastic pollution monitoring in the sediment. The microplastics were identified by Fourier transform infrared micro spectroscopy, and the polymer types were mainly cellophane, polyester, and polyethylene terephthalate. This study revealed that, microplastics widely existed in sea cucumber farms, and that sea cucumbers ingest microplastics as suitable with their mouth open. Moreover, the microplastics might transfer to the coelomic fluid of the sea cucumber. Further investigations are needed to assess the chronic effect of the microplastics on the growth and physiological status of the sea cucumber.

Pan, Y., Zhang, L., Lin, C., Sun, J., Kan, R., & Yang, H. (2015). Influence of flow velocity on motor behavior of sea cucumber *Apostichopus japonicus*. *Physiology & Behavior*, 144, 52-59 <https://doi.org/10.1016/j.physbeh.2015.02.046>.

The influence of flow velocity on the motor behavior of the sea cucumber, *Apostichopus japonicus* was investigated in the laboratory. Cameras were used to record sea cucumber movements and behavior analysis software was used to measure the distance traveled, time spent, upstream or downstream of the start position and the speed of movements. In general, the mean velocity of *A. japonicus* was below

0.7mms⁻¹. The maximum velocity recorded for all the sea cucumbers tested was for a large individual (89.25±17.11g), at a flow rate of 4.6±0.5cms⁻¹. Medium sized (19.68±5.53g) and large individuals moved significantly faster than small individuals (2.65±1.24g) at the same flow rate. *A. japonicus* moved significantly faster when there was a moderate current (4.6±0.5cms⁻¹ and 14.7±0.3cms⁻¹), compared with the fast flow rate (29.3±3.7cms⁻¹) and when there was no flow (0cms⁻¹). Sea cucumbers did not show positive rheotaxis in general, but did move in a downstream direction at faster current speeds. Large, medium and small sized individuals moved downstream at the fastest current speed tested, 29.3±3.7cms⁻¹. When there was no water flow, sea cucumbers tended to move in an irregular pattern. The movement patterns show that the sea cucumber, *A. japonicus* can move across the direction of flow, and can move both upstream and downstream along the direction of flow.

Viyakarn, V., Chavanich, S., Heery, E., & Raksasab, C. (2020). Distribution of sea cucumbers, *Holothuria atra*, on reefs in the upper Gulf of Thailand and the effect of their population densities on sediment microalgal productivity. *Estuarine, Coastal and Shelf Science*, 235, 106514 <https://doi.org/10.1016/j.ecss.2019.106514>.

Populations of sea cucumbers in Thailand have been declining because of overfishing in recent years; however, little is known about the possible long-term effects of this decline on the sea cucumber population and reef communities. The purpose of this study was to examine the distribution patterns and habitat compositions of *Holothuria atra* in the upper Gulf of Thailand. In addition, field and laboratory experiments were conducted to investigate the impact of sea cucumber density and feeding activity on the sedimentary microalgal community. The results showed that there was a correlation between the density of *H. atra* and substrate composition. The density of *H. atra* increased as the percentage of sand cover in the habitats increased. High concentrations of chlorophyll-a were detected in gut contents. In addition, results from field and laboratory experiments showed that when *H. atra* was absent, a high concentration of chlorophyll-a in the reef sediment was recorded. The higher the number of *H. atra*, the greater the capability to reduce the microalgal biomass in the sediment. Thus, *H. atra* plays an important role in recycling nutrient in reefs in the Gulf of Thailand, and consequently, a decline in the sea cucumber population may alter the reef community.

Wolfe, K., & Davey, M. (2020). Localised high-density population of a sea cucumber on a Malaysian coral reef. *Coral Reefs*, 39(1), 33-38 <https://doi.org/10.1007/s00338-019-01877-7>.

While tropical sea cucumbers are among the most conspicuous mobile invertebrates on coral reefs, information on their population biology and ecology is limited, particularly for dendrochirotid (suspension feeders). Here, we characterised a localised high-density population of the small and poorly described dendrochirotid, *Colochirus quadrangularis*, on a coral reef around Pom Pom Island, Malaysia. The high-density population was restricted to one site (Lobster Wall) on the south-eastern edge of Pom Pom Reef, with only 16 individuals found across all other sites. Average densities of this species were 669 +/- 76 ind m⁻² in the population epicentre, with a maximum of 1444 ind m⁻², and mean body length across the population of 2.78 cm (SD +/- 0.87). *Colochirus quadrangularis* showed preference for consolidated dead coral substrate while avoiding live corals. Asexual reproduction (transverse fission) was observed for the first time in this species along with cases of novel species interactions. There are no prior data for this species around Pom Pom Island, or elsewhere, to determine the drivers and impacts of this high-density *Colochirus* population, but these holothuroids may be an indication of the shifts in community states that can be expected for future coral reefs.

Woo, S. P., Kajihara, H., Byrne, M., & Fujita, T. (2019). Description and phylogenetic relationships of a new genus of sea cucumbers from Australia, with two new combinations (Holothuroidea, Stichopodidae). *Marine Biodiversity*, 49(6), 2499-2518 <https://doi.org/10.1007/s12526-019-00974-8>.

A new genus of Holothuroidea, *Notostichopus*, from Australia is described and its phylogenetic relationship examined. The new genus is based on two species within the family Stichopodidae, previously attributed to *Stichopus*. *Notostichopus* is characterized by the absence of rosette ossicles and the presence of table ossicles with at most one crossbeam in dorsal body wall. The two species revised here (*N. ludwigi* and *N. ellipes*) are distributed in the shallow, tropical, and temperate waters of Australia. Phylogenetic analyses indicate that this genus is closely related to the genera *Isostichopus* and *Stichopus* but is distinct based on ossicles and phylogenetic analyses. We describe the ossicle assemblages of both species.

Woo, S. P., Yasin, Z., Ismail, S. H., & Tan, S. H. (2013). The distribution and diversity of sea cucumbers in the coral reefs of the South China Sea, Sulu Sea and Sulawesi Sea. *Deep Sea Research Part II: Topical Studies in Oceanography*, 96, 13-18 <https://doi.org/10.1016/j.dsr2.2013.04.020>.

A study on the distribution and diversity of sea cucumbers in the coral reefs of the South China Sea, Sulu Sea and Sulawesi Sea was carried out in July 2009. The survey was done using wandering transect underwater with SCUBA. Twelve species of sea cucumber were found from four different families and nine genera. The most dominant family was Holothuriidae (five species), followed by Stichopodidae (three species), Synaptidae (three species) and Cucumariidae with only one species. The most dominant species found around the island was *Pearsonothuria graffei*, which can be found abundantly on substrate of dead corals in a wide range of depth (6–15m). The Sulawesi Sea showed a higher diversity of sea cucumber with seven different species compared to the South China Sea with only six different species and Sulu Sea with only two species. Ordination by multidimensional scaling of Bray–Curtis similarities clustered the sampling locations to three main clusters with two outgroups. Previous studies done indicated a higher diversity of sea cucumber as compared to this study. This can be indication that the population and diversity of sea cucumbers in the reef is under threat.

Yuan, X., Shao, S., Yang, X., Yang, D., Xu, Q., Zong, H., & Liu, S. (2016). Bioenergetic trade-offs in the sea cucumber *Apostichopus japonicus* (Echinodermata: Holothuroidea) in response to CO₂-driven ocean acidification. *Environmental Science and Pollution Research International*, 23(9), 8453-8461 <https://doi.org/10.1007/s11356-016-6071-0>.

Environmental issues facing Chemical, Biological, Radiological and Nuclear risks Ocean acidification (OA) caused by excessive CO₂ is a potential ecological threat to marine organisms. The impacts of OA on echinoderms are well-documented, but there has been a strong bias towards sea urchins, and limited information is available on sea cucumbers. This work examined the effect of medium-term (60 days) exposure to three pH levels (pH 8.06, 7.72, and 7.41, covering present and future pH variability) on the bioenergetic responses of the sea cucumber, *Apostichopus japonicus*, an ecologically and economically important holothurian in Asian coasts. Results showed that the measured specific growth rate linearly decreased with decreased pH, leading to a 0.42 %·day⁻¹ decrease at pH 7.41 compared with that

at pH 8.06. The impacts of pH on physiological energetics were variable: measured energy consumption and defecation rates linearly decreased with decreased pH, whereas maintenance energy in calculated respiration and excretion were not significantly affected. No shift in energy allocation pattern was observed in *A. japonicus* upon exposure to pH 7.72 compared with pH 8.06. However, a significant shift in energy budget occurred upon exposure to pH 7.41, leading to decreased energy intake and increased percentage of energy that was lost in feces, thereby resulting in a significantly lowered allocation into somatic growth. These findings indicate that adult *A. japonicus* is resilient to the OA scenario at the end of the twenty-first century, but further acidification may negatively influence the grazing capability and growth, thereby influencing its ecological functioning as an "ecosystem engineer" and potentially harming its culture output.

Zhang, Z., Zhou, J., Song, J., Wang, Q., Liu, H., & Tang, X. (2017). Habitat suitability index model of the sea cucumber *Apostichopus japonicus* (Selenka): A case study of Shandong Peninsula, China. *Marine Pollution Bulletin*, 122(1), 65-76 <https://doi.org/10.1016/j.marpolbul.2017.06.001>.

A habitat suitability index (HSI) model for the sea cucumber *Apostichopus japonicus* (Selenka) was established in the present study. Based on geographic information systems, the HSI model was used to identify potential sites around the Shandong Peninsula suitable for restoration of immature (<25g) and mature (>25g) *A. japonicus*. Six habitat factors were used as input variables for the HSI model: sediment classification, water temperature, salinity, water depth, pH and dissolved oxygen. The weighting of each habitat factor was defined through the Delphi method. Sediment classification was the most important condition affecting the HSI of *A. japonicus* in the different study areas, while water temperature was the most important condition in different seasons. The HSI of Western Laizhou Bay was relatively low, meaning the site was not suitable for aquaculture-based restoration of *A. japonicus*. In contrast, Xiaoheishan Island, Rongcheng Bay and Qingdao were preferable sites, suitable as habitats for restoration efforts.

Section III: Fisheries & Aquaculture

Abhishay, A. (2017). SEA CUCUMBER: Sustainable management of a seafood delicacy. *Spore*, (185), 16-17. Retrieved from www.jstor.org/stable/44242672.

Sea cucumber is becoming increasingly profitable in the Pacific, as fishing communities are helped to improve post-harvest processing and sustainably produce high-quality beche-de-mer. A variety of initiatives led by the Secretariat of the Pacific Community are boosting incomes from high-quality sea cucumber exports, whilst protecting against overexploitation.

Anonymous. (2015). South Australian scientists looking to enter Asian sea cucumber market. *Professional Fisherman*, 37(10), 12. Retrieved from <https://search.proquest.com/docview/1811894171?accountid=28258>.

South Australian scientists have been looking into expanding the local aquaculture industry by entering the lucrative Asian market for sea cucumbers. Sea cucumbers are an expensive and highly sought-after delicacy across Asia, and in China have been known to sell for up to \$200 a kilogram. They can be found in some Adelaide restaurants, but can cost more than \$150 per dish. Professor Graham Mair, from the

Australian Seafood Cooperative Research Centre, explained that they are looking into whether sea cucumbers could be exported from South Australia to Asia.

Bai, Y., Chen, Y., Pan, Y., Zhang, L., Liu, S., Ru, X., . . . Li, J. (2018). Effect of Temperature on Growth, Energy Budget, and Physiological Performance of Green, White, and Purple Color Morphs of Sea Cucumber, *Apostichopus japonicus*. *Journal of the World Aquaculture Society*, 49(3), 625-637 <https://doi.org/10.1111/jwas.12505>.

As an intertidal species, *Apostichopus japonicus* is subject to diel and seasonal temperature fluctuations. Color variation is a distinct characteristic of *A. japonicus*, and a new color morph, purple *A. japonicus*, was recently found on the coast of Rushan, Weihai City. This study was conducted to compare the performance of green, white, and purple color morphs of *A. japonicus* at different water temperatures to help improving aquaculture technology and management. In this study, green, white, and purple color morphs of juvenile *A. japonicus* (1.5 ± 0.1 g) were cultured at 10, 14, 18, 22, and 26 C for 60 d, according to the suitable temperature range for sea cucumber growth. Temperature was shown to have a significant effect on growth, energy budget, and physiology of sea cucumbers ($P < 0.05$). Specific growth rates, feed conversion efficiencies, and the proportion of energy allocated to growth of all three color morphs were optimal at 18 C. Activities of the enzymes related with oxidative stress, immune response, and digestion were determined. Superoxide dismutase (SOD) and trypsin activities generally reached a maximum in all three color morphs at 18 C. The purple color morph of *A. japonicus* was higher in growth rate, food conversion efficiency, and proportion of energy allocated to growth than green and white color morphs at 18 and 22 C, consistent with its higher trypsin and SOD activity, indicating the mutual effect of growth and physiology. At 18, 22, and 26 C, the green color morph had the highest level of lysozyme activity and purple color morph had the lowest, indicating possible infection by external pathogens of green color morph, which might be caused by high temperature. These results suggested that the optimum temperature for culture of the three color morphs was approximately 18 C, the purple had a better adaption to high temperature, and the green and white color morphs may be more susceptible to thermal stress than the purple color morph.

Baker-Medard, M., & Ohl, K. N. (2019). Sea cucumber management strategies: challenges and opportunities in a developing country context. *Environmental Conservation*, 46(4), 267-277 <https://doi.org/10.1017/s0376892919000183>.

Sea cucumbers play a critical role in maintaining healthy marine ecosystems. Sea cucumbers are also a key source of income for millions of small-scale fishers worldwide. The lucrative nature of this industry has led to severe reductions in sea cucumber populations in numerous regions globally. A large proportion of sea cucumber fisheries are located in developing countries, which present unique challenges to management, including addressing highly decentralized methods of extraction and processing, limited economic and technological resources for governance and, in many cases, a high dependency on sea cucumbers as a primary source of income for small-scale coastal fishers. In this review, we review the benefits and challenges of seven categories of sea cucumber management strategies used globally in developing countries, including gear restrictions, size and weight limits, effort and catch controls, temporal closures, area closures, value chain licensing and territorial use rights in fisheries. We conclude that sea cucumber management in developing countries could benefit from focusing regulatory solutions on narrowed parts of the value chain, coupling production-based

management strategies with processing and export regulations and providing avenues for local fishers to inform policy at the local, regional and national levels.

Bauer, J., Vázquez-Vera, L., Espinoza-Montes, A., Lorda, J., Beas-Luna, R., Vela-Gallo, C., & Reyes-Bonilla, H. (2019). Multi-Trophic Aquaculture of the Green Abalone *Haliotis fulgens* and the Warty Sea Cucumber *Apostichopus parvimensis*. *Journal of Shellfish Research*, 38(2), 455-461, 457
<https://doi.org/10.2983/035.038.0229>.

Around the world, abalone species are a highly valuable marine resource. In recent years, abalone fisheries in the Northeast Pacific have suffered massive mortalities because of environmental factors. Aquaculture has been proposed as a solution to stop the collapse of this multimillion-dollar resource. Moreover, it has been shown widely that coculturing two or more species can increase the productivity of the resources cultured. The aim of this study was to test whether the growth rates of the green abalone *Haliotis fulgens* would increase when cocultured with the warty sea cucumber *Apostichopus parvimensis*. Growth rates of juvenile abalone increased by 29% in the presence of medium densities of *A. parvimensis*; however, coculture settings are not common in the Northeast Pacific. To our knowledge, this is the first coculture reported of these two species. Thus, these findings provide relevant information to promote innovative strategies for sustainable production of food.

Beltran-Gutierrez, M., Ferse, S. C. A., Kunzmann, A., Stead, S. M., Msuya, F. E., Hoffmeister, T. S., & Slater, M. J. (2016). Co-culture of sea cucumber *Holothuria scabra* and red seaweed *Kappaphycus striatum*. *Aquaculture Research*, 47(5), 1549-1559
<https://doi.org/10.1111/are.12615>.

Commercially valuable sea cucumbers are potential co-culture species in tropical lagoon environments, where they may be integrated into established aquaculture areas used for seaweed farming. In the current study, wild-caught juvenile sea cucumbers, *Holothuria scabra*, and red seaweed *Kappaphycus striatum* were co-cultured on Zanzibar, United Republic of Tanzania. Sea cucumbers (97 g \pm 31 SD, n = 52) were cultured in mesh enclosures at initial cage stocking densities of 124 \pm 21 SD and 218 \pm 16 SD g m² under seaweed culture lines. Over 83 days, individual growth rate (1.6 g d⁻¹ \pm 0.2 SD) of sea cucumbers at low stocking density was significantly higher ($F = 8.292$, d.f. = 1, $P = 0.004$) than at high-stocking density (0.9 g d⁻¹ \pm 0.1 SD). Seaweed individual growth rates [6.27 (\pm 0.3 SE) g d⁻¹] were highest in co-culture with sea cucumber at low density but did not differ significantly from high sea cucumber density or seaweed monoculture treatments ($F = 3.0885$, d.f. = 2, $P = 0.2135$). Seaweed growth varied significantly ($F = 35.6$, d.f. = 2, $P < 0.0001$) with sampling period, with the final sampling period resulting in the highest growth rate. Growth performance for seaweed and sea cucumbers ($F = 3.089$, d.f. = 2, $P = 0.21$ and $F = 0.08$, d.f. = 1, $P = 0.777$ respectively), did not differ significantly between monoculture and co-culture treatments, yet growth in co-culture was comparable with that reported for existing commercial monoculture. Results indicate *H. scabra* is a highly viable candidate species for lagoon co-culture with seaweed. Co-culture offers a more efficient use of limited coastal space over monoculture and is recommended as a potential coastal livelihood option for lagoon farmers in tropical regions.

Carson, H. S., Ulrich, M., Lowry, D., Pacunski, R. E., & Sizemore, R. (2016). Status of the California sea cucumber (*Parastichopus californicus*) and red sea urchin (*Mesocentrotus franciscanus*)

commercial dive fisheries in the San Juan Islands, Washington State, USA. *Fisheries Research*, 179, 179-190 <https://doi.org/10.1016/j.fishres.2016.03.001>.

The San Juan Archipelago is the most intensely fished region of Washington State for echinoderms. Commercial dive fisheries for both the California sea cucumber (*Parastichopus californicus*) and red sea urchin (*Mesocentrotus franciscanus*) were characterized by high levels of harvest in the late 1980s and early 1990s. Here we evaluate stock performance of both species under the current fishery management regime using biomass estimates from a remotely-operated vehicle survey, time series of relative abundance from SCUBA index station surveys, and harvester log book data. We also report habitat associations of both species with depth and seafloor substrate composition. The fully-utilized quota for *Parastichopus* represents an 11.4% annual harvest rate on the current harvestable biomass estimate, and signs that this rate is unsustainable include: low density in shallow waters, a relative abundance that has remained depressed, and a continuous decline in catch-per-unit-effort (CPUE). Abundant *Parastichopus* below harvestable depths may not be of sufficient density to act as a consistent reservoir to replenish the shallows with recruits. The partially-utilized quota for *Mesocentrotus* represents a 3.9% annual harvest rate on the current biomass estimate, relative abundance has increased from a recent low, and there is no trend in CPUE. Numerous similarities between the two fisheries with regard to fleet composition and harvest history, coupled with diverging stock status, suggest that the sea cucumber fishery may be slower to recover from over-exploitation. Despite the challenges of co-managing the fisheries among several stakeholder groups, agreement has been reached to improve the long term viability of the *Parastichopus* fishery using reduced harvest quotas and a closure during peak spawning months, and to continue to closely monitor the *Mesocentrotus* fishery.

Chaiyamoorn, A., Tinikul, Y., Chaichotranunt, S., Poomtong, T., Suphamungmee, W., Sobhon, P., & Tinikul, R. (2020). Existence of two mature sequences of cubifrin neuropeptide and their effects on spawning in the sea cucumber, *Holothuria scabra*. *Aquaculture*, 519, 8 <https://doi.org/10.1016/j.aquaculture.2019.734753>.

NG-related neuropeptide is a myoactive neuropeptide identified in deuterostome invertebrates. Recent studies indicated that in sea cucumbers NG-related neuropeptide can stimulate muscle contraction and is involved in reproduction, including oocyte maturation and gamete spawning. In the present study, we first characterized the NG-related neuropeptide precursor, named cubifrin in *Holothuria scabra* and further investigated its effect on spawning. The deduced amino acid sequence of the neuropeptide precursor transcript provided five copies of two different mature sequences and were designated as cubifrin-Y and cubifrin-F based on C-terminal amino acid sequences of NGIWYamide and NGIWFamide. Interestingly, physiological bioassay demonstrated that the newly identified cubifrin-F was more potent in stimulating spawning with about 70% success rate, than cubifrin-Y that could stimulate only 10% spawning, compared with the control group. The in situ hybridization showed intense expression of cubifrin transcript within the wall of the ovarian tubule at late ovarian stages, suggesting that cubifrin was produced locally and stimulated spawning by causing contraction of the wall of ovarian tubule. Taken together, gained knowledge provided important insight into spawning mechanisms which could be applied by using these cubifrin amides to stimulate spawning of broodstocks for seed and larval productions in aquaculture of this sea cucumber species.

Charan-Dixon, H., Goldstien, S. J., Vanderhaven, B. J., Halafih, T., Tuiano, T. L., Gaw, S., & Glover, C. N. (2019). Effects of traditional fishing techniques on internal organ regeneration, physiology, and biochemistry in the tropical sea cucumber *Stichopus horrens*. *Journal of Experimental Marine Biology and Ecology*, 510, 15-22 <https://doi.org/10.1016/j.jembe.2018.09.007>.

The sea cucumber *Stichopus horrens* is an important resource in the Kingdom of Tonga. Domestically, there are two fisheries; one at a commercial scale and one for subsistence purposes. Both fisheries involve harvesting all viscera (digestive tract, gonads and respiratory tree) through a lateral body wall incision, although only the digestive tract and gonads are consumed. Under the right conditions the sea cucumber can survive organ harvest and regenerate the viscera. This study investigated the biochemical and physiological consequences of organ regeneration by comparing sham (longitudinal body wall incision without organ removal) and excised (internal tissues removed after incision) sea cucumbers to control (handled but not incised) animals. Biochemical measurements of lactate, glucose, and glycogen showed that body wall energy reserves were depleted in both sham and excised animals relative to controls at the Day 10 measurement. The presence of an energy substrate depletion in sham animals indicated an effect related to loss of body wall integrity, rather than internal organ regeneration. Although the regeneration of digestive and respiratory organs was rapid, oxygen consumption rate and ammonia excretion rate were unchanged in excised and sham animals relative to controls. These data suggest that *S. horrens* can survive the internal organ harvest associated with subsistence fishing and regenerate excised tissues rapidly. However, this comes at an energetic cost that is likely to affect growth and reproduction. Fisheries management measures such as the implementation of a minimum rest period between harvests may promote the sustainability of this important fishery.

Chary, K., Aubin, J., Sadoul, B., Fiandrino, A., Coves, D., & Callier, M. D. (2020). Integrated multi-trophic aquaculture of red drum (*Sciaenops ocellatus*) and sea cucumber (*Holothuria scabra*): Assessing bioremediation and life-cycle impacts. *Aquaculture*, 516, 17 <https://doi.org/10.1016/j.aquaculture.2019.734621>.

Environmental sustainability of aquaculture is a complex issue involving effects at local (e.g. benthic deterioration), regional (e.g. eutrophication) and global (e.g. catches for feed production) scales as a consequence of farming operations (e.g. waste emissions) and industrial processes involved in the product value chain. Integrating these effects using a holistic and multi-scale framework is essential to assess the environmental sustainability of innovative production systems such as Integrated Multi-Trophic Aquaculture (IMTA), in which organisms of different trophic levels are co-cultured on the same farm to minimize aquaculture waste. The environmental performances of theoretical production scenarios of red drum (*Sciaenops ocellatus*) sea cage monoculture and an open-water IMTA co-culturing of red drum and sea cucumber (*Holothuria scabra*) were assessed with mathematical models at local and global scales. First, the particulate waste bioremediation potential of sea cucumber production was estimated using an individual-based bioenergetic model. Second, environmental impacts of the monoculture and the IMTA systems were estimated and compared using life cycle assessment (LCA), calculated per kg of edible protein and t of product, including uncertainty analysis. Given the current limits to stocking density observed for sea cucumbers, its co-culture in sea cages suspended beneath finfish nets may decrease slightly (by 0.73%) farm net particulate waste load and benthic impact. The monoculture and IMTA showed little difference in impact because of the large difference in production scales of finfish and sea cucumber species. Removing 100% of finfish feces particulate waste requires cultivating sea cucumber at scale similar to that of finfish (1.3 kg of sea cucumber per kg of finfish). Nonetheless, LCA showed trends in IMTA performance: lower eutrophication impact and net primary

production use but higher cumulative energy demand and climate change impacts, generating an impact transfer between categories. Intensification of sea cucumber culture could increase local and global environmental benefits, but further research is necessary to design rearing units that can optimize production and/or bioremediation and that can be practically integrated into existing finfish monoculture units. The methodology defined here can be a powerful tool to predict the magnitude of environmental benefits that can be expected from new and complex production systems and to show potential impact transfer between spatial scales. We recommend applying it to other IMTA systems and species associations and including socio-economic criteria to fully assess the sustainability of future seafood production systems.

Chen, X. R., Mai, K. S., Zhang, W. B., Tan, B. P., Yuan, Y. H., Wang, Q. C., . . . Zhao, L. M. (2018). Dietary supplements of guanosine improve the growth, non-specific immunity of sea cucumber, *Apostichopus japonicus* Selenka, and its resistance against *Vibrio splendidus*. *Aquaculture Nutrition*, 24(1), 571-578 <https://doi.org/10.1111/anu.12590>.

The growth response, non-specific immune activities and disease resistance were measured in sea cucumber, *Apostichopus japonicus* Selenka (initial average weight 6.80 ± 0.10 g), when fed diets supplemented with graded levels of guanosine from the guanosine-5'-monophosphate disodium (GMP) at 0 (control), 0.3, 0.6 and 1.2 g/kg for 8 weeks. The results showed that GMP supplemented at 0.6 and 1.2 g/kg significantly enhanced the growth of sea cucumber. Sea cucumber fed a diet with 0.6 g/kg of GMP had significantly higher intracellular superoxide anion production, nitric oxide synthase activity, lysozyme activity and the total superoxide dismutase (T-SOD) activity than those in control group ($p < .05$). Increased lysozyme activity and T-SOD activity were also found in sea cucumber fed GMP at 1.2 g/kg. Moreover, there was significantly lower cumulative mortality after the disease challenge in sea cucumber fed the diets with 0.6 and 1.2 g/kg GMP than that in control and 0.3 g/kg GMP groups ($p < .05$), and no significant difference was observed between 0.6 and 1.2 g/kg GMP groups. These results suggested that feeding GMP at a dose of 0.6 g/kg could enhance growth, non-specific immunity of sea cucumber as well as its resistance against *Vibrio splendidus*.

Conand, C. (2018). Tropical sea cucumber fisheries: Changes during the last decade. *Marine Pollution Bulletin*, 133, 590-594 <https://doi.org/10.1016/j.marpolbul.2018.05.014>.

Tropical sea cucumber fisheries are generally traditional, small-scale, multispecies and poorly managed. Many recent studies have improved our knowledge on the biology and ecology of the commercially important species; the main results are analysed and the remaining gaps discussed. The fisheries and the patterns of trade changes during the last decade are presented from the data available and confirm overexploitation in the traditional Indian Ocean and West Pacific countries and territories. Several Latino-American countries now have active fisheries. Despite the management and conservation issues which have recently received more attention at international, regional and national levels, more measures are still needed at all these levels, to ensure sustainable exploitations of these resources.

Dai, F., Zhuang, Q., Zhao, X., Shao, Y., Guo, M., Lv, Z., . . . Zhang, W. (2020). Green fluorescent protein-tagged *Vibrio splendidus* for monitoring bacterial infection in the sea cucumber *Apostichopus japonicus*. *Aquaculture*, 523, 735169 <https://doi.org/10.1016/j.aquaculture.2020.735169>.

Vibrio splendidus is an important opportunistic pathogen that infects many important marine animals; for example, it can cause skin ulcer syndrome in the sea cucumber *Apostichopus japonicus*. In this study, a green fluorescent protein (GFP)-tagged *V. splendidus* was constructed by ligating GFP into the plasmid pET28a. The growth of GFP-tagged *V. splendidus* showed no difference from that of the wild type strain. The distribution of *V. splendidus* in various tissues after artificial infection was determined by colony counting. When *V. splendidus* infected *A. japonicus* at a concentration of 5.0×10^7 CFU·mL⁻¹, *V. splendidus* could be detected in the tissues of respiratory tree, intestine, body wall, tentacle, and muscle, with a level over 1.0×10^6 CFU·g⁻¹ at 48 h post-infection and with *V. splendidus* remaining in coelomic fluid at a level of 2.1×10^9 CFU·mL⁻¹. Green fluorescence was only observed in the respiratory tree and intestine in a paraffin section at 48 h of infection, which indicated that *V. splendidus* could adhere to these two tissues. Moreover, *V. splendidus* could adhere to coelomocytes of *A. japonicus* but it could poorly internalize coelomocytes in vitro. The adherence of *V. splendidus* to coelomocyte was dependent on the β -integrin on the surface of coelomocytes.

Dominguez-Godino, J. A., & Gonzalez-Wanguemert, M. (2020). Habitat associations and seasonal abundance patterns of the sea cucumber *Holothuria arguinensis* at Ria Formosa coastal lagoon (South Portugal). *Aquatic Ecology*, 54(1), 337-354 <https://doi.org/10.1007/s10452-020-09746-0>.

Sea cucumbers have an important economic value and high demand. Despite that, there is a lack of knowledge about their biology, ecology and habitat distribution patterns, which is very important for sea cucumber stock management, establishment and sizing of no-take zones, restocking actions and selection of grow-out areas. This work aimed to determine the density, abundance and habitat associations of *Holothuria arguinensis* for a better understanding of its distribution along the coastal lagoon Ria Formosa and to select suitable areas for grow-out. In the duration of a year, monthly visual censuses were performed in two locations at Ria Formosa along the intertidal zone. The number and length of *H. arguinensis* ' individuals found were registered, and the coverage of algae and seagrass was estimated. It was found that *H. arguinensis* was distributed along the lower intertidal zone, linked to *Zostera noltii* meadows on muddy and sandy bottoms. These areas showed the densest population and the largest sizes of *H. arguinensis*. However, during the warmer months, *H. arguinensis* seemed to migrate to deeper waters in the channels, to avoid exposition to high temperatures and solar/UV irradiance during low tides. Areas located in the lower intertidal zone with *Z. noltii* meadows on sand-muddy bottoms should be selected for *H. arguinensis* grow-out sites.

Dominguez-Godino, J. A., Santos, T. F., Pereira, H., Custodio, L., & Gonzalez-Wanguemert, M. (2020). Seagrass debris as potential food source to enhance *Holothuria arguinensis*' growth in aquaculture. *Aquaculture Research*, 13 <https://doi.org/10.1111/are.14495>.

Holothuria arguinensis aquaculture started to be developed in 2014, being the first sea cucumber species from Europe. However, some aspects of its aquaculture biotechnology, such diets, need to be assessed. This work aimed to evaluate seagrass debris of *Zostera noltii* and *Cymodocea nodosa* as food source for broodstock maintenance in tanks, during breeding periods. The given feed rations per tank were calculated as the 30% of the total sea cucumber biomass in each tank and reviewed each week. Then, feed rations of seagrass and sediment were calculated from this value, according to the following percentages: 40% sediment, 15% *Z. noltii*, 40% *Z. noltii*, 15% *C. nodosa* and 40% *C. nodosa*. *H. arguinensis* growth, feeding rate and nutritional value were assessed under these diets. *H. arguinensis* fed with 40% of *Z. noltii* showed the highest growth (specific growth rate = 0.09 +/- 0.06%/day, absolute

growth rate = 0.11 +/- 0.07 g/day) increasing their final weight in 5.86 +/- 3.57% in 57 days. However, the individuals fed with *C. nodosa* showed a negative growth. *H. arguinensis* showed a reduction in its feeding rate as the organic matter content in the diets increased. *H. arguinensis* did not show any important change on proximate composition, protein, lipid, mineral contents and fatty acids profile among the feeding groups, or in comparison with the individuals collected from wild habitat. Therefore, *H. arguinensis* could be fed with *Z. noltii* debris during tanks maintenance along breeding period, ensuring its growth and maintaining its nutritional profile.

Domínguez-Godino, J. A., Slater, M. J., Hannon, C., & González-Wangüermert, M. (2015). A new species for sea cucumber ranching and aquaculture: Breeding and rearing of *Holothuria arguinensis*. *Aquaculture*, 438, 122-128 <https://doi.org/10.1016/j.aquaculture.2015.01.004>.

Multi-species sea cucumber fisheries, including the species *Holothuria arguinensis*, have developed recently in the North-eastern Atlantic and Mediterranean Sea. In this context, the current study evaluated the potential use of *H. arguinensis* in aquaculture and to enhance natural populations, describing the embryonic and larval development for a better understanding and application in marine conservation and population genetics. Wild broodstock collected in Ria Formosa (37°0'33.92"N, 7°59'44.99"W; Faro, South Portugal) was induced to spawn using established methodology of thermal stimulation from June to August. The larval development under controlled conditions exhibited the classic five stages described for most aspidochirote holothurians, reaching the juvenile stage after 18 days post-spawning. Low mortality was registered during the pelagic larval stage, however high mortality (85–95%) was registered at doliolaria and juvenile stages. Results indicate that *H. arguinensis* is suited to hatchery rearing for aquaculture and enhancement of natural populations. Nevertheless, as this is the first European sea cucumber species reproduced in a hatchery, further research is required to improve the survival of post-settlement stages and optimize the rearing of juveniles.

Eriksson, H., & Byrne, M. (2015). The sea cucumber fishery in Australia's Great Barrier Reef Marine Park follows global patterns of serial exploitation. *Fish and Fisheries*, 16(2), 329-341 <https://doi.org/10.1111/faf.12059>.

Tropical sea cucumber fisheries follow a predictable pattern of serial depletion. Overfishing is exacerbated in developing countries where management systems lack capacity to control large numbers of fishers influenced by poverty. In contrast, the tropical sea cucumber fishery in Australia's World Heritage listed Great Barrier Reef Marine Park (GBRMP) is operating in a developed high-income country with relatively few licensed fishers to manage. The development of this fishery is reviewed here in a meta-analysis of catches from 1991 to 2011. The fishery expanded to replace high-value teatfish species (*Holothuria whitmaei* and *H. fuscogilva*), fished heavily in initial stages of the fishery, with newly commercialized medium-value species such as burying blackfish (*Actinopyga spinea*) and curryfish (*Stichopus herrmanni*). These two species now constitute 80% of total catch. The annual average catch of burying blackfish was 208 tonnes years 2004-11 and curryfish catches increased rapidly at an average annual pace of 200% from 2007-11. This serial harvest pattern occurred in the absence of baseline studies and without independent resource assessments, information required to inform relevant harvest predictions and to determine fishery impacts. This situation does not support ecologically relevant and adaptive decision-making in management and the unfolding catch patterns in the GBRMP follow those in low-income developing countries. The missing knowledge and lack of data serve as arguments to support precautionary reductions in harvests and extending fallow periods in fishing zones.

Eriksson, H., Conand, C., Lovatelli, A., Muthiga, N. A., & Purcell, S. W. (2015). Governance structures and sustainability in Indian ocean sea cucumber fisheries. *Marine Policy*, 56, 16-22
<https://doi.org/10.1016/j.marpol.2015.02.005>.

Good governance is paramount to the sustainability of fisheries, and inclusiveness of stakeholder groups has become the centerpiece in the ethos of managing small-scale fisheries. Understanding the effect of governance network structures on fishery sustainability can help guide governance to achieve desired outcomes. Data on resource users, fishing methods, governance networks and classifications of stock health were compiled for 17 sea cucumber fisheries in the Indian Ocean. The subjective influence of the actors and the complexity of governance networks on the health of wild stocks were analyzed. The fisheries differed widely in their resource users, fishing methods and governance networks. Little correspondence was found between the number of nodes in the governance networks and the health (exploitation status) of wild stocks. Government entities dominated the networks but neither their relative influence in the networks nor their proportionate contribution to the number of entities in the networks greatly affected stock health. These findings do not refute the benefits of inclusive governance, but rather suggest that multiple other factors (e.g. inadequate regulations, weak enforcement, high number of fishers) are also likely to play a role in influencing sea cucumber fishery sustainability. These factors must be tackled in tandem with good governance.

Galimany, E., Baeta, M., & Ramón, M. (2018). Immune response of the sea cucumber *Parastichopus regalis* to different temperatures: implications for aquaculture purposes. *Aquaculture*, 497, 357-363 <https://doi.org/10.1016/j.aquaculture.2018.08.005>.

Interest in sea cucumber aquaculture is increasing worldwide for both consumption and ecological purposes. In the NW Mediterranean there is only one commercially exploited and edible sea cucumber, *Parastichopus regalis*, whose muscles are considered a culinary delicacy. With the aim to understand the potential for *P. regalis* to be grown in aquaculture facilities, we studied its resistance to the high temperature conditions that characterize the Mediterranean mariculture facilities. The immune response of adult *P. regalis* exposed to different temperatures (18 °C, 23 °C and 28 °C) was compared to the response to its natural environmental conditions (13 °C) during a 2-week period. Moreover, the immune response after a 1-week recovery period was also investigated. Mortality and coelomocyte characteristics and functions were analyzed, i.e. phagocytosis and dead coelomocytes. Results showed that 90% of the sea cucumbers exposed to 28 °C died before 48 h and at 23 °C they had 50% survivorship after 2 weeks of exposure. The proportion of coelomocyte types did not change during the study for animals exposed to 18 °C or 23 °C. Coelomocyte density increased throughout the experiment at 23 °C for sea cucumbers exposed to both control and high temperature. However, high temperature *P. regalis* exposed to 23 °C had significantly less phagocytic and dead coelomocytes during the two weeks of exposure. After a 1-week recovery period, the differences found between temperatures disappeared, except that the phagocytic capacity of the coelomocytes exposed to 23 °C was still lower than controls. In summary, *P. regalis* seems to have a maximum thermal tolerance below 23 °C, above which their survival is compromised. Thus, the use of *P. regalis* for aquaculture purposes should be constrained to areas where temperatures do not exceed 23 °C throughout the year.

Gao, L., He, C., Bao, X., Su, H., Gao, X., Li, Y., . . . Ma, Z. (2017). Comparative study of water environment variation in the industrial aquaculture system of sea cucumber *Apostichopus japonicus*. *Aquaculture Research*, 48(4), 1787-1798 <https://doi.org/10.1111/are.13016>.

This study investigated the microbial community, water quality, bacterial densities and growth performance in the industrial aquaculture system of sea cucumber *Apostichopus japonicus* without water exchange. Six treatments were set including, C (control treatment without sea cucumber culturing), S (small individual treatment), B (big individual treatment), Sd (small individual treatment with high density), Ss (small individual treatment adding carbohydrate source) and Sb (small individual treatment adding effective microorganisms). A total of 27916?32236 optimized reads and 564?742 operational taxonomic units (OTUs) were obtained from each samples. The phylum Proteobacteria, Actinobacteria, Bacteroidetes and Cyanobacteria predominated, representing 69.01?97.21% of the bacterial communities in the water samples. Cluster analysis and principal component analysis (PCA) showed that higher similarity was observed among S, Sd, Ss and Sb. The densities of TB and *Vibrio* in Ss were significantly higher than those in the other culture treatments after the 7th day. The concentrations of NH₄-N, NO₂-N, NO₃-N and PO₄-P in Ss and Sb were relatively lower than the other treatments. Conclusively, no deterioration was found in the water environment parameters during the 21-day culture period without water exchange, indicating that low-level water exchange protocol may be applied to the industrial aquaculture system. Based on the effects of different operations on culture system, industrial aquaculture is proved to be a viable way to rear sea cucumber.

González-Wangüemert, M., Domínguez-Godino, J. A., & Cánovas, F. (2018). The fast development of sea cucumber fisheries in the Mediterranean and NE Atlantic waters: From a new marine resource to its over-exploitation. *Ocean & Coastal Management*, 151, 165-177 <https://doi.org/10.1016/j.ocecoaman.2017.10.002>.

In the last years, sea cucumbers consumption is increasing in the Asian region, as consequence more than 70% of the sea cucumber fisheries around the world are fully/over exploited or depleted. Therefore, Asiatic markets are looking for new target species mainly from Mediterranean Sea and NE Atlantic Ocean. In this paper, we establish the state of the art of the sea cucumber fisheries in this geographical area, analyze the negative effects of over-exploitation on five species (*Holothuria polii*, *Holothuria tubulosa*, *Holothuria mammata*, *Holothuria arguinensis* and *Parastichopus regalis*) through three study cases well documented in Turkey, Spain and Portugal, assess the *Holothuria forskali* fishery under regulation in NW Spain, and finally suggest some management measures to improve, and/or develop a right regulation for the exploitation of these new resources. The current fishery pressure has already provoked some important negative effects on wild populations of sea cucumbers from Mediterranean and NE Atlantic waters, such as decrease in density, abundance, and genetic diversity, loss of the biggest individuals, increase on the prevalence of some diseases, and even “local extinction” in some places. Most of the countries where these species are being caught, have not legislation for these fisheries. Therefore, an improvement in the biological knowledge of these new target species is mandatory to effectively suggest right management measures to protect stocks, and to favor the development of national, and international legislation to prevent illegal catches. Existing legislation, e.g., that from Galicia (NW Spain) or Turkey, could be used as a starting point to develop a more effective set of rules. Fishery on sea cucumbers by using scuba diving equipment should be forbidden or better regulated because of its heavy impact on wild populations. Current increasing demand on sea cucumbers should be satisfied by aquaculture production; its biotechnology on species from the Mediterranean and NE Atlantic is being already developed with increasing success, which will allow a

reduction of fishery pressures on wild populations of these new target species, and the possibility to develop restocking programs.

Guo, X., Zhang, Q., Zhang, X., Zhang, J., & Gong, J. (2015). Marine fungal communities in water and surface sediment of a sea cucumber farming system: habitat-differentiated distribution and nutrients driving succession. *Fungal Ecology*, 14, 87-98
<https://doi.org/10.1016/j.funeco.2014.12.001>.

The planktonic and benthic fungi in a sea cucumber farming system were simultaneously investigated on three sampling dates. Analyses of SSU rRNA gene libraries of four samples revealed 131 fungal operational taxonomic units, of which 58 % were potentially novel. Chytridiomycota, Blastocladiomycota and Monoblepharidomycota were detected only from sediment, whereas ascomycetes and basidiomycetes dominated in sediment and water, respectively. Cryptomycota phylotypes were detected in both water and sediment samples. Based on terminal-restriction fragment length polymorphisms, distinct succession and contrasting community structure were found between planktonic and benthic habitats. Redundancy analysis indicated that the concentration of dissolved silicate in surface water and N:P in porewater were the most significant abiotic variables shaping the planktonic and benthic communities, respectively. This study indicates that plankton and benthos are distinct habitats for fungal distribution even in shallow coastal systems, and nutrients and stoichiometric ratios play important roles in driving succession of fungal communities.

Hair, C., Mills, D. J., McIntyre, R., & Southgate, P. C. (2016). Optimising methods for community-based sea cucumber ranching: Experimental releases of cultured juvenile *Holothuria scabra* into seagrass meadows in Papua New Guinea. *Aquaculture Reports*, 3, 198-208
<https://doi.org/10.1016/j.aqrep.2016.03.004>.

Hatchery-cultured juveniles of the commercial holothurian, sandfish (*Holothuria scabra*), were used for release experiments in a variety of marine habitats under traditional marine tenure near Kavieng, Papua New Guinea (PNG). Juveniles of approximately 4g mean weight were released inside 100m² sea pens installed within seagrass meadows nearby partner communities, under the care of local 'wardens'. Within each sea pen, varying levels of protection (free release, 1-day cage and 7-day cage) were provided at release in order to determine if short-term predator exclusion improved survival. Ossicles of juvenile sandfish were tagged with different fluorochromes for each treatment and sandfish survival and growth was recorded after release. A range of biophysical parameters were recorded at the four sites. Contrary to expectations, short-term cage protection did not lead to higher survival at three sites, while a fourth site, despite meeting all considered criteria for suitable release habitat, experienced total loss of juveniles. There were significant differences in mean weight of juveniles between sites after four months. Multivariate analysis of biophysical factors clearly separated the sea pen habitats, strongly differentiating the best-performing site from the others. However, further research is needed to elucidate which biophysical or human factors are most useful in predicting the quality of potential sea ranch sites. Methods developed or refined through these trials could be used to establish pilot test plots at potential ranching sites to assess site suitability and provide guidance on the level of animal husbandry required before commencing community sea ranching operations in New Ireland Province, PNG.

Hajas, W., Hand, C., Duprey, N., Lothead, J., & Deault, J. (2011). Using production models with new and developing fisheries: A case study using the sea cucumber *Parastichopus californicus* in British Columbia, Canada. *Fisheries Research*, 110(3), 421-434
<https://doi.org/10.1016/j.fishres.2011.05.009>.

Data from four experimental sea cucumber (*Parastichopus californicus*) fishing areas in British Columbia are used to estimate productivity that has occurred during the experiments. The estimates are made by incorporating the data into a Bayesian model describing both productivity and survey-error. The Bayesian nature of the analyses enables the estimated productivity to be expressed probabilistically. The estimated productivities that have occurred in the data can serve as a guide for managing commercial sea cucumber fisheries for stocks with similar characteristics to those in the experiment. Since productivities are presented probabilistically, they can, under certain conditions, be used to generate a level of confidence that a particular harvest-management strategy is sustainable. Thus far, the applicability of the analyses is limited by the range of data that has occurred during the experiment. All the stocks began the experiment in a near-virgin state. The lowest level of abundance that has occurred so far is approximately 28% of the virgin-value. To estimate productivity for lower levels of abundance would rely on mathematical models to extrapolate the current results. As the experiments continue, it is expected that data for stocks that are more depleted will be collected and that the revised analyses will be applicable over a wider range of conditions.

Hou, H., Shao, S., Zhang, Y., Kang, H., Qin, C., Sun, X., & Zhang, S. (2019). Life cycle assessment of sea cucumber production: A case study, China. *Journal of Cleaner Production*, 213, 158-164
<https://doi.org/10.1016/j.jclepro.2018.12.141>.

Environmental pollution caused by aquaculture production has become an increasing problem in China. In the present study, life cycle assessment (LCA) was used to evaluate and analyze the environmental impact of sea cucumber (*Apostichopus japonicas*) production in Dalian as an example for Chinese aquaculture cleaner production (CP) research. The production process included three stages: feeding, farming, and processing. In addition, to analyze the key factors that influence the environmental performance, the feeding stage was divided into breeding and culturing phases; the farming stage was divided into planting and harvesting phases; and the processing stage comprised sorting, stewing, salting, and freezing phases. The popular LCA software tool GaBi and the CML-2001 method for a problem-oriented approach to LCA were used to calculate the environmental impact at each stage and phase of the sea cucumber production process. The results showed that the normalization results of LCA in the three stages were 1.21 E-08 yr, 2.44 E-10 yr, and 1.11 E-09 yr, respectively. The feeding stage had the greatest environmental impact, because high levels of electricity, fossil fuel, and water are required to maintain the culturing water temperature and oxygen status for juvenile sea cucumbers. Moreover, from the analysis of the LCA normalization results in each phase, we found that the marine aquatic ecotoxicity potential (MAETP) was the largest contributor to the environmental impact, with electricity use, water requirements, and fossil fuel consumption as the key factors that affected the results. Improvement measures toward CP in each stage were proposed, such as energy substitution (nuclear energy, natural gas, or solar-energy), water reduction (microecologics), and bio-waste management (bio-waste recycling). These measures will provide a reference for policy makers and enterprise managers to enact strategies to improve the sustainability of Chinese aquaculture.

Hou, Y.-R., Sun, Y.-J., Gao, Q.-F., Dong, S.-L., Wen, B., & Yu, H.-B. (2017). Optimal mud to sand ratios in sediment for sea cucumber aquaculture as revealed by carbon stable isotopes. *Aquaculture Environment Interactions*, 9, 281-291 <https://doi.org/10.2307/26391987>.

Sediment, which is central as a sink for organic material and nutrient cycling, provides habitat for feeding, resting, and nesting of sea cucumbers in aquaculture systems. We conducted a 2 mo experiment to investigate the optimal sea mud to sand ratios in sediment for sea cucumber *Apostichopus japonicus* (Selenka, 1867) aquaculture. Sea mud (<0.08 mm) and sand (0.08–0.5 mm) were used to prepare 5 different sediment formulations with different sea mud:sand ratios: 3:1, 1:1, 1:3, 1:0, and 0:1. Sea cucumbers were cultured in 20 fiberglass tanks (50 l) with 5 cm thick sediment spread on the bottom. Results showed that the specific growth rate of sea cucumbers and the contribution of the seaweed *Sargassum muticum* to food uptake by sea cucumber in the 3:1 ratio group were significantly higher than in the 1:0, 0:1, and 1:3 ratio groups, while no significant differences were observed between the 3:1 and 1:1 ratio groups. Furthermore, the total nitrogen, total organic carbon, and ammonium contents of the 1:1 and 3:1 ratio groups significantly decreased with time. These findings suggest that sea mud:sand ratios of 1:1 and 3:1 are optimal in sediment for *A. japonicus* aquaculture and effectively promote growth and bioremediation.

Hu, C., Li, H., Xia, J., Zhang, L., Luo, P., Fan, S., . . . Wen, J. (2013). Spawning, larval development and juvenile growth of the sea cucumber *Stichopus horrens*. *Aquaculture*, 404-405, 47-54 <https://doi.org/10.1016/j.aquaculture.2013.04.007>.

Tropical commercial sea cucumber *Stichopus horrens* is extensively distributed throughout the tropical Indo-Pacific region, and wild stocks are severely depleted over the past decade. This study firstly presented preliminary results on the spawning, the development of larvae and the growth of the juvenile of *S. horrens* in Xisha Islands. It was proved that *S. horrens* followed a predictable lunar spawning periodicity and might reproduce throughout the year in Xisha Islands. Dry stimulation was a simple and efficient way to induce *S. horrens* to spawn. The mean quantity of spawned eggs was 1.37×10^6 (s.e.= 2.09×10^6 , n=8), and the mean egg diameter was $114 \mu\text{m}$ (s.e.= $2.8 \mu\text{m}$, n=8). *S. horrens* developed from fertilized eggs to pentactula larval after 19–27 days at 25–27°C. From oosperm to settled juvenile, the survival rate of *S. horrens* was 1.0%–6.83% when enough live microalgae were supplied. The mean growth rate of juveniles was 0.4 mm per day and the survival rate was about 23.3%–50.5% during 80 days culture after settlement. Then some juveniles of *S. horrens* were further cultivated in tanks and majority were released in the wild. Ongoing observations showed good survival and growth of juvenile in the wild. The study indicates *S. horrens* are amenable to culture using standard techniques which may also be applied on the culture of other tropical species. They exhibit a relatively quick growth both in indoor and wild culture. Furthermore, the test results support possible aquaculture and stock restoration using hatchery produced stocks.

Hu, Y. N., Han, Y. Z., Wang, L. S., Bai, Z. A., Shohel, R. M., Jiang, Z. Q., & Ren, T. J. (2019). Toxicity effects of different dietary selenium forms on sea cucumber, *Apostichopus japonicus*. *Aquaculture Reports*, 15, 6 <https://doi.org/10.1016/j.aqrep.2019.100209>.

This experiment was conducted to determine the toxicological effect of selenomethionine (Se-met) and biofermenting Selenium (Se-bio) supplementation with basal diet to investigate growth performance, bioaccumulation and non-specific immune function in sea cucumber, (*Apostichopus japonicus*). Three

groups of sea cucumbers in triplicate were given basal diet or supplemented with selenium (Se) from Se-met or Se-bio for 30 days. No significant difference in survival was observed among three treatments, but both groups fed with Se exhibited significant inhibition in body weight gain, specific growth rate and protein efficiency ratio compared to control group, meanwhile, feed conversion rate was significantly ($P < 0.05$) higher than control group. The Se content in the body wall significantly ($P < 0.05$) increased in Se-treated animals as compared with the control group. Antioxidant enzyme activities (superoxide dismutase and total antioxidant capacity) were significantly ($P < 0.05$) lower in body wall of sea cucumber fed Se-met supplemented diet compared to other groups. Se-met group resulted in significantly lower level of lysozyme activity compared to the control group. Therefore, when comparing similar doses from different Se sources, responses in bioaccumulation and nonspecific immune function were markedly greater in Se-met as opposed to Se-bio.

Jontila, J. B. S., Monteclaro, H. M., Quintio, G. F., Santander-de Leon, S. M., & Altamirano, J. P. (2018). Status of sea cucumber fishery and populations across sites with different levels of management in Palawan, Philippines. *Ocean & Coastal Management*, 165, 225-234 <https://doi.org/10.1016/j.ocecoaman.2018.08.025>.

This study was conducted to investigate the sea cucumber fishery and compare populations between exploited and unexploited sites. Three islands were selected, the Arrecife Island as the unexploited site and the Johnson and Green Islands representing the exploited sites. In each site, sea cucumber species richness, diversity and densities were assessed by laying as much as 15 transects (50 m × 5 m) per habitat in each island. Differences in species richness, diversity and relative densities across sites and habitats were tested using a Two-way Analysis of Variance (ANOVA) and Tukey test for post hoc comparisons. An interview with gatherers, key informants and focus group discussions were also conducted to gather information on the sea cucumber fishery and its management. Results showed that the unexploited site had a higher species richness (14 vs. 7 and 7). Relative density of species was also higher in the unexploited site at 1245 ind ha⁻¹ while it was only 78 and 39 ind ha⁻¹ in exploited sites ($p < 0.05$). Interviews and a focus group discussion revealed that national regulations on permit system and size limits were not enforced at the local level and that gatherers had low levels of awareness regarding regulations on sea cucumber harvest. Current management measures appear to be ineffective and insufficient, leaving the sea cucumbers in areas open to exploitation at risk of depletion. Given that sea cucumbers provide substantial income to local communities, the depletion of this resource could compromise the livelihood of people in island communities that rely heavily on marine resources for living. Thus, this study highlights the need to review national policies on sea cucumber fishery and place the management at the local level.

Kim, Y. D., Shin, Y. K., Park, M. S., Lee, H. J., Hur, J. W., Park, M. A., . . . Choi, J. S. (2020). A Study on Polyculture of Oyster (*Crassostrea gigas*), Sea Squirt (*Halocynthia roretzi*) and Sea Cucumber (*Apostichopus japonicas*) under a Hanging Culture System. *Turkish Journal of Fisheries and Aquatic Sciences*, 20(5), 387-400 https://doi.org/10.4194/1303-2712-v20_5_07.

This study aimed to develop a novel polyculture technology for sea cucumber using seabed under hanging culture farms of oyster and sea squirt. The survival, growth and sheltering rates of sea cucumber seedlings were determined. The habitation rate of sea cucumber was 20% with 20.8 - 31.0 animals per shelter. The density was calculated to be 3 animals per m² (m² × 3 × 900 = 2,700 animals), which shows that approximate 2,000 kg of sea cucumbers could be produced from 1 ha

(10,000 m²) x 200 g; when one individual grows every m²). Even though seabed under the hanging culture farms is muddy and not suitable for rearing sea cucumbers, the results of this study showed that polyculture of sea cucumber is possible using the oyster and sea squirt hanging culture farms. Therefore, the method of utilizing the bottom surface in a hairstyling farm is proposed as a new aquaculture model for sea cucumber farming. The results of this study could contribute to improve the culturing environment of sea cucumbers and could help to increase production and capital generation from the aquaculture farms.

Kühnhold, H., Kamyab, E., Novais, S., Indriana, L., Kunzmann, A., Slater, M., & Lemos, M. (2017). Thermal stress effects on energy resource allocation and oxygen consumption rate in the juvenile sea cucumber, *Holothuria scabra* (Jaeger, 1833). *Aquaculture*, 467, 109-117
<https://doi.org/10.1016/j.aquaculture.2016.03.018>.

Water temperature is a key factor in aquaculture production of the commercially valuable sea cucumber *Holothuria scabra*. Knowledge is scarce about actual energetic costs that can be associated with internal acclimatization processes as a response to thermal extremes. In the present study changes in cellular energy allocation, oxygen consumption rate and energy related enzymes' activity (IDH and LDH) were measured in juvenile *H. scabra*, held at different temperatures: 21, 27 and 33 °C. The results showed that the steady temperature change (1 °C/day) to both temperature treatments, until reaching the testing temperatures (day 0), clearly affected cellular energy consumption and available energy reserves, measured in the respiratory tree and muscle tissue, respectively. However, 15 and 30 days after acclimation, the initial differences in cellular energy allocation between treatments decreased. In contrast to the variations measured in cellular energy allocation, oxygen consumption was highest at 33 °C and lowest at 21 °C at all three measurement times. Moreover, a significant positive correlation between oxygen consumption rate and temperature was detected at day 15 and day 30. Likewise, a shift from anaerobic to aerobic energy metabolism, indicated by changes in LDH and IDH activities, was observed in the animals from the warm temperature treatment. Results imply that juvenile *H. scabra* were able to recover from initial disturbances in energy balance, caused by the incremental temperature change of ± 6 °C. Over the experimental period of 30 days, elevated temperature did however, lead to a metabolic shift and more efficient energy turnover, indicated by changes in oxygen consumption rate, LDH and IDH. The synergy of cellular energy allocation and oxygen consumption proved to be a viable indicator to assess the capability of sea cucumbers like *H. scabra* to cope with extreme temperature conditions. Surprisingly, juvenile *H. scabra* were able to sustain their energy balance and oxygen consumption rate within the homeostatic range, even at 33 °C. Thus, we assume that rearing temperatures of 33 °C might be possible, which could improve aquaculture production of *H. scabra*. However, further research is required to understand the mechanisms and effects of acclimation under aquaculture conditions.

Kumara, A., & Dissanayake, C. (2017). Preliminary study on broodstock rearing, induced breeding and grow-out culture of the sea cucumber *Holothuria scabra* in Sri Lanka. *Aquaculture Research*, 48(3), 1058-1069 <https://doi.org/10.1111/are.12948>.

Experiments were conducted to identify suitable methods for broodstock rearing, induced breeding and grow-out culture of *Holothuria scabra* in Sri Lanka. Two hundred and seventy-two brooders (500-600 g) collected from off Mannar were individually packed in oxygen-filled polythene bags with and without sea water and transported to a sea cucumber hatchery at Kalpitiya. Lagoon pens, sand-filled fibreglass

tanks and bare tanks were used in triplicates to maintain brooders. Spawning was initiated using air dry, water jet and thermal-stimulation methods. Hatchery produced juveniles with an average weight of 11 ± 5 g were reared (2 individuals m⁻²) in lagoon pens, mud ponds and fibreglass tanks in triplicates. The significantly high evisceration rate was observed when brooders were transported without sea water (t-test, $P < 0.05$). Brooders maintained in bare tanks showed a significant weight reduction than the brooders in sand-filled tanks and lagoon pens (anova, $P < 0.05$, d.f. = 2). Thermal stimulation (ambient temperature ± 3 -5°C) was found to be the most successful method of spawning initiation of *H. scabra*. The mean (\pm SD) percentage males and females participated for spawning per trial was 9.2 (± 10) and 4.6 (± 5.6) respectively. On an average, 1.16 millions of eggs (± 1.03 SD, $n = 5$) were obtained per spawning trial. *H. scabra* juveniles reared in tanks showed significantly lower growth rate than the juveniles in pens and ponds (anova, $P < 0.05$). Lagoon pens and sand-filled tanks are suitable to maintain brooders and lagoon pens can be successfully used for mass rearing of juveniles.

Laguerre, H., Raymond, G., Plan, P., Améziane, N., Bailly, X., & Le Chevalier, P. (2020). First description of embryonic and larval development, juvenile growth of the black sea-cucumber *Holothuria forskali* (Echinodermata: Holothuroidea), a new species for aquaculture in the north-eastern Atlantic. *Aquaculture*, 521, 734961 <https://doi.org/10.1016/j.aquaculture.2020.734961>.

Holothuria forskali (Delle Chiaje, 1823), also called the “black sea cucumber or cotton spinner”, is a native species from the North East Atlantic Area and the Mediterranean Sea. This holothurian is newly targeted to supply the Asian Market. In this context, developing aquaculture is important to prevent risks of over fishing. This paper describes the first successful reproduction, larval rearing, and juvenile growth of *H. forskali* performed in captivity. Reproduction of *H. forskali* was observed in April 2018. The reproductive behavior was similar to those observed in other species. The auricularia stage hatched after 4 days and lasted >30 days. Pentactula and metamorphosis to the benthic life was obtained after 40 days. Juveniles have been observed only after 90 days and measured 8 mm long. Juvenile growth was slow (0.1 mm/day) for this first breeding. This first description of *H. forskali* breeding and rearing in hatchery is encouraging for a new innovative and sustainable aquaculture.

Leopold, M., Cornuet, N., AndréFouËT, S., Moenteapo, Z., Duvauchelle, C., Raubani, J., . . . Dumas, P. (2013). Comanaging small-scale sea cucumber fisheries in New Caledonia and Vanuatu using stock biomass estimates to set spatial catch quotas. *Environmental Conservation*, 40(4), 367-379 <https://doi.org/10.1017/S037689291300009X>.

Many sea cucumber fisheries have dramatically declined worldwide due to rapid overexploitation and ineffective management. This study designed an innovative management strategy for small-scale, data-limited sea cucumber fisheries in Pacific Island countries. Firstly, a local quota-based comanagement system was implemented in New Caledonia to manage a small-scale sandfish *Holothuria scabra* fishery. A habitat map derived from high-resolution satellite imagery was used to stratify survey sampling and assess the harvestable stock biomass. The latter has been monitored as the reference biomass (RB) since 2008 and repeatedly used by the local fishers’ organization and Fisheries Department officers to set adaptive total allowable catches and regulations of fishing effort. Results showed the excellent performance of this fishery between 2008 and 2012, both biologically (167% increase in total stock biomass) and economically (146% increase in annual returns from catches). Secondly, the assessment of the RB was generalized to multispecies sea cucumber fisheries in Vanuatu in 2011 before the proposed lifting of a five-year national moratorium. Building upon these practical case studies in New Caledonia

and Vanuatu, this paper outlines an operational framework to inform sea cucumber fisheries policy in these two countries and discusses the upscaling of the proposed management strategy.

Li, B. S., Wang, L. L., Wang, J. Y., Sun, Y. Z., Wang, S. X., Jiang, L. S., & Huang, B. S. (2020). Requirement of vitamin E of growing sea cucumber *Apostichopus japonicus* Selenka. *Aquaculture Research*, 9 <https://doi.org/10.1111/are.14479>.

This feeding trial was conducted to determine the vitamin E requirement of growing sea cucumber *Apostichopus japonicus* Selenka. Six isonitrogenous and isoenergetic experimental diets were formulated to contain graded levels of vitamin E (6.7, 81.2, 159.3, 237.8, 314.6, 395.9 mg/kg diet). Each diet was assigned randomly to 30 growing sea cucumber with initial body weight 15.43 g in triplicates for 8 weeks. Survival rate was not affected by dietary vitamin E; meanwhile, both the weight gain (WG) and specific growth rate were presented the trend of increasing first and then kept stable. With the increasing of dietary vitamin E, crude lipid content of body wall was evaluated firstly and dropped afterwards. When dietary vitamin E contents were lower than 159.3 mg/kg, vitamin E contents of body wall were increased by dietary vitamin E levels, but there were no more differences when dietary vitamin E higher than 159.3 mg/kg. There were minor effects on digestive enzymes of intestine by dietary vitamin E. Contents of malondialdehyde were decreased, while the total superoxide dismutase activity was increased first and then decreased with the increasing of dietary vitamin E. Activities of intestinal alkaline phosphatase were increased, and glutamic oxaloacetic transaminase were decreased first and then increased with the increasing of dietary vitamin E. In conclusion, analysis by a linear regression equation of WG or vitamin E contents in body wall indicated that the optimum requirement of vitamin E for growing sea cucumber (initial body weight 15.43 g) was 165.2-187.2 mg/kg diet.

Li, L., Zhang, Y., Dong, S., Wang, F., & Gao, Q. (2019). Effects of light intensity on larval development and juvenile growth of sea cucumber *Apostichopus japonicus*. *Aquaculture Research*, 50(9), 2333-2340 <https://doi.org/10.1111/are.14113>.

The growth rate, survival rate, development and setting rate of larval sea cucumber *Apostichopus japonicus* were measured under four light intensities (0, 50, 500 and 2,000 lx), and the growth rate and metabolism of the juvenile sea cucumbers were investigated under four light intensity treatments (0, 100, 1,000 and 2,500 lx). The light requirements (i.e. intensity) of the sea cucumber changed as they grew. Better growth performance, development and survival rate were observed in embryos and larvae under 500 lx treatment. However, reduced light intensity (50 lx) increased the settlement rate of the larvae. The highest specific growth rate occurred in juvenile sea cucumbers under 1,000 lx. The sea cucumbers in this group also had the lowest oxygen consumption rate and ammonia excretion rate, but the highest O:N ratio, indicating that the optimal light intensity for the juvenile sea cucumber culture was 1,000 lx. Therefore, appropriate light intensities were suggested to provide larval and juvenile sea cucumbers with better growth and development conditions.

Li, Z., Ren, H. Y., Li, Q., Murtaza, B., Li, X. Y., Zhang, J. C., & Xu, Y. P. (2020). Exploring the effects of phage cocktails in preventing *Vibrio* infections in juvenile sea cucumber (*Apostichopus japonicus*) farming. *Aquaculture*, 515, 10 <https://doi.org/10.1016/j.aquaculture.2019.734599>.

Vibrio infection poses a threat to the health of juvenile sea cucumber (*Apostichopus japonicus*) farming. In the present study, three phages, PVA1, PVc1 and PVS3, are respectively lytic to *Vibrio alginolyticus*, *V. cyclitrophicus* and *V. splendidus* and were used to make a phage cocktail with a ratio of 1:1:1 (V/V/V). Bioinformatic analyses showed that gene related toxins and virulence proteins were not detected in the genome of the three phages. Based on these results, a small pilot study was carried out to measure the effectiveness of a three-phage cocktail on sea cucumber farming. During the 48-day cultivation time, the total *Vibrio* counts in phage treatment groups decreased and phage particles were detected in the coelomic fluids of sea cucumbers over the cultivation time. In-vitro studies of those incubated with phages showed no significant cell viability loss ($P > 0.05$) compared to the control group. The level of superoxide dismutase and lysozyme in the phage immersion group remained lower than the control group ($P < 0.05$), while the activities of nitric oxide synthase and acid phosphatase remained stable. At the end of 48-day cultivation time, the total weight gain of the sea cucumbers in the phage cocktail immersion treatment group increased significantly ($P < 0.01$) compared to the control group, while remained lower than the antibiotic treatment group ($P < 0.05$). No significant differences were detected in the viscera body wall ratio and feed conversion among the three groups ($P > 0.05$). After the metagenomic analysis of sea cucumber intestinal tracts, the *Vibrio* abundance in the phage cocktail group decreased compared to control group, while there was no effect on the abundance of the other genera. Hence, all results of this small pilot study indicate that using a phage cocktail is a safe and feasible way to combat *Vibrio* infections in juvenile sea cucumber farming.

Li, Z., Zhang, J., Li, X., Wang, X., Cao, Z., Wang, L., & Xu, Y. (2016). Efficiency of a bacteriophage in controlling vibrio infection in the juvenile sea cucumber *Apostichopus japonicus*. *Aquaculture*, 451, 345-352 <https://doi.org/10.1016/j.aquaculture.2015.09.024>.

Vibrio cyclitrophicus is thought to be responsible for the cause of severe infection in juvenile sea cucumber (*Apostichopus japonicus*). Increases in the prevalence of antibiotic resistant pathogens have promoted us to develop effective agents to antibiotics for combating microbial infection among animals as well as human. In the present study, we isolated a bacteriophage with the ability to cleave *V. cyclitrophicus* present in the sewage of sea cucumber farms. This bacteriophage was designated as phage vB_VcyS_Vc1 (*Vibrio* phage Vc1). A one-step growth curve analysis of the phage revealed eclipse and latent periods of 25 and 45min, respectively, with a burst size of 215PFU/infected cell. Morphological analysis revealed the phage belongs to family of Siphoviridae. Furthermore, genomic sequencing results revealed a double-stranded DNA containing 44,541bp with a G+C content of 44.16%. Forty four coding sequences were annotated in the genome, and nineteen of these were associated with a known function. Genes related to virulence and toxins were not detected in the genome. In addition, a prevention experiment conducted in a marine environment demonstrated that the phage increased the survival rate of juvenile sea cucumbers ($18 \pm 2g$) from 18% to 81% when the sea cucumber were fed with feedstuff containing the freeze-dried phage powder, 58% when the sea cucumber was injected with purified phages (MOI=10), and 63% when the sea cucumbers were immersed in a suspension containing purified phages. Notably, when the phage provided nearly the same protection to the sea cucumbers as antibiotic when it was fed to the sea cucumbers in the form of freeze-dried powder mixed with feedstuff. Taken together, the results demonstrated that the use of phage to control the infection of *V. cyclitrophicus* in sea cucumber may be a feasible alternative to antibiotics. Statement of relevance The *A. japonicus* (sea cucumber) is the most profitable aquaculture animal with the highest output as single variety in China, which is of high nutritional value and economic value. In the past decade, as the growth of the market demand, *A. japonicus*'s artificial breeding scale expands rapidly and the sea cucumber industry has become a vigorous sector in China aquaculture. However, with the high

density and intensive development model of *A. japonicus* breeding, the various diseases have resulted in serious economic losses. Skin ulceration syndrome (SUS) is one of the most epidemic and serious diseases that affect sea cucumbers. At present, sanitizer and antibiotics are still commonly used in farms or hatcheries to control the bacterial disease in juvenile sea cucumbers, which resulted in the environment pollution and antibiotic residues. Nowadays, increased appearance of antibiotic resistant phenomenon promoted us to develop effective agents. Hence, alternative strategies to antibiotics should be further developed. This study was the first to monitor the effectiveness of using feedstuff mixed with freeze-dried phage powder as a form of protection for sea cucumber against vibrio infection, and demonstrated the effectiveness of phage in the control of pathogen in aquaculture.

Li, Z. Q., Xue, X. Q., Yang, H., Liao, M. L., Han, Y. Z., Jiang, Z. Q., & Ren, T. J. (2019). Effect of dietary carbohydrate levels on growth performance, non-specific immune enzymes and acute response to low salinity and high temperature of juvenile sea cucumber *Apostichopus japonicus*. *Aquaculture Nutrition*, 10 <https://doi.org/10.1111/anu.13027>.

This study was performed to determine the optimum dietary carbohydrate (CHO) levels of sea cucumber, based on the parameters of growth, digestive enzymes, digestibility, non-specific immune enzymes and acute low-salinity (20 g/L) stress and high-temperature (30 degrees C) stress tolerance. Diets with eight different CHO (dextrin) levels (32.9, 107.6, 192.5, 257.2, 316.8, 428.0, 482.4 and 572.8 g/kg) were fed to sea cucumber juveniles (0.49 +/- 0.01 g) for 60 days. Significant higher amylase activity was observed in sea cucumbers fed diet with CHO ranging between 32.9 and 192.5 g/kg than that of other treatments ($p < .05$). The sea cucumbers fed with 192.5 g/kg CHO showed significantly higher acid phosphatase activity than the treatments of 482.4 and 572.8 g/kg CHO ($p < .05$), and significantly higher alkaline phosphatase activity than other treatments ($p < .05$, except 257.2 g/kg). The treatments of 428.0-572.8 g/kg were found significantly lower values than other treatments in apparent digestibility coefficients for dry matter and crude protein ($p < .05$). The sea cucumbers fed with 192.5, 257.2 and 316.8 g/kg CHO showed better tolerance to high-temperature (30 degrees C) and low-salinity (20 g/L) stress than other treatments. In brief, the optimal dietary CHO level for the growth of juvenile sea cucumber is 177.96 g/kg. However, excessive CHO will inhibit amylase enzyme activity and decrease digestibility, resulting in low growth of sea cucumber.

Liao, M.-L., Ren, T.-J., Chen, W., Han, Y.-Z., Liu, C.-M., Jiang, Z.-Q., & Wang, F.-Q. (2017). Effects of dietary lipid level on growth performance, body composition and digestive enzymes activity of juvenile sea cucumber, *Apostichopus japonicus*. *Aquaculture Research*, 48(1), 92-101 <https://doi.org/10.1111/are.12864>.

A feeding trial aimed to determine the effects of dietary lipid level on growth performance, body composition and digestive enzymes activity of juvenile sea cucumber, *Apostichopus japonicus*. Diets with six crude lipid levels (1.9, 13.8, 29.1, 43.6, 59.6 and 71.6 g kg⁻¹) were fed to sea cucumbers (initial weights 0.65 ± 0.01 g) at a density of 30 juveniles, once a day. After 60 days, body weight gain (BWG), specific growth rate (SGR), feed intake (FI) and protein efficiency ratio (PER) decreased with increasing dietary lipid levels. The sea cucumbers fed 1.9 g kg⁻¹ crude lipid showed significantly higher ($P < 0.05$) BWG than those of the sea cucumbers fed 59.6 and 71.6 g kg⁻¹ crude lipid. Intestinal protease and lipase activities generally increased with increasing dietary lipid levels. Eicosapentaenoic acid (EPA) content of body walls generally increased with increasing dietary lipid levels. Docosahexaenoic acid (DHA) content of body walls reached the maximum value at a dietary lipid level of 13.8 g kg⁻¹. N-3

highly unsaturated fatty acid content followed the same pattern of DHA. According to the growth performance and body composition of sea cucumbers, it can be indicated that the optimum dietary lipid level for juvenile sea cucumbers is between 1.9 and 13.8 g kg⁻¹.

Liao, M., Ren, T., Chen, W., Jiang, Z., Yang, H., & Han, Y. (2015). Optimum Level of Dietary n-3 Highly Unsaturated Fatty Acids for Juvenile Sea Cucumber, *Apostichopus japonicus*. *Journal of the World Aquaculture Society*, 46(6), 642-649 <https://doi.org/10.1111/jwas.12231>.

A feeding trial was conducted to estimate the optimum level of dietary n-3 highly unsaturated fatty acids (HUFAs) for juvenile sea cucumber, *Apostichopus japonicus*, based on growth performance and fatty acid compositions. Diets with five n-3 HUFAs levels (0.15, 0.22, 0.33, 0.38, and 0.46%) were fed to sea cucumber juveniles (1.97±0.01g) once a day for 60 d. The sea cucumbers fed diets containing 0.22% n-3 HUFAs showed significantly ($P < 0.05$) higher body weight gain, feed efficiency, and protein efficiency ratio than the sea cucumbers fed diets containing 0.15% n-3 HUFAs, but not significantly different ($P > 0.05$) from those of sea cucumbers fed diets containing 0.33, 0.38, and 0.46% n-3 HUFAs. The sea cucumbers fed diets containing 0.46% n-3 HUFAs showed significantly ($P < 0.05$) higher eicosapentaenoic acid and saturated fatty acid than the sea cucumber fed diets containing 0.15% n-3 HUFAs, but not significantly different ($P > 0.05$) from those of sea cucumbers fed diets containing 0.22, 0.33, and 0.38% n-3 HUFAs. The results of growth performance and n-3 HUFA compositions of body wall indicated that the optimum level of dietary n-3 HUFAs for juvenile sea cucumber is between 0.22 and 0.46%.

Lv, X., Yu, P., Mao, W., & Li, Y. (2018). Vertical Variations in Bacterial Community Composition and Environmental Factors in the Culture Pond Sediment of Sea Cucumber *Apostichopus Japonicus*. *Journal of Coastal Research*, 84(sp1), 69-76, 68 <https://doi.org/10.2112/SI84-010.1>.

The bacterial communities in culture pond sediments play important roles in the decomposition of organic matter, the release of nutrients and conservation of water quality. To explore the vertical variations in the microbial communities and environmental factors in the sediment accumulation of the sea cucumber (*Apostichopus japonicus* Selenka) culture pond, microbial community compositions were determined by highthroughput sequencing and environmental factors were measured using samples collected at different sediment depths. A total of 113,161 high-quality reads and 17,317 operational taxonomic units (OUTs) were obtained from different sediment samples. The results showed that the sediment of culture ponds has the characteristics of high organic matter, nitrogen, and sulfur contents and low phosphate contents. The bacterial richness was higher in the surface layer of the sediment. In total, 31 phyla were identified, among which the Proteobacteria, Acidobacteria, Bacteroidetes, Chloroflexi, Planctomycetes, Gemmatimonadetes and Nitrospirae were the dominant phyla in the sediment. Principle component analysis (PCA) showed that total-phosphate, salinity, NH₄⁺, pH and PO₄³⁻ were the main factors that influenced the microbial communities. This study will deepen our understanding of aquaculture environmental regulation and provide theoretical guidance for the exploitation of probiotics.

Martínez-Milián, G., & Olvera-Novoa, M. A. (2016). Evaluation of Potential Feed Ingredients for the Juvenile Four-sided Sea Cucumber, *Isostichopus badionotus*. *Journal of the World Aquaculture Society*, 47(5), 712-719 <https://doi.org/10.1111/jwas.12309>.

The objective of this study was to evaluate two seaweed species, *Solieria filiformis* and *Macrocystis piryfera*, both as dry-meal powder and predigested meal, to be used as ingredients in artificial diets for the juvenile four-sided sea cucumber, *Isostichopus badionotus*. Four diets were tested in triplicate: *S. filiformis* dry-meal powder and predigested meal and *M. piryfera* dry-meal powder and predigested meal, mixed with 70% of beach sand. Survival exceeded 90% in all the treatments, and there were no differences in the growth of juveniles using dry-meal powder or predigested meal. Weight gain was calculated for all the diets, and the highest values were obtained by animals fed *S. filiformis*. No differences between using dry-meal powder and predigested meal were found, so these diets were excluded from the second trial. The ingestion rate was the same with both algae, but the feed conversion ratio was twice as high for *M. piryfera*. *Solieria filiformis* exhibited a number of differences in fatty acid and amino acid profiles, including higher proline, arginine, and saturated fatty acid levels. The results indicate that *S. filiformis* has better nutritional characteristics to be an ingredient for an artificial *I. badionotus* juvenile diet.

Muthiga, N. A., Kawaka, J. A., & Ndirangu, S. (2009). The timing and reproductive output of the commercial sea cucumber *Holothuria scabra* on the Kenyan coast. *Estuarine, Coastal and Shelf Science*, 84(3), 353-360 <https://doi.org/10.1016/j.ecss.2009.04.011>.

The sea cucumber *Holothuria scabra* is a widely distributed and economically important species that has been harvested in Kenya for decades. No previous studies have been carried out on the reproduction of this species in Kenya. Standard gonad index methods were used to analyze reproductive patterns of individuals collected monthly in 1998–1999, 2000–2001 and 2006–2007. Morphological characteristics, gonad tubule lengths and fecundity were also measured. Mean monthly gonad indices were significantly correlated between males and females indicating synchronous gonad development between the sexes. Gonad indices showed a biannual pattern that was consistent in all three years with a minor spawning event occurring between August and September and a major spawning event between November and December. The pattern of gonad growth showed significant variability between years and between months. Temporal changes in gonad growth correlated significantly with gonad tubule length and absolute fecundity. Monthly gonad indices also correlated significantly with monthly measurements of air temperature and light suggesting a possible role for both factors in timing gametogenesis and spawning. There was a shift in sex ratio from unity in the 1998–1999 and 2000–2001 samples to significantly more males in the 2006–2007 samples, as well as a significant reduction in mean sizes (body wall weight) and reproductive output (gonad index) which suggests that the reproductive success of this species is potentially negatively affected by fishing.

Namukose, M., Msuya, F. E., Ferse, S. C. A., Slater, M. J., & Kunzmann, A. (2016). Growth performance of the sea cucumber *Holothuria scabra* and the seaweed *Eucheuma denticulatum*: integrated mariculture and effects on sediment organic characteristics. *Aquaculture Environment Interactions*, 8, 179-189. Retrieved from <https://www.int-res.com/abstracts/aei/v8/p179-189/>.

Deposit-feeding sea cucumbers play a key role in marine ecosystems through bioturbation, burrowing and feeding on organic matter in marine sediments. Many deposit-feeding holothurians have therefore been recommended for integrated multitrophic aquaculture systems (IMTA). We set up an integrated mariculture system of sea cucumber *Holothuria scabra* and seaweed *Eucheuma denticulatum* in Bweleo, Unguja Island of Zanzibar, Tanzania, to investigate the effect of stocking density on the growth and

survival of culture species, total organic matter (TOM) and total organic carbon (TOC) content in the sediment. Treatments that included a fixed stocking density (500 g, ca. 200 g m⁻²) of *E. denticulatum* and 4 sea cucumber stocking densities (monoculture, low, medium and high density; 0, 150 ± 5, 236 ± 24, 345 ± 48 g m⁻², mean ± SD) of medium-sized *H. scabra* (114 ± 37 g) were established. Stocking density of *H. scabra* did not influence survival of either species. Seaweed cultured under high stocking density of *H. scabra* had a higher specific growth rate of 2.33% d⁻¹ than that cultured at the medium or low densities or without sea cucumbers. Sea cucumbers cultured at low stocking density had a higher mean growth rate of 0.80 g d⁻¹ compared to those cultured at medium or high densities. TOM and TOC in sediments decreased over the experimental period at medium sea cucumber stocking density, while at low and high stocking densities, organic matter accumulated. The study demonstrates that the integration of *E. denticulatum* and *H. scabra* at 200 g m⁻² enhances seaweed growth and can reduce organic matter content in the sediments.

Neofitou, N., Lolos, A., Ballios, I., Skordas, K., Tziantziou, L., & Vafidis, D. (2019). Contribution of sea cucumber *Holothuria tubulosa* on organic load reduction from fish farming operation. *Aquaculture*, 501, 97-103 <https://doi.org/10.1016/j.aquaculture.2018.10.071>.

An investigation was carried out in the field and in the laboratory in order to evaluate the contribution of sea cucumber *Holothuria tubulosa* on organic load reduction from fish farming in the Eastern Mediterranean. Five experimental cages and three double systems of seawater aquaria were used for this purpose. The mean reduction of OM and OC was 30.73% and 58.58%, respectively. Moreover, the mean absorption efficiency of OM and OC during transit in the intestine of *H. tubulosa* was 43.40% and 54.65%, respectively. One-way ANOVA indicated significant differences on OM and OC accumulation rate between holothurians and control ($p < .05$). The results indicated that the feeding activity of *H. tubulosa* seemed to reduce the total organic load of the fish farm biodeposits, demonstrating their potential as an important organic-reducing component for the sustainability of aquaculture in the Mediterranean region.

Ning, J., Chang, Y., Liu, W., Song, J., Zhang, W., & Ding, J. (2015). Stress responses to mild and acute temperature decrease for two strains of sea cucumber *Apostichopus japonicus*. *Aquaculture*, 448, 552-563 <https://doi.org/10.1016/j.aquaculture.2015.06.035>.

In order to understand the effect of low temperature shock to *Apostichopus japonicus*, we measured the concentration of soluble proteins, soluble sugars and five ions (Ca²⁺, Mg²⁺, Na⁺, Cl⁻ and NO₃⁻) derived from different organs to evaluate the adaptive capacities and stress responses to mild temperature decrease (MTD, initial temperature was set at 14°C and decreased from 8°C to -2°C by step changes of 2°C, temperature was decreased to each temperature through 24h) and to rapid temperature decrease (ATD, step changes of 2°C over 1.5h) in the laboratory. Two commercial strains of *A. japonicus*, hybrid Shuiyuan No. 1 sea cucumbers (Ss) and Dalian local sea cucumbers (Ls), were used as test animals. In the MTD treatments, concentrations of soluble proteins and soluble sugars on the whole showed similar trends of an initial increase, a subsequent decrease and then an increase to a level similar to or higher than the initial level. Ca²⁺ concentration increased to the maximum level at 4°C and did not return to the original concentration. The concentrations of Mg²⁺ and Cl⁻ increased significantly to a higher level, which was maintained until the end of the experiment. However, the concentrations of Na⁺ and NO₃⁻ showed an opposite trend: an initial decrease in concentration to a low concentration that was maintained until the end of the experiment. In contrast, in the ATD experiment, the concentration

of soluble proteins, soluble sugars, Mg²⁺, NO and Na⁺ showed a tendency for fluctuation or decrease. Only Ca²⁺ and Cl⁻ concentrations showed a rising trend. Earlier responses and faster homeostatic ability were observed for Ss individuals than for Ls individuals, indicating a greater cold tolerance. Such findings provide the basis for improving aquaculture techniques for *A. japonicus*, particularly for providing a new stress-resistant sea cucumber variety for *A. japonicus* culture in farm ponds. Statement of relevance The manuscript titled “Stress responses to mild and acute temperature decrease for two strains of sea cucumber *Apostichopus japonicus*” was finished by Junhao Ning, Yaqing Chang, Wei Liu, Jian Song, Weijie Zhang and Jun Ding, we all made contribution to this manuscript and agreed with the authors' sorting order. This paper is first submitted in your journal. Neither the entire paper nor any part of its content has been published or has been accepted elsewhere. It is not being submitted to any other journal. We believe the paper may be of particular interest to the readers of your journal because the study reports that: (1) a preliminary relationship between the changes of soluble proteins, soluble sugars and five biogenic ions in *A. japonicus* and cold stress is established in the study; (2) the turning point of stress reaction in *A. japonicus* when suffering low-temperature was found at 0°C or at 2°C; and (3) we provide a new stress-resistant sea cucumber variety for *A. japonicus* culture in farm ponds.

O'Regan, S. M. (2015). Harvesters' perspectives on the management of British Columbia's giant red sea cucumber fishery. *Marine Policy*, 51, 103-110 <https://doi.org/10.1016/j.marpol.2014.07.025>.

In recent decades, sea cucumber fisheries have rapidly expanded worldwide to meet rising demand in Asian markets. Catch trends have often followed a boom-and-bust trajectory and skyrocketing sea cucumber value has often spurred fishery development that outpaced adequate biological research for informed stock assessment. Currently, the dive fishery for Giant red sea cucumber (*Parastichopus californicus*) in British Columbia, Canada is considered moderately exploited. However, basic population parameters such as recruitment and mortality rates are still largely unknown, creating important sources of uncertainty in the fishery's stock assessment model. This study presents the results of an interview-based survey of experienced commercial harvesters' (1) perceptions of local trends in sea cucumber abundance, size, and fishing effort (CPUE), and (2) perceptions of management efficacy. The majority of harvesters perceived abundance (14/20) and CPUE (15/20) to have declined over their careers, and half of the harvesters reported decreased sea cucumber size. The harvesters most commonly cited overfishing as the most pressing problem facing the fishery (13/20), and the majority felt that Fisheries and Oceans Canada (DFO) needed to lower licence and/or area quotas to avoid further declines. Despite many knowledge gaps in the fishery, almost all harvesters (16/20) perceived that they are not adequately consulted and their concerns are not adequately considered by DFO. These results suggest a disjoint between DFO forecasts and perceived local sea cucumber trends, and highlight that the fishery may lack a resource-rights framework with adequate checks to decouple fishing pressure from increasing global market value and demand. Maintaining the long-term health of the BC sea cucumber fishery may depend on working more closely with harvesters to inform future management decisions and, ideally, moving towards a harvester-owned-and-operated licencing system that can better integrate the feedback that comes from attachment to place.

Plagányi, É. E., Skewes, T., Murphy, N., Pascual, R., & Fischer, M. (2015). Crop rotations in the sea: Increasing returns and reducing risk of collapse in sea cucumber fisheries. *Proceedings of the National Academy of Sciences*, 112(21), 6760 <https://doi.org/10.1073/pnas.1406689112>.

Rotating the harvest of natural resources is a management strategy that humans have used on land for centuries, but it is less commonly applied to marine resources. Marine animals, such as sea cucumbers, scallops, and abalone, may be particularly suited for this form of management. Although highly important to many communities worldwide, they are often severely overexploited, underlining the need for effective and easy to manage harvest strategies. We modeled the rotational zone strategy applied to the multispecies sea cucumber fishery in Australia's Great Barrier Reef Marine Park and show a substantial reduction in the risk of localized depletion, higher long-term yields, and improved economic performance. Hence, our results support the use of rotational harvests to better manage these marine resources. Rotational harvesting is one of the oldest management strategies applied to terrestrial and marine natural resources, with crop rotations dating back to the time of the Roman Empire. The efficacy of this strategy for sessile marine species is of considerable interest given that these resources are vital to underpin food security and maintain the social and economic wellbeing of small-scale and commercial fishers globally. We modeled the rotational zone strategy applied to the multispecies sea cucumber fishery in Australia's Great Barrier Reef Marine Park and show a substantial reduction in the risk of localized depletion, higher long-term yields, and improved economic performance. We evaluated the performance of rotation cycles of different length and show an improvement in biological and economic performance with increasing time between harvests up to 6 y. As sea cucumber fisheries throughout the world succumb to overexploitation driven by rising demand, there has been an increasing demand for robust assessments of fishery sustainability and a need to address local depletion concerns. Our results provide motivation for increased use of relatively low-information, low-cost, comanagement rotational harvest approaches in coastal and reef systems globally.

Plagányi, É. E., Skewes, T. D., Dowling, N. A., & Haddon, M. (2013). Risk management tools for sustainable fisheries management under changing climate: a sea cucumber example. *Climatic Change*, 119(1), 181-197 <https://doi.org/10.1007/s10584-012-0596-0>.

Sustainable fisheries management into the future will require both understanding of and adaptation to climate change. A risk management approach is appropriate due to uncertainty in climate projections and the responses of target species. Management strategy evaluation (MSE) can underpin and support effective risk management. Climate change impacts are likely to differ by species and spatially. We use a spatial MSE applied to a multi-species data-poor sea cucumber/bêche-de-mer fishery to demonstrate the utility of MSE to test the performance of alternative harvest strategies in meeting fishery objectives; this includes the ability to manage through climate variability and change, and meeting management objectives pertaining to resource status and fishery economic performance. The impacts of fishing relative to the impacts of climate change are distinguished by comparing future projection distributions relative to equivalent no-fishing no-climate-change trials. The 8 modelled species exhibit different responses to environmental variability and have different economic value. Status quo management would result in half the species falling below target levels, moderate risks of overall and local depletion, and significant changes in species composition. The three simple strategies with no monitoring (spatial rotation, closed areas, multi-species composition) were all successful in reducing these risks, but with fairly substantial decreases in the average profit. Higher profits (for the same risk levels) could only be achieved with strategies that included monitoring and hence adaptive management. Spatial management approaches based on adaptive feedback performed best overall.

Ponte, I. d. A. R., & Feitosa, C. V. (2019). Evaluation of an unreported and unregulated sea cucumber fishery in eastern Brazil. *Ocean & Coastal Management*, 167, 1-8
<https://doi.org/10.1016/j.ocecoaman.2018.09.016>.

Holothuria grisea is abundant in Brazil, however there is only one study on this species. This study aimed to characterize the sea cucumber fishery in the State of Ceará, Brazil, through the evaluation of the capture, length classes most susceptible to catch, fishing effort as well as the processing, stakeholders characterization, income and marketing of the final product. The study was carried out in two fishing communities (Xavier and Camocim) from August 2015 to July 2016. Processing is performed in four stages: evisceration, cooking, draining and drying. The fishing cycle occurs in spring tides. The annual catch was 12,341 kg, which was totally commercialized. The t-test shows that there was no significant difference for capture per unit effort (CPUE) and fishing effort between communities. The processed individuals showed an average loss of 79% weight and 49% length. 66% of the captured organisms were below the size at first maturity. This activity plays an important role as complementary income. However, this is an unreported and unregulated activity and an intense fishing pressure can lead to overexploitation of this resource. This study is essential to not only the knowledge of the dynamics of this activity, but also as an attempt to contribute to a future fishery management.

Purcell, S. W., Lovatelli, A., & Pakoa, K. (2014). Constraints and solutions for managing Pacific Island sea cucumber fisheries with an ecosystem approach. *Marine Policy*, 45, 240-250
<https://doi.org/10.1016/j.marpol.2013.11.005>.

The ecosystem approach to fisheries (EAF) is a holistic paradigm that considers stocks of exploitable species, marine ecosystems and stakeholders. Management agencies must strike a balance between their capacity constraints and the requisites of management measures. Most small-scale sea cucumber fisheries of Pacific Islands have been plundered while others are being opened to commercial exploitation. Data from fishery managers and a regional workshop were used to assess the current problems, institutional constraints and solutions to the management of sea cucumber fisheries in 13 Pacific Island countries (PICs). Technical capacity was often strong for some management actions such as developing marine reserves but weak for others, such as enforcement. Using multi-disciplinary indicators, half of the fisheries were diagnosed by their managers as being overfished or depleted, despite evidence of optimistic bias. Fishery governance varied greatly among the PICs, and co-management frameworks were not typical of any cultural region. Management objectives were prioritised differently among managers but most highly ranked was to protect ecological resilience. The fishery managers proposed different sets of regulatory measures and various management actions, such as surveys to collect socio-economic and fishery-dependent data, support for local governance and strong enforcement – all widely under-practised. Pacific sea cucumber fisheries exemplify how the transition to an EAF by management institutions must involve reorganisation of their technical and human-resource capacities among management tasks. Levies on exports need to be internalised to fund improved management. Management agencies should consider a shift in resources from developing marine reserves, conducting underwater surveys and aquaculture-based restocking to strengthening enforcement capacity, stakeholder involvement and communication with fishers. In concert with these actions, short fishing seasons, shortlists of allowable species and tighter enforcement at export points may serve to turn the tide on boom-and-bust exploitation and safeguard biodiversity.

Purcell, S. W., Ngaluafe, P., Aram, K. T., & Lalavanua, W. (2016). Trends in small-scale artisanal fishing of sea cucumbers in Oceania. *Fisheries Research*, 183, 99-110 <https://doi.org/10.1016/j.fishres.2016.05.010>.

Multi-species sea cucumber fisheries in Oceania involve vast numbers of small-scale fishers exploiting stocks on coral reefs and tropical lagoons. Fishery development measures might need to be specific to locations or fisher groups, and regulations should be appropriate to fishing activities. To understand fishing among countries, locations, gender and age, we conducted questionnaire-based interviews of 479 sea cucumber fishers in Fiji, Kiribati, New Caledonia and Tonga. Fishers included youth and elderly, and the average age within countries was 36–42 years. Women commonly gleaned sea cucumbers from shallow habitats and dived for them in some countries. Although spatially variable, our results indicate intense fishing pressure based on high trip frequencies and fishing effort. Catch-per-unit-effort (CPUE) differed significantly among countries and locations, and fishers on some islands caught high numbers of low-value species. Young fishers went fishing more often, but age did not affect fishing effort and CPUE. Fishers collected a wide range of sea cucumbers, and up to 27 species were harvested in Fiji. Species composition in catches differed significantly among countries and between genders; women usually harvest species typical of shallower reef habitats. Fishers tended to view stocks as declining or greatly over-exploited. Based on fisher knowledge, recent catch rates for an average fishing day have declined by 33–92% across the study countries compared to 10+ years in the past. Our study shows that fishing modes, catch rates and catch composition in small-scale fisheries can be highly context-dependent. Management measures and interventions to support fisher livelihoods must consider gender differences and location-specific fishing activities. Sharp declines in catch rates over time in all countries, fisher perceptions of resource trajectories, and a predominance of low-value species in present-day harvests, provide strong evidence of widespread over-exploitation.

Purcell, S. W., Ngaluafe, P., Lalavanua, W., & Ceccarelli, D. M. (2018). Market price trends of Latin American and Caribbean sea cucumbers inform fisheries management. *Regional Studies in Marine Science*, 17, 127-132 <https://doi.org/10.1016/j.rsma.2017.12.003>.

Market price trends of seafood can inform fishery management measures and strengthen the bargaining power of fishers. The four-sided sea cucumber *Isostichopus badionotus* and donkey dung sea cucumber *Holothuria mexicana* are heavily exploited in small-scale fisheries in the Gulf of Mexico and Caribbean for export to China. We recorded prices and sizes of the dried sea cucumbers from 41 lots in 28 shops in Hong Kong and Guangzhou, China. Market value ranged 132-358 US.kg(-1) for *I. badionotus*, and 16-209 US.kg(-1) for *H. mexicana*. The relationship between product length and price per kg was weak for both species, revealing large variability in the marketplace. Price per individual increased linearly with product length for *H. mexicana*, and increased nonlinearly for *I. badionotus* indicating that large specimens were disproportionately more valuable than small ones. Thus, the economic performance of fisheries, especially those for *I. badionotus*, could be optimised by strictly enforcing large minimum size limits. High market value identifies *I. badionotus* as a species of conservation concern. A large difference between reported prices received by fishers and market retail prices suggests substantial scope for upgrading value chains of small-scale export fisheries.

Qi, Z., Wang, J., Mao, Y., Liu, H., & Fang, J. (2013). Feasibility of Offshore Co-culture of Abalone, *Haliotis discus hannai* Ino, and Sea Cucumber, *Apostichopus japonicus*, in a Temperate Zone. *Journal of the World Aquaculture Society*, 44(4), 565-573 <https://doi.org/10.1111/jwas.12056>.

Feasibility of offshore co-culture of abalone and sea cucumber was investigated in Northern China. Survival and growth of abalone, *Haliotis discus hannai* Ino, and sea cucumber, *Apostichopus japonicus*, co-cultured in abalone cages from suspended longlines, in the offshore area, were examined. Abalone and sea cucumbers were co-cultured at density ratios of both 3:1 and 6:1 for 1?yr. Abalone were fed with fresh kelp and no additional feed was given to sea cucumbers. Survival of abalone and sea cucumber was 100% for all treatments. Abalone and sea cucumber grew well; the body weight (BW) of abalone and sea cucumber was nearly doubled and had reached a commercial size. There were no significant differences in the growth rates for both abalone and sea cucumber between the two density treatments. The specific growth rate of BW of abalone (SGR_{bw}) was highest in June, with a value of 0.536%/d. Growth rate of sea cucumber (SGR_{sc}) was highest in December, reached 1.84%/d, with an annual average SGR_{sc} of 0.182%/d. Results suggested that the offshore co-culture of abalone and sea cucumber was feasible offshore. The co-culture of abalone with sea cucumbers may provide an additional valuable crop without additional financial input.

Ramírez-González, J., Moity, N., Andrade-Vera, S., & Mackliff, H. R. (2020). Estimation of age and growth and mortality parameters of the sea cucumber *Isostichopus fuscus* (Ludwig, 1875) and implications for the management of its fishery in the Galapagos Marine Reserve. *Aquaculture and Fisheries*, <https://doi.org/10.1016/j.aaf.2020.01.002>.

The fishery of the sea cucumber *Isostichopus fuscus* was the most important one in the early 2000s in the Galapagos Marine Reserve. Its overexploitation leads to its total closure from 2016 to 2021. At the end of this period, if the co-management system of the Galapagos Marine Reserve decides to open this fishery, a total allowed catch must be established using the methodology of Wolff, Schuhbauer, and Castrejón (2012). The objective of this paper is to evaluate this methodology and improve the total allowed catch calculation. We replicated Wolff et al.'s methodology that uses the Cadima equation of Maximum Sustainable Yield (in Troadec, 1977). We determined the age and growth parameters of *I. fuscus* to estimate total mortality and improved the calculation of the area of fishing and habitat of this species in Galapagos to estimate its abundance. We found inconsistencies in Wolff et al.'s estimations of mortality and abundance and we recommend that the Maximum Sustainable Yield be used not as the total allowed catch, but as a limit reference point for this fishery. We propose, instead, to use a dynamic abundance model that is capable of estimating a variety of reference points, including the fishing mortality for optimal fishing that is recommended to use to establish a total allowed catch. In addition, for the first time, the age and growth parameters of *I. fuscus* for Galapagos and the eastern-central region of the Pacific Ocean are determined ($L_{\infty} = 42.5$ cm; $K = 0.21$ /year).

Ren, H., Li, Z., Xu, Y., Wang, L., & Li, X. (2019). Protective effectiveness of feeding phage cocktails in controlling *Vibrio parahaemolyticus* infection of sea cucumber *Apostichopus japonicus*. *Aquaculture*, 503, 322-329 <https://doi.org/10.1016/j.aquaculture.2019.01.006>.

Vibrio parahaemolyticus is a common zoonotic bacterium that causes infections and disease in both sea cucumbers (*Apostichopus japonicus*) and humans, potentially greatly impacting both aquaculture and human health. In this study, two phages with the ability to control *V. parahaemolyticus* were isolated and designated as vB_VpaP_VP-ABTNL-1 (PVP1) and vB_VpaS_VP-ABTNL-2 (PVP2). Morphological analyses showed that PVP1 belonged to C3 phage group Podoviridae while PVP2 belonged to the family Siphoviridae. In vitro phage-treated cultures showed significant ($P < 0.05$) inhibition of growth for *V.*

parahaemolyticus VP-ABTNL when compared to untreated groups. Subsequently, we determined that skim milk might be the best protective agent, as the dissolution time and moisture content were both significantly ($P < 0.05$) higher than other agents tested. We also explored the utility of using feedstuff mixed with freeze-dried phage powder as a form of protection for sea cucumbers against *V. parahaemolyticus* infection. The antibiotic group had a significant ($P < 0.05$) difference with $MOI = 1$, but not with the two phage treatments ($MOI = 10$, $MOI = 100$), indicating an increase of phage protection with $MOI = 10$ and $MOI = 100$ against *V. parahaemolyticus* VP-ABTNL. There were no significant differences in weight gain, wall-to-wall ratio, feeding rate or food conversion efficiency among sea cucumbers fed the two phage treatments compared with those fed the non-supplemented diet ($P > 0.05$). Hence, feeding phage cocktails might be another optimal therapeutic agents to treat *V. parahaemolyticus* infections in sea cucumber aquaculture.

Ren, Y., Dong, S., Wang, X., Gao, Q., & Jiang, S. (2014). Beneficial co-culture of jellyfish *Rhopilema esculenta* (Kishinouye) and sea cucumber *Apostichopus japonicus* (Selenka): implications for pelagic-benthic coupling. *Aquaculture Research*, 45(2), 177-187 <https://doi.org/10.1111/j.1365-2109.2012.03225.x>.

This study investigated monthly changes of sedimentation and sediment properties in three different culture systems (ponds) i.e. jellyfish *Rhopilema esculenta* monoculture (J), sea cucumber *Apostichopus japonicus* and jellyfish co-culture (SJ) and sea cucumber monoculture (S) to verify the feasibility of co-culturing jellyfish and sea cucumbers. Results showed that jellyfish culture accelerated the settling velocity of total particulate matter (TPM). Average TPM settling velocities in the SJ ($75.6 \text{ g m}^{-2} \text{ day}^{-1}$) and J ($71.1 \text{ g m}^{-2} \text{ day}^{-1}$) ponds were significantly higher than that in the S pond ($21.7 \text{ g m}^{-2} \text{ day}^{-1}$) from June to September during the jellyfish culture period. Average settling velocities of organic matter (OM), total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP) in the SJ pond increased significantly by 3.0, 2.9, 3.3 and 3.8 times, respectively, compared with those in the S pond. Sediment contents of OM, TOC, TN and TP in the SJ and J ponds were significantly higher than those in the S pond during the jellyfish culture season. The specific growth rate of sea cucumbers feeding on SJ sediment was significantly higher than that of those feeding on S sediment. Co-culturing sea cucumbers with jellyfish may help alleviate benthic nutrient loading due to the jellyfish and provide a secondary cash crop.

Rogers, A., Hamel, J.-F., Baker, S. M., & Mercier, A. (2018). The 2009–2016 Belize sea cucumber fishery: Resource use patterns, management strategies and socioeconomic impacts. *Regional Studies in Marine Science*, 22, 9-20 <https://doi.org/10.1016/j.rsma.2018.05.003>.

While sea cucumbers have been fished in Belizean waters for ~20 years for trade through Guatemala and the local Asian market in Belize, harvesting for export to international markets only started with the establishment of the sea cucumber fishery regulations in 2009. The fishery included two main species, *Holothuria mexicana* and *Isostichopus badionotus* but only the former was legally managed by the Belize Fisheries Department through a closed season and catch reporting. By 2016, *H. mexicana* was considered overfished and in 2017, the entire fishery was closed. Here we provide a comprehensive analysis of this fishery in Belize from 2009–2016 with the goal to make recommendations for policy development. This study combined key informant interviews with secondary data collection and observation of sea cucumber fishing, landing and processing. Fishers hand-picked sea cucumbers using mask and snorkel and sold their catch to exporters or middlemen. Sea cucumber harvesting increased

fishers' income to 154 times the minimum wage in 2010 and 5 times the minimum wage in 2016, concurrent with a drastic decline of stocks. Some fishers rated sea cucumber harvesting as their primary fishing activity but knew very little about their biology or ecology. They were concerned about the decrease in catch that forced them to fish in deeper waters and about the illegal fishing by Guatemalan and Honduran fishers in Belizean waters. Sea cucumbers sold locally since 2009 were neither reflected in the market economy nor used to adjust the Total Allowable Catch by the Belize Fisheries Department. Maintaining the long-term sustainability of this fishery will rely on greater investments in enforcing fisheries regulations, in scientific research to determine the viability of sea cucumber fishing, and in the education of fishers. A closer collaboration with fishers is necessary to adequately inform future management decisions on the socioeconomic consequence of overfishing.

Rosales, R. M., Pomeroy, R., Calabio, I. J., Batong, M., Cedo, K., Escara, N., . . . Sobrevega, M. A. (2017). Value chain analysis and small-scale fisheries management. *Marine Policy*, 83, 11-21
<https://doi.org/10.1016/j.marpol.2017.05.023>.

A value chain analysis is conducted to identify upgrading, that is, improvements in quality and product design that enable producers to gain enhanced value or through diversification in the product lines served. However, a range of data and information of use to managing small-scale fisheries can be also be produced. Eight value chain studies, carried out for specific fish species in different locations around the Philippines, are examined. Policy and management lessons learned and interventions resulting from the value chain analysis for small-scale fisheries management are discussed. Recommendations for using value chain analysis in small-scale fisheries management include stricter regulation on size limits of harvest, monitoring schemes, certification processes, post-harvest facilities, seasonal closures, social enterprises, credit facilities, and habitat protection.

Shao, Y., Li, C., Chen, X., Zhang, P., Li, Y., Li, T., & Jiang, J. (2015). Metabolomic responses of sea cucumber *Apostichopus japonicus* to thermal stresses. *Aquaculture*, 435, 390-397
<https://doi.org/10.1016/j.aquaculture.2014.10.023>.

Elevated water temperature is generally considered as one of the most widespread and problematic stressors on *Apostichopus japonicus* farming. To date, however, little is known about the intrinsic mechanisms of *A. japonicus* to cope with the rising temperature at the metabolic level. In the present study, the metabolomic responses were characterized in the muscles of *A. japonicus* at two thermal points, 20 °C and 25 °C by 1H NMR-based metabolomics. The results showed that both temperatures disturbed energy metabolism and induced osmotic regulation based on the metabolic biomarkers such as elevated threonine, alanine, arginine, glutamate, tyrosine, histidine, glycine, fumarate, glucose, and AMP and decreased ATP, aspartate, hypotaurine, and choline after exposure for 0 days and 3 days. At 7 days of thermal-stress, several metabolites were similarly altered including the increased glutamine, glycine, glucose, AMP, tyrosine, and histidine and the decreased ATP at 20 °C. Surprisingly, a large amount of amino acids (valine, leucine, isoleucine, threonine, arginine, glutamate, phenylalanine) markedly declined at 25 °C. In addition, the mRNA expression levels of HSP70 and ATP synthase as well as SOD activity and MDA content were also investigated, and their expression levels were significantly altered at different exposure conditions. Our present results provided new insights into thermal-stressed effects on *A. japonicus* at metabolic responses.

Shi, C., Dong, S., Pei, S., Wang, F., Tian, X., & Gao, Q. (2015). Effects of diatom concentration in prepared feeds on growth and energy budget of the sea cucumber *Apostichopus japonicus* (Selenka). *Aquaculture Research*, 46(3), 609-617 <https://doi.org/10.1111/are.12206>.

Eight test diets were used in the experiment: seven fresh diatom (*Cylindrotheca fusiformis*) diets in which diatom occupied 100%, 83.3%, 50%, 33.3%, 20%, 14.3% and 11.1% in dry matter of the feeds (marked as D100, D83, D50, D33, D20, D14 and D11), and a formulated diet (70% *Sargassum thunbergii* powder, 20% sea mud and 10% fish meal, based on dry weight, marked as ST). The results showed that the specific growth rates (SGRs) of the animals fed diets D33, D20, D14 and D11 were not significantly different from the SGR of those fed diet ST. However, the energy allocated to growth for the animals fed with diet D14 was twice that of diet ST. For sea cucumbers fed diet D14 the largest expenditure part was allocated to respiration (55.4%), but for those fed diet ST, the largest part was allocated to faeces (62.7%). The organic content of diet D14 was also much lower than that of diet ST. Frozen diatom diets containing 14% (dry matter weight) fresh diatom could be an environmentally friendly feed as an alternative option for macroalgae powder.

Sitoresmi, D. A. N., & Pursetyo, K. T. (2020). The effect of concrete tanks for the breeding technique of the sand sea cucumber (*Holothuria scabra*). *IOP Conference Series: Earth and Environmental Science*, 441, 012054 <https://doi.org/10.1088/1755-1315/441/1/012054>.

Sea cucumber are one of the Echinodermata type that have nutritional value in high protein content and as the sea of commodities with high economical value. The attempts to Obtain sea cucumber are increasingly declining. Based on the review above, it is noticed that the cultivation of sea cucumber are needed to fulfill the needs of the market and restore the wild population. Sand sea cucumber breeding begins with the preparation of the broodstock rearing media, the availability preparation of the broodstock, water quality management, the broodstock feeding, the broodstock selection for high quality broodstock, conducting the artificial spawning using the method of temperature shock, egg incubation, hatching egg, and the larval rearing. The larvae were fed using the phytoplankton *Chaetoceros* sp. with a feeding frequency of once per day. The water quality parameters measured include temperature, DO, pH and salinity. The obstacles that were found on the sand sea cucumber breeding is the difficulty of getting the high quality of the broodstock, so the egg produced from spawning process are limited.

Song, X., Xu, Q., Zhou, Y., Lin, C., & Yang, H. (2017). Growth, feed utilization and energy budgets of the sea cucumber *Apostichopus japonicus* with different diets containing the green tide macroalgae *Chaetomorpha linum* and the seagrass *Zostera marina*. *Aquaculture*, 470, 157-163 <https://doi.org/10.1016/j.aquaculture.2016.12.035>.

Apostichopus japonicus is one of the main aquaculture species in northern China. The green tide macroalgae *Chaetomorpha linum* and the seagrass *Zostera marina* occur in this region. Our previous study has suggested that *Z. marina* detritus can be a food source for *A. japonicus*. In the present study, we carried out a laboratory simulation experiment for 60 days to understand whether *C. linum* can also be utilized to fulfill the nutrient demands of *A. japonicus*. The powdered *C. linum* and *Z. marina* detritus, mixed in five ratios (100:0; 75:25; 50:50; 25:75; 0:100), were fed to sea cucumbers along with muddy sediment in a fixed proportion. *Sargassum thunbergii* (40%) combined with the muddy sediment (60%) was also used as a standard reference/control diet. Results showed that the specific growth rates

(SGRs), food utilizing efficiencies and energy budgets of *A. japonicus* were strongly influenced by the ratio of *C. linum* and *Z. marina* in their diets. The growth energy deposited in the bodies of sea cucumbers fed higher proportions of *C. linum* was significantly higher than those fed higher proportions of *Z. marina*. Furthermore, sea cucumbers fed on *C. linum* and *S. thunbergii* had similar growth performances. This study indicated that *C. linum* could replace *S. thunbergii* as a food source for *A. japonicus*. Statement of relevance Because of its high nutritive and medical properties, the sea cucumber *Apostichopus japonicus* has become a highly valuable fishery and aquaculture species in Asia. Influenced by eutrophication in coastal waters, blooming events of the green tide algae *Chaetomorpha linum* are increasing around the world, including some natural habitats for *A. japonicus* in northern China. However, whether *C. linum* can also be utilized to fulfill the nutrient demands of sea cucumbers, such as *A. japonicus*, is unknown. We carried out a laboratory simulation experiment for 60 days to study this question. Our results showed that sea cucumbers fed on *C. linum* and *Sargassum thunbergii* had similar performances. Due to its higher protein and lower cellulose contents, *C. linum* was easier for *A. japonicus* to digest and absorb, and more energy per unit of food was converted to growth. This study indicated that *C. linum* could act as a food source for *A. japonicus*. The results of this research are also beneficial for promoting the collection and control of *C. linum*.

Sonnenholzner-Varas, J. I., Moreira, J. A., & Orrala, M. M. P. (2019). Growth performance and survival of *Holothuria theeli* (holothurian) fed with feces of *Tripneustes depressus* (echinoid): A multi-trophic aquaculture approach. *Aquaculture*, 512, 12
<https://doi.org/10.1016/j.aquaculture.2019.734345>.

Integrate Multi-Trophic Aquaculture (IMTA) for deposit-feeding sea cucumbers and herbivorous sea urchin is currently a booming industry worldwide, including South America. Hence, it requires novel biotechnological protocols for culturing juvenile sea urchins and sea cucumbers with a high quality of natural food that meet organisms' nutritional needs. This study evaluated the effect on the growth performance (Specific Growth Rate, Feed Conversion Ratio, Feces Production) and survival of the sea urchin *Tripneustes depressus* (producer of feces) and the sea cucumber *Holothuria theeli* (consumer sea urchin 's feces). Two independent experiments were conducted. For *T. depressus*, experiment #1: diet of seaweeds (D1: *Padina durvillaei*, D2: *Sargassum ecuadorenum*, D3: *Kappaphycus alvarezii*, D4: mix of three seaweeds) and size categories (small, S: 15.0 +/- 1.1 mm test diameter, TD and large, L: 25.0 +/- 1.1 mm TD) were considered. For *H. theeli*, experiment #2: feces of diets of experiment #1 and sediment (with, without sediment) were considered. Experiment #1, SGR: small and large sea urchins fed *P. durvillaei* grew and gained weight faster, respectively (S: 3.0 +/- 0.05 cm TD, 7.9 +/- 0.2 g; L: 2.1 +/- 0.1 cm TD, 5.3 +/- 0.1 g). Sea urchins fed *P. durvillaei* and those of small size had lower FCR (diet: 7.2 +/- 0.6 g; size: 13.1 +/- 2.4 g, $P < .05$) and large and small sea urchins fed *P. durvillaei* (L: 31.1 +/- 2.7 g d⁻¹; S: 11.1 +/- 1.2 g d⁻¹) and mixture of seaweeds produced higher amount of feces per day, respectively (L: 28.9 +/- 1.9 g d⁻¹; S: 10.9 +/- 1.2 g d⁻¹, $P < .05$). Experiment #2, sea cucumbers fed diets plus sediment grew and gained weight faster (1.69 +/- 0.31 cm, 4.1 +/- 0.4 g, $P < .05$) than those diets without sediment (0.96 +/- 0.25 cm, 3.3 +/- 0.4 g). Sea urchins kept in the starved condition massively died at day 80, but sea cucumbers in the starved condition without sediment reduced their length and weight, by 85%, but did not die. This study highlighted the importance of feces of *T. depressus* on the growth of the sea cucumber *H. theeli*. This is a perfectible protocol for production of juveniles of *T. depressus* and *H. theeli* at IMTAs in Ecuador.

Sun, J., Hamel, J.-F., Stuckless, B., Small, T. J., & Mercier, A. (2020). Effect of light, phytoplankton, substrate types and colour on locomotion, feeding behaviour and microhabitat selection in the sea cucumber *Cucumaria frondosa*. *Aquaculture*, 526, 735369 <https://doi.org/10.1016/j.aquaculture.2020.735369>.

While the suspension-feeding sea cucumber *Cucumaria frondosa* is commercially exploited in the North Atlantic and is considered to have potential for integrated aquaculture, the impact of environmental conditions on its behaviour and population structure remains incompletely understood. The present study showed that adults are not photosensitive; they do not exhibit any preference for either illuminated or shaded areas. Within each photoperiod treatment, analyses of the daily activity cycle revealed that the proportion of individuals with feeding tentacles deployed did not change over time; however, the proportion of moving individuals increased in the dark phase under the 12 h light/12 dark regime, but remained constant under continuous light or darkness. Hence, from an aquaculture perspective, long days (i.e. summer photoperiod) might decrease the time spent moving in favour of feeding, potentially shifting the energy budget toward faster growth. Variations in phytoplankton concentration modulated the deployment of tentacles but did not trigger any displacement toward the food source, indicating that feeding responds directly to the presence of food. Moreover, *C. frondosa* exhibited a clear preference for substrates composed of bare rocks and rocks with coralline algae and displayed a weak preference for darker substrate backgrounds. Together, these findings highlight how some key environmental factors can govern the feeding, locomotor activities, and eventual distribution of cold-water suspension-feeding sea cucumbers.

Sun, J., Zhang, L., Pan, Y., Lin, C., Wang, F., Kan, R., & Yang, H. (2015). Feeding behavior and digestive physiology in sea cucumber *Apostichopus japonicus*. *Physiology & Behavior*, 139, 336-343 <https://doi.org/10.1016/j.physbeh.2014.11.051>.

The feeding behavior and digestive physiology of the sea cucumber, *Apostichopus japonicus* are not well understood. A better understanding may provide useful information for the development of the aquaculture of this species. In this article the tentacle locomotion, feeding rhythms, ingestion rate (IR), feces production rate (FPR) and digestive enzyme activities were studied in three size groups (small, medium and large) of sea cucumber under a 12 h light/12 h dark cycle. Frame-by-frame video analysis revealed that all size groups had similar feeding strategies using a grasping motion to pick up sediment particles. The tentacle insertion rates of the large size group were significantly faster than those of the small and medium-sized groups ($P < 0.05$). Feeding activities investigated by charge coupled device cameras with infrared systems indicated that all size groups of sea cucumber were nocturnal and their feeding peaks occurred at 02:00–04:00. The medium and large-sized groups also had a second feeding peak during the day. Both IR and FPR in all groups were significantly higher at night than those during the daytime ($P < 0.05$). Additionally, the peak activities of digestive enzymes were 2–4 h earlier than the peak of feeding. Taken together, these results demonstrated that the light/dark cycle was a powerful environment factor that influenced biological rhythms of *A. japonicus*, which had the ability to optimize the digestive processes for a forthcoming ingestion.

Tolon, T., Emiroğlu, D., Günay, D., & Hancı, B. (2017). Effect of stocking density on growth performance of juvenile sea cucumber *Holothuria tubulosa* (Gmelin, 1788). *Aquaculture Research*, 48(8), 4124-4131 <https://doi.org/10.1111/are.13232>.

Stock density is one among the most important factors in aquaculture that directly influences the growth of organisms; however, there is limited information about the effects of stocking density on growth performance of sea cucumber *Holothuria tubulosa* (Gmelin, 1788) that has a commercial potential and represents a new species for aquaculture. In this study, we investigated the effect of stocking densities on the growth performance of juvenile *H. tubulosa* (40.3 ± 3.34 g) in laboratory conditions. Stocking densities were selected as 6, 15 and 30 ind m² with total biomass 253.3 ± 0.18 , 601.2 ± 0.11 and 1201.4 ± 0.15 g m² respectively. We monitored the growth by wet weights and calculated the growth performance through weight gain, growth rate, specific growth rate, relative weight gain, coefficients of variation and survival rate during 8 weeks of research period. We found that individual mean weight gain in 6 ind m² group was approximately 29.53 g while it was 3.03 g and 4.36 g for 15 ind and 30 ind m² groups respectively. Results have shown that the specific growth rate tends to decrease as the number of individuals in unit area increases. The final mean weight, growth rate, specific growth rate, relative weight gain and coefficients of variation were significantly different among treatment groups. In conclusion, a density of 6 ind m² is recommended for stocking juvenile *H. tubulosa* under rearing conditions. Stocking density of 15 ind m² is not favourable for long term as the growth rate is negligible where 30 ind m² should be avoided in tank-based rearing units.

van Dam-Bates, P., Curtis, D. L., Cowen, L. L. E., Cross, S. F., & Pearce, C. M. (2016). Assessing movement of the California sea cucumber *Parastichopus californicus* in response to organically enriched areas typical of aquaculture sites. *Aquaculture Environment Interactions*, 8, 67-76. Retrieved from <https://www.int-res.com/abstracts/aei/v8/p67-76/>.

An increasing global demand for sea cucumbers has led to interest in benthic ranching of the California sea cucumber *Parastichopus californicus* beneath existing aquaculture sites in British Columbia, Canada, where high levels of total organic matter (TOM) are typical. The objective of the present study was to investigate movement of *P. californicus* in relation to areas of increased organic content to assess the feasibility of sea cucumber ranching beneath existing aquaculture sites. A laboratory experiment using adult sea cucumbers showed that *P. californicus* changed their foraging behaviour based on available amounts of TOM, moving more randomly in high-TOM (~8.0%) areas and more directly in low-TOM (~1.4%) ones. They also moved more rapidly in areas with high TOM than in those with low TOM. As long as animals were exposed to high TOM, they did not abandon random movement. Because of this behaviour, aquaculture tenures may retain a population of cultured individuals, but could also attract wild individuals from the surrounding area.

Wang, G., Meng, Z., Chen, L., Jiang, J., Feng, Y., & Zhang, B. (2020). Effects of kelp residues fermented with probiotics on the culture of sea cucumber, *Apostichopus japonicus*. *Aquaculture Research*, 51(3), 1133-1142 <https://doi.org/10.1111/are.14460>.

The kelp aquaculture production in China is the largest in the world, and a large amount of kelp residue is produced by kelp processing. Kelp residues contain substantial quantities of crude fibre, protein, and residual alginic acid, and may be used as feedstuff for aquaculture animals. In this study, we used probiotics to ferment kelp residues to improve kelp nutrient content and then fed the fermented kelp to the sea cucumber, *Apostichopus japonicus*. To study the effect of fermented feed on sea cucumber, its growth performance, digestive enzyme activity, diversity of intestinal microbiota and water quality of the sea cucumber culture water were determined. Growth performance of sea cucumber fed with fermented feed significantly ($p < .01$) increased when compared with sea cucumber fed with formulated

feed. Amylase, cellulose and alginase activities were significantly ($p < .01$) higher in the fermented feed group when compared with the formulated feed group. The total number and diversity of intestinal microbiota showed a significant increase in sea cucumbers fed with the fermented feed. The water quality of the fermented feed group showed much lower ammonia and nitrite (<0.050 mg/L) levels when compared with the formulated feed group. These results suggest that kelp residues fermented with probiotics enhance the growth, digestive enzyme activities and intestinal microbiota of sea cucumbers and improve the culture water quality. Fermented kelp residues are a new supplementary nutrient source for sea cucumbers and may be applicable to other animal aquacultures.

Wang, J. h., Guo, H., Zhang, T. r., Wang, H., Liu, B. n., & Xiao, S. (2017). Growth performance and digestion improvement of juvenile sea cucumber *Apostichopus japonicus* fed by solid-state fermentation diet. *Aquaculture Nutrition*, 23(6), 1312-1318 <https://doi.org/10.1111/anu.12506>.

In this study, the compound probiotics including *Pseudoalteromonas* Sp D11, *Bacillus subtilis* A142, *Saccharomyces cerevisiae* Y23 and *Lactobacillus plantarum* L54 were applied for solid-state fermenting the artificial diet of juvenile sea cucumber *Apostichopus japonicus*. The quality of solid-state fermented (SSF) feed and its potential effects on growth performance and digestive enzyme activities were investigated. The results showed that, compared to unfermented diet, SSF feed had a better palatability quality; meanwhile, a higher ratio of crude protein, free amino acids and reducing sugars and a lower ratio of crude fibre, crude ash and alginic acid were found in SSF feed. The results of the feeding trial showed that feeding SSF feed could improve growth performance of sea cucumbers more than those fed with the unfermented diet. The results of digestive enzyme assays showed that feeding SSF feed to animals could significantly improve activities of amylase, cellulase, alginic acid enzyme and protease, which implied that fermented feed could improve digestibility of *A. japonicus*. In summary, the SSF feed fermented by compound probiotics had better palatability and nutrition value than unfermented feed. And feeding SSF feed could significantly improve the growth performance and digestion ability for sea cucumbers in the phases of nursery and grow-out.

Wen, B., Sun, Y.-J., Gao, Q.-F., Dong, S.-L., Chen, Z.-Z., & Gao, J.-Z. (2018). Replacement of dietary macroalgae with corn starch in juvenile sea cucumber *Apostichopus japonicus* (Selenka). *Aquaculture Nutrition*, 24(3), 1024-1033 <https://doi.org/10.1111/anu.12639>.

A 70-day experiment was conducted to investigate the optimal dietary macroalgae and substitute proportion by corn starch in juvenile sea cucumber *Apostichopus japonicus*. Sea cucumbers were fed by eighteen different diets formulated with one of the three macroalgae including *Sargassum muticum*, *Gracilaria lemaneiformis* and *Ulva lactuca* and six graded levels (0, 50, 100, 200, 300 and 400 g/kg) of corn starch as the replacements for each seaweed. An isotope mixing model indicated that the relative contribution of corn starch to the growth of *A. japonicus* did not consistently increase, even slightly decreased with increasing dietary corn starch level. The contributions of corn starch to *A. japonicus* fed by diets containing *S. muticum* were higher than those fed by diets containing *G. lemaneiformis* with corresponding corn starch levels or containing *U. lactuca* at 200–400 g/kg replacement proportions. The growth of *A. japonicus* first significantly increased and then decreased with increasing corn starch level, regardless of macroalgal species. The corn starch could replace up to 200 g/kg of dietary *G. lemaneiformis* or *U. lactuca*, even up to 300 g/kg of *S. muticum* without affecting growth performance. Based on the polynomial regression model, the replacement of *S. muticum* with 114 g/kg corn starch was optimal for *A. japonicus*.

Whitefield, C. R., & Hardy, S. M. (2019). Estimates of Reproductive Potential and Timing in California Sea Cucumbers *Parastichopus californicus* (Stimpson, 1857) from Southeast Alaska Based on Natural Spawning. *Journal of Shellfish Research*, 38(1), 191-199, 199
<https://doi.org/10.2983/035.038.0118>.

Accurate estimates of fecundity and spawn timing are essential to fisheries management but can be difficult to obtain in nonaggregating broadcast-spawning species such as the commercially harvested sea cucumber *Parastichopus californicus*. Individuals of *P. californicus* collected from Southeast Alaska (SEAK) over 3 y were examined to determine the timing of spawning based on seasonal variations in gonad indices (GI). Gonad indices measured at different time points in the annual reproductive cycle were compared with gonad lipid content and egg development to validate GI as an indicator of gonad maturation. Fecundity was estimated as the total number of eggs and as the number of viable eggs produced in both live-spawned and strip-spawned animals. Results suggest spawning may occur slightly earlier than previously reported in British Columbia, Canada, where fecundity was about two times higher than in SEAK. Seasonal changes in gonad total lipid and maturation stage were recorded. Gonad index was moderately correlated with both gonad lipid content and maturation stage. Estimates of total fecundity and viable eggs based on live spawning did not significantly differ among the 3 y sampled. Live spawning yielded comparable estimates of total fecundity and viable eggs per gram female wet weight compared with strip spawning. These findings inform aquaculture efforts and management of the commercially harvested SEAK population of *P. californicus*.

Wu, B., Xia, S., Rahman, M. M., Rajkumar, M., Fu, Z., Tan, J., & Yang, A. (2015). Substituting seaweed with corn leaf in diet of sea cucumber (*Apostichopus japonicus*): Effects on growth, feed conversion ratio and feed digestibility. *Aquaculture*, 444, 88-92
<https://doi.org/10.1016/j.aquaculture.2015.03.026>.

A 60-day experiment was conducted to develop a practical diet for sea cucumber (*Apostichopus japonicus*) substituting seaweed with corn leaf. Five experimental diets were constructed with each containing a 70% sea mud. The other 30% is composed of (A) 30% *Sargassum thunbergii* (seaweed) only, (B) 22.5% seaweed and 7.5% corn (*Zea mays*) leaves, (C) 15% seaweed and 15% corn leaves, (D) 7.5% seaweed and 22.5% corn leaves and (E) 30% corn leaves only. The experiment was conducted in 15 plastic aquaria containing seawater, each of which stocked with 20 sea cucumbers. Three replicate groups of sea cucumber were fed one of the five experimental diets. The results revealed that the apparent digestibility coefficients for dry matter (ADMD) and crude protein (ACPD) of the test diets decreased with increasing corn leaf content in diets. Corn leaf content in the sea cucumber diet did not affect the body composition of sea cucumber. 22.5% seaweed can be replaced with powdered corn leaf in the sea cucumber diet without any negative effects on weight gain and specific growth rate (SGR) of sea cucumber. Diet containing higher than 15% corn leaf significantly increased the feed conversion ratio (FCR) of sea cucumber. However, the growth performance and FCR of sea cucumber fed the mixed diet of 15% corn leaf plus 15% seaweed were better than the growth performance and FCR of sea cucumber fed other experimental diets. The regression analysis of dietary corn leaf inclusion level versus SGR revealed that the optimal corn leaf inclusion level was 11.2% for the best growth rate of sea cucumber. Therefore, under the present experimental design and condition, a diet with 70% sea mud plus 18.8% seaweed plus 11.2% corn leaf can be recommended for the best growth performance of sea

cucumber. The findings of this study will encourage feed manufacturers and sea cucumber culturists to utilize corn leaf in producing low-cost aqua-feed.

Xia, B., Sun, Z. L., Gao, Q. F., Dong, S. L., Li, L., Wen, H. S., & Feng, J. X. (2017). Uptake of farming wastes by sea cucumber *Apostichopus japonicus* in polyculture systems of abalone *Haliotis discus hannai*: evidence from C and N stable isotopes. *Aquaculture Environment Interactions*, 9, 223-230 <https://doi.org/10.3354/aei00226>.

With the development of intensive aquaculture, worldwide concerns are increasingly focused on the biological control of farming wastes for the purpose of reducing nutrient loadings. In the present study, 5 experimental polyculture systems combining abalone and sea cucumber (SC) as different inter-species biomass ratios, i.e. 100:0, 70:30, 50:50, 30:70 and 0:100 (referred to as Group A, B, C, D and E, respectively), were set up to evaluate the potential of sea cucumber *Apostichopus japonicus* as scavengers to alleviate the farming wastes derived from the co-culture of abalone *Haliotis discus hannai*. Growth performance and significant isotopic shifts of the SCs in Groups B, C and D demonstrated the uptake of farming wastes, i.e. feces and uneaten feed residues. The proportional contributions of SC assimilated from uneaten feed residues, feces and sea mud were 21.7, 62.5 and 15.8% in Group B, 18.5, 54.3 and 27.2% in Group C, 11.5, 44.4 and 44.1% in Group D, respectively. The results revealed that sea cucumber had great potential to become an effective organic extractive species and aid in the concordant reduction of farming wastes in polyculture systems. The biomass ratio of abalone to sea cucumber 70:30 was recommended for aquaculture practice as providing the greatest economic and environmental benefits.

Xia, B., Wang, J., Gao, Q.-F., Sun, Y., Zhang, L., Ma, J., & Liu, X. (2015). The nutritional contributions of dietary protein sources to tissue growth and metabolism of sea cucumber *Apostichopus japonicus* (Selenka): Evidence from nitrogen stable isotope analysis. *Aquaculture*, 435, 237-244 <https://doi.org/10.1016/j.aquaculture.2014.09.042>.

Stable isotope technologies can effectively yield valuable information on the feasibility of estimating incorporation of specific macro- and micro-nutrients, rather than ingestion, through straightforward procedures with high accuracy and rapid sample analysis. In the present study, sea cucumbers were fed five isonitrogenous and isoenergetic diets containing different ratios of *Sargassum thunbergii* to soybean meal (100:0, 75:25, 50:50, 25:75 and 0:100; in terms of supplied nitrogen content) for 3mo to assess the nutritional contributions of dietary protein sources. The results revealed that owing to the different enzyme systems and biochemical components of tissue and the discrepancy in dietary protein quality, nitrogen isotopic turnover rates exhibited obvious shifts between the tissues and between the experimental diets. Nitrogen half-lives reached 12.48–20.89d for intestine and 25.28–40.37d for body wall, respectively. The faster metabolism in intestine resulted in the higher metabolic contributions to nitrogen turnover (76–79%) than body wall (52–59%). The constant proportional contributions of growth and metabolism between the experimental diets indicated that the tissues kept stable bioenergetic distribution strategy in response to the fluctuation of dietary protein quality. The fractionations ($\Delta^{15}\text{N}$) ranged from 2.07‰ to 3.26‰. Calculated by nitrogen isotopic mixing model and estimated $\Delta^{15}\text{N}$ by time-based turnover model, the biased nutritional contributions of dietary protein sources were observed, demonstrating higher dietary quality and preferential absorption of *S. thunbergii* for sea cucumber.

Xu, Q., Gao, F., Zhang, L., Zhang, T., & Yang, H. (2017). A new tagging method and its early stress effect on the sea cucumber *Apostichopus japonicus*. *Aquaculture*, 468, 156-161
<https://doi.org/10.1016/j.aquaculture.2016.10.002>.

The sea cucumber *Apostichopus japonicus* is a widely exploited species that is highly valued as a traditional medicine and as a food product in China, Singapore, Japan and many other countries of Southeast Asia. With the fast development of sea cucumber fisheries and aquaculture, in-situ investigation is necessary to assess the stock amount, growth and migration of cultured sea cucumbers. Unfortunately, this work is limited for the lacking of effective tagging method for the species. In this study, a calcareous-ring-threading method (CRT method) was tried to tag the sea cucumber *A. japonicus*. The early stress response of the sea cucumber to tagging operation and invasive tag was monitored so as to evaluate the reliability of the new method. This method had a tag retention rate of 84%, which was higher than the T-bar method (65%), during a 1-month experiment. The results showed that the side effects on large individuals (wet weight above 40g) disappeared after 2 days. The individuals with a wet weight below 40g had less tolerance on the new tagging method and couldn't recover after 7 days. It is feasible to select large *A. japonicus* individuals with a wet weight above 60g for this new tagging method. Based on the result of present study, the CRT method is considered to be applicable for tagging *A. japonicus* individuals with wet weights above 60g.

Yokoyama, H. (2013). Growth and food source of the sea cucumber *Apostichopus japonicus* cultured below fish cages — Potential for integrated multi-trophic aquaculture. *Aquaculture*, 372-375, 28-38 <https://doi.org/10.1016/j.aquaculture.2012.10.022>.

In order to examine the efficiency of co-culturing fish with the Japanese common sea cucumber *Apostichopus japonicus*, field cultivation experiments were conducted in Gokasho Bay, central Japan. I cultured *A. japonicus* juveniles below a fish cage and at a control station for 238 days, monitored the wet weight, and analyzed its stable carbon and nitrogen isotopes ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) together with potential food sources, and found that (1) juveniles cultured below fish cages exhibited high survivorship (96%) and significantly higher specific growth rate (1.9%) than those at the control site (1.2%), and (2) the juveniles had significantly reduced $\delta^{13}\text{C}$ values (mean \pm SD= $-19.1\pm 0.3\text{‰}$ vs. $-17.5\pm 0.4\text{‰}$ at the control station), suggesting the incorporation of C3 plant material in fish feed through fish feces and settling organic matter. All sea cucumbers which were further cultured for additional 307 days below fish cages grew to the marketable size (range and mean wet weight= $142\text{--}181\text{g}$, 160g , $n=9$). In order to evaluate the effect of density on growth, 6 culture vessels, in which 1, 5, 10, 15, 20 and 25 juveniles of *A. japonicus* were stocked, were maintained below the fish cage over 118 days. The results showed that the final mean weight of *A. japonicus* decreased from 6.68g to 0.94g as the density increased with a large variation of weight at the end of the experiment (coefficient of variation= $52.1\text{--}62.2\%$), suggesting that there was competition between individuals for a limited food supply and there were intraspecific effects on the growth. This study shows the possibility of integrated multi-trophic aquaculture in which *A. japonicus* is cultured in the water column below fish cages, because the survival and growth of the sea cucumbers were enhanced due to the ability to avoid predator interactions and adverse environmental conditions as well as nutritional feed supply from the fish cage.

Yu, Z., Luo, P., Liu, W., Huang, W., & Hu, C. (2018). Influence of water temperature on physiological performance of the sea cucumber *Holothuria moebii*. *Aquaculture Research*, 49(11), 3595-3600 <https://doi.org/10.1111/are.13826>.

We conducted a laboratory investigation of the influence of water temperature on the physiological performance including faecal production, oxygen consumption, and ammonia excretion rates of the sea cucumber *Holothuria moebii*. Adult *H. moebii* (34.39 ± 5.17 g, wet weight) were exposed to four experimental temperatures (15, 20, 25, and 30°C), which represented the temperature range in their natural habitat. Results showed that the maximum faecal production rate was observed at 30°C (71.06 ± 7.21 mg g⁻¹ day⁻¹), which was significantly higher than at other temperatures. This indicated that, at a high temperature, *H. moebii* could take in more energy than at lower temperatures. The oxygen consumption rate increased with water temperature, and the minimum value observed at 15°C (5.68 ± 0.86 µg O₂ g⁻¹ hr⁻¹) was significantly lower than at other temperatures. The low oxygen consumption rate at 15°C indicated a low level of energy production by *H. moebii* during winter. The maximum ammonia excretion rate observed at 30°C (0.029 ± 0.007 µmol g⁻¹ hr⁻¹) was significantly higher than at other temperatures, and the positive effect of water temperature on nitrogen catabolism indicated the possibility of *H. moebii* being in a better nutritional status during the hot season. The minimum value of O/N ratio at 15°C (25.55 ± 4.70) indicated the mixed utilization of protein- and carbon-based substrates during winter, while the high value of O/N ratios in other treatments (all >32) indicated the dominance of carbohydrate and/or lipid metabolism in warm and hot seasons. The results of this study suggest that *H. moebii* is more suitable for rearing in warm waters (>20°C).

Yu, Z. H., Shawna, R., Bruce, M., Terralynn, L., & Craig, S. (2019). Effect of diets on the feeding behavior and physiological properties of suspension-feeding sea cucumber *Cucumaria frondosa*. *Journal of Oceanology and Limnology*, 11 <https://doi.org/10.1007/s00343-019-9190-x>.

The suspension-feeding sea cucumber *Cucumaria frondosa* has become commercially important in recent years. Finding proper diets is the first important step for intensive aquaculture of this sea cucumber. In this study, adult *C. frondosa* were exposed to one of the following diet treatments: control (no diet provided), two powdered seaweeds (*Ascophyllum nodosum* and *Saccharina latissima*), a commercially available microalgal diet (shellfish diet) and natural seston. The effects of diets on the feeding behavior and physiological properties of sea cucumbers were investigated after a 5-week rearing period. Results show that sea cucumbers fed with shellfish diet exhibited a significantly higher tentacle insertion rate (1.80 ± 0.20 insertion/min) than those fed with seaweed powders, and there was no significant difference between the two groups fed by seaweed powders. No significant difference was found on the fecal production rate among the feeding groups. The minimum oxygen consumption rate was observed in the control group (5.76 ± 0.99 µg O₂ / (g center dot h)), which is significantly lower than individuals fed with *A. nodosum*, shellfish diet, and natural seston; however, no significant difference was shown between those of control and *S. latissima* groups. The maximum ammonium excretion rate was found in the *A. nodosum* group (0.03 ± 0.01 µmol / (g center dot h)), which is significantly higher than other groups. The minimum O/N ratio was observed in the *A. nodosum* group (14.57 ± 1.04), which is significantly lower than the *S. latissima*, shellfish diet, and natural seston groups. Individuals fed with seaweed powders had similar physiological properties with those fed with microalgae diet and natural seston, indicating that *A. nodosum* and *S. latissima* can be explored as promising diets for intensive aquaculture of *C. frondosa*.

Zacarias-Soto, M., & Olvera-Novoa, M. Á. (2015). Effect of Different Diets on Body Biochemical Composition of the Four-sided Sea Cucumber, *Isostichopus badionotus*, Under Culture Conditions. *Journal of the World Aquaculture Society*, 46(1), 45-52
<https://doi.org/10.1111/jwas.12163>.

The successful development of intensive farming of sea cucumbers requires diets tailored to their needs; hence, the objective of this study was to test different commercial diets and measure their effects on the growth and biochemical composition of four-sided sea cucumber, *Isostichopus badionotus*. Three diets were used: diet A (37.66% protein and 7.27% lipids), diet B (20.09% protein and 3.34% lipids), and diet C (14.83% protein and 2.45% lipids). No differences in weight gain among treatments were observed; however, sea cucumbers fed diet C presented lower carcass protein levels. Lipid content decreased in all treatments compared to the initial values. *I. badionotus* maintained its initial body profile regardless of the fatty acids composition of the diets; however, the body level of saturated fatty acids increased significantly in animals fed diets B and C. The concentration of polyunsaturated fatty acids was very low in all diets; nevertheless, the sea cucumbers maintained their corporal levels of C20:2, C20:3n-3, C20:4n-6, C20:5n-3, and C22:6n-3. They are also capable of elongate and desaturate 16C and 18C fatty acids supplied in the diet. These results suggest that *I. badionotus* is capable of maintaining its biochemical composition when fed diets containing at least 20% protein and low levels of lipids.

Zacarías-Soto, M., Olvera-Novoa, M. A., Pensamiento-Villarauz, S., & Sánchez-Tapia, I. (2013). Spawning and Larval Development of the Four-Sided Sea Cucumber, *Isostichopus badionotus* (Selenka 1867), under Controlled Conditions. *Journal of the World Aquaculture Society*, 44(5), 694-705
<https://doi.org/10.1111/jwas.12061>.

The objective of this study was to generate information for the development of *Isostichopus badionotus* culture protocols by determining optimal spawning methods, egg production, length and duration of larval stages, and larval habitat settlement preferences. Studies performed during the spawning seasons of 2010 and 2011 showed that this organism spawns between July and November without mechanical or chemical induction. The larval development has five well-defined stages: early, mid and late auricularia, doliolaria, and pentactula. Juveniles (654.3 µm length) were obtained on average 25 days after fertilization (DAF), when larvae were incubated at 25 ± 1 °C. No preference was observed for any of the materials used for settlement of the larvae. The easy adaptation of *I. badionotus* to the culture conditions and the competence of the larvae to complete metamorphosis while feeding solely on microalgae concentrates make this species an excellent candidate for farming. However, it is necessary to continue designing techniques for larval culture and to establish appropriate captivity conditions that allow multiannual reproduction.

Zamora, L. N., & Jeffs, A. G. (2013). A Review of the Research on the Australasian Sea Cucumber, *Australostichopus mollis* (Echinodermata: Holothuroidea) (Hutton 1872), with Emphasis on Aquaculture. *Journal of Shellfish Research*, 32(3), 613-627, 615
<https://doi.org/10.2983/035.032.0301>.

The Australasian sea cucumber, *Australostichopus mollis*, has an extensive distribution; it is found along the coast of southern Australia and throughout New Zealand's coastal waters. This species is very similar in appearance to the highly prized Japanese sea cucumber, *Apostichopus japonicus*, and as a

consequence has attracted increasing interest for commercial fishing and aquaculture. The sea cucumber *A. mollis* currently supports a small commercial fishery in New Zealand of 10–20 t/y. A review of the research on this sea cucumber indicates that the development of aquaculture for this species has been impeded by a general lack of background biological knowledge. Future research needs to be targeted toward resolving the constraints the aquaculture industry is facing for this species, including reliable methods for broodstock conditioning, mass larval rearing, juvenile nutrition and husbandry, as well as development of effective grow-out technology and identification of suitable farming sites.

Zamora, L. N., Maxwell, K. H., & Jeffs, A. G. (2017). Growth of Hatchery-reared Juveniles of the Australasian Sea Cucumber, *Australostichopus mollis*, Fed with Artificial and Natural Diets. *Journal of the World Aquaculture Society*, 48(4), 643-655 <https://doi.org/10.1111/jwas.12389>.

Australostichopus mollis is the most common and valuable sea cucumber species on the coasts of New Zealand and southern Australia. However, information supporting the development of artificial diets to advance the aquaculture of this species is scarce. In this study, the nutrient absorption, growth, pigmentation, and survival of small (111 mg) and large (434 mg) early juveniles were measured. The juveniles were fed with mussel biodeposits (MB); a commercial hatchery diet-powdered macroalgae (HD); and artificial diets with different protein levels, 5% (5P) and 10% (10P), respectively. During the experiment, survival was greater than 66% in all diet treatments, with the juveniles feeding actively and absorbing all major macronutrients. The small juveniles, which were starting pigmentation, had higher growth rates (0.8–2.5%/d) than the large juveniles (0.2–1.2%/d), which were completing pigmentation. Growth was higher with the MB and HD diets than with the 5P and 10P diets, which could be explained by differences in the food consumption and nutrient absorption among the diet treatments. This study shows the feasibility of developing artificial diets without depending on naturally available ingredients; however, palatability and consumption need to be improved in order to make artificial diets for this species more effective and commercially available.

Zamora, L. N., Yuan, X., Carton, A. G., & Slater, M. J. (2018). Role of deposit-feeding sea cucumbers in integrated multitrophic aquaculture: progress, problems, potential and future challenges. *Reviews in Aquaculture*, 10(1), 57-74 <https://doi.org/10.1111/raq.12147>.

There is significant commercial and research interest in the application of sea cucumbers as nutrient recyclers and processors of particulate waste in polyculture or integrated multitrophic aquaculture (IMTA) systems. The following article reviews examples of existing IMTA systems operating with sea cucumbers, and details the role and effect of several sea cucumber species in experimental and pilot IMTA systems worldwide. Historical observations and quantification of impacts of sea cucumber deposit-feeding and locomotion are examined, as is the development and testing of concepts for the application of sea cucumbers in sediment remediation and site recovery. The extension of applied IMTA systems is reported, from basic piloting through to economically viable farming systems operating at commercial scales. The near-global recognition of the ecological and economic value of deposit-feeding sea cucumbers in IMTA applications within existing and developing aquaculture industries is discussed. Predictions and recommendations are offered for optimal development of sea cucumber IMTA globally. Future directions within the industry are indicated, and key areas of ecological, biological and commercial concern are highlighted to be kept in mind and addressed in a precautionary manner as the industry develops.

Zhang, L., Zhang, T., Xu, Q., Qiu, T., Yang, H., & Liu, S. (2015). An artificial oyster-shell reef for the culture and stock enhancement of sea cucumber, *Apostichopus japonicus*, in shallow seawater. *Aquaculture Research*, 46(9), 2260-2269 <https://doi.org/10.1111/are.12383>.

Because of its high nutritional value and health benefits, aquaculture production of *Apostichopus japonicus* in China is the largest of any single species. Therefore, the development of new farming methods is of considerable significance. In this study, discarded oyster shells have been used to create an artificial reef for the culture of this species. The results have shown that from 6th March 2009 to 26th November 2009, the wet weight of sea cucumber increased from 49.57 ± 1.16 to 79.87 ± 1.46 g ind⁻¹. Between 16th July and 18th October, the specific growth rate and daily weight gain of *A. japonicus* differed significantly from other periods. Population density was higher within the reef compared with outside the reef area, and the difference was significant ($P < 0.01$). The maximum distance between *A. japonicus* individuals within the reef area on 3rd March and 16th July was 65.0 ± 3.3 and 62.9 ± 4.4 cm, respectively, but the difference was not significant ($P > 0.05$). The diatom species attached to the oyster shells were similar to those found in the stomach content of *A. japonicus*. In conclusion, the oyster-shell reef provides a suitable habitat and shelter for the culture of the sea cucumber, *A. japonicus*.

Zhang, Z., Lv, Z., Zhang, W., Shao, Y., Zhao, X., Guo, M., & Li, C. (2019). Comparative analysis of midgut bacterial community under *Vibrio splendidus* infection in *Apostichopus japonicus* with hindgut as a reference. *Aquaculture*, 513, 734427 <https://doi.org/10.1016/j.aquaculture.2019.734427>.

Animal gut harbors diverse microbes in the protection against pathogen invasion and the regulation of host immune responses. In our previous work, we found that environmental factors destroy hindgut intestinal flora to promote pathogen infection in sea cucumber. Midgut microbiota could protect host from pathogen infection via producing of antibiotics and enzymes in human and insect. To address the function role of midgut microbiota, the bacterial community in the midgut of *Apostichopus japonicus* was assessed using 16S rRNA sequencing technology, as well as following the *Vibrio splendidus* infection in this study. Results showed that the relative abundance of Actinobacteria in the midgut under *V. splendidus* infection was lower compared to the normal midgut, and the Clostridiaceae, Ruminococcaceae and Lachnospiraceae were increased under pathogen infection in the midgut at the family level. Notably, the abundance of *V. splendidus* was significantly lower in the midgut than hindgut in both healthy and diseased conditions. Function analysis indicated that the basal metabolic pathways were significantly higher in midgut than hindgut under diseased condition, while, the signaling molecules and interaction, xenobiotics biodegradation and metabolism pathways with the bacteria were lower in midgut than hindgut under *V. splendidus* infection. Less cooperative interactions were dominant in the hindgut in response to pathogen infection, but more cooperative and complex interactions predominated in the microbial community in the midgut under diseased condition. Among them, the interaction with Vibrionaceae was significantly decreased in the midgut compared with the hindgut under *V. splendidus* infection. All our results suggested the difference function role of the microbiota in midgut and hindgut of sea cucumber, in which *V. splendidus* was more likely to colonized in the hindgut and promote the occurrence and development of skin ulceration syndrome, rather than the midgut.

Section IV: Population Abundance & Trends

Calderon-Aguilera, L. E., Graham, L. J., & Eigenbrod, F. (2019). Ignoring the spatial structure of the sea cucumber *Isostichopus fuscus* distribution when granting quotas can be costly. *Ocean & Coastal Management*, 178, 104859 <https://doi.org/10.1016/j.ocecoaman.2019.104859>.

There is an increasing demand for fisheries resources worldwide. For example, the Asian markets have traditionally consumed sea cucumber as a delicacy and their buoyant economies have promoted demand for it in recent years. The brown sea cucumber *Isostichopus fuscus* is the most valuable species from the Eastern Pacific and it has been almost depleted due to overfishing. In this work, we analyzed data of sea cucumber abundance collected monthly (October 2014–December 2016) along the west coast of the Gulf of California (29.95 oN – 28.05 oN) in 1,107 swath (25 × 2 m) quadrats performed at 118 sites with the goal of determining if current fishing quotas are sustainable. We applied a Bayesian hierarchical modelling approach with integrated nested Laplace approximation (INLA) to this data to account for spatial structure in the data when calculating densities. The observed density ranged from a minimum of 0 to a maximum of 0.58 ind/m², with an average of 0.03 ind/m² in suitable habitat, defined as the habitat less than 30 m deep and with hard substrate. There are large spatial variations in abundance, but the overall mean suitable habitat is 15.7% (min = 7.8%, max = 28.8%) of the total fishing area. Current quotas are usually higher than 5% of the lower bounds of population density estimates. We propose, among other management measures, that quotas should be granted taking into account the spatial structure of sea cucumber densities as well as the proportion of suitable area within each estate. Given the high levels of illegal fishing within the Gulf of California, it is imperative that quotas are based on the lower bounds of spatially explicit density estimates – along with increased surveillance and enforcement – if the long-term commercial sustainability of the fishery is to be maintained.

Eriksson, H., Conand, C., Lovatelli, A., Muthiga, N. A., & Purcell, S. W. (2015). Governance structures and sustainability in Indian Ocean sea cucumber fisheries. *Marine Policy*, 56, 16-22 <https://doi.org/10.1016/j.marpol.2015.02.005>.

Good governance is paramount to the sustainability of fisheries, and inclusiveness of stakeholder groups has become the centerpiece in the ethos of managing small-scale fisheries. Understanding the effect of governance network structures on fishery sustainability can help guide governance to achieve desired outcomes. Data on resource users, fishing methods, governance networks and classifications of stock health were compiled for 17 sea cucumber fisheries in the Indian Ocean. The subjective influence of the actors and the complexity of governance networks on the health of wild stocks were analyzed. The fisheries differed widely in their resource users, fishing methods and governance networks. Little correspondence was found between the number of nodes in the governance networks and the health (exploitation status) of wild stocks. Government entities dominated the networks but neither their relative influence in the networks nor their proportionate contribution to the number of entities in the networks greatly affected stock health. These findings do not refute the benefits of inclusive governance, but rather suggest that multiple other factors (e.g. inadequate regulations, weak enforcement, high number of fishers) are also likely to play a role in influencing sea cucumber fishery sustainability. These factors must be tackled in tandem with good governance.

Glockner-Fagetti, A., & Benítez-Villalobos, F. (2017). Spatio-temporal variation in density and size structure of the endangered sea cucumber *Isostichopus fuscus* in Huatulco National Park, Mexico. *Marine Ecology*, 38(1), e12386 <https://doi.org/10.1111/maec.12386>.

The brown sea cucumber *Isostichopus fuscus* (Ludwig, 1875) has been subjected to strong fishing pressure and is currently considered an endangered species by the IUCN Red List of Threatened Species. Spatial and temporal variations in density were analysed and population parameters of *I. fuscus* were estimated in three localities of the Southern Mexican Pacific. Density was estimated using circular transects covering a 300 m² area in each locality. Body length and weight were also measured. The mean density was 0.018 ± 0.013 individuals·m⁻², and was statistically significantly lower during summer. The mean length and weight were 22.4 ± 3.8 cm and 396 ± 130 g, respectively, and statistically significant differences were found among localities. The weight-length relationship was $W = 0.28 \cdot L^{1.32}$ and the mean relative condition index (K_n) = 1.04 ± 0.31 . The von Bertalanffy growth equation was $L_t = 38.7 \cdot (1 - \exp(-0.4 \cdot t))$. The lowest values of length, weight and age were found at Dos Hermanas, suggesting that this locality could be favorable for the settlement of larvae and recruitment and growth of juveniles. The present study is the second to estimate densities of *I. fuscus* and the first one to publish data on size structure and growth for the population at Bahías de Huatulco. The densities were so low in the three sampled localities that none of them would be able to support a fishery, even under a sustainable management scheme. The information collected in the present study could be helpful for management programs of the Huatulco National Park, as all the data used for these currently come mainly from the populations of *I. fuscus* in the Gulf of California.

Glockner-Fagetti, A., Calderon-Aguilera, L. E., & Herrero-Pérezrul, M. D. (2016). Density decrease in an exploited population of brown sea cucumber *Isostichopus fuscus* in a biosphere reserve from the Baja California peninsula, Mexico. *Ocean & Coastal Management*, 121, 49-59 <https://doi.org/10.1016/j.ocecoaman.2015.12.009>.

The sea cucumber *Isostichopus fuscus* (Ludwig, 1875) has been exploited, legally, and illegally, on the Baja California peninsula since 1988. The fishery was closed in 1994 due to overfishing symptoms but reopened in 2007 under management strategies and harvesting permits. Nocturnal samplings surveyed abundance, size and weight of *I. fuscus*. Density, proportion of individuals above the minimum size for fishing (MSF), weight-length relationship parameters, relative condition index (K_n), parameters of the von Bertalanffy growth equation (VBGE), individual and average age from the VBGE, natural mortality rate (M) and survival percentage cohort were estimated from the data set for the population in 2005–2007, and compared with the same population in 2013 at the Biosphere Reserve Bahía de los Ángeles. Semi-structured interviews were also conducted to obtain the stakeholders' perspectives and opinions about the fishery. There were no significant differences in the weight-length relationship ($W = 7.17 \cdot L^{1.29}$), relative condition index ($K_n = 1.08$), and parameters of the von Bertalanffy growth equation ($L_\infty = 35.74$ cm, $K = 0.26$ y⁻¹), between the study periods. The population in the 2005–2007 period was mainly constituted by individuals <20 cm in length (90%), probably due to intensive poaching. Only 10% of the population was in the reproductive age (4–5 y; 21 cm), and juveniles were observed (4%). The mean length and proportion of individuals ≥ 20 cm in length increased in the 2013 samplings (17.8 ± 3.8 cm and 35%), although observed mean length is shorter than minimum size for fishing and size at first maturity. On the other hand, density decreased in 2013 (0.15 ± 0.01 ind m⁻²), compared to the 2005–2007 period (0.27 ± 0.04 ind m⁻²). Interviewees agreed that poaching was the main problem for the fishery, as well as the difficulty for fishers to obtain their own harvesting permits, because they were dependent on the permits holders to operate. Our results corroborated that the

growth rate and mortality rate of the *I. fuscus* population in its northernmost geographical distribution were similar to those from southern locations. However, the observed values of the density and mean length were well below those previously registered in Bahía de los Ángeles or in other localities, and may compromise reproductive success, because low recruitment was observed. Some actions are proposed for the sustainable management of this resource.

González-Wangüemert, M., Aydin, M., & Conand, C. (2014). Assessment of sea cucumber populations from the Aegean Sea (Turkey): First insights to sustainable management of new fisheries. *Ocean & Coastal Management*, 92, 87-94 <https://doi.org/10.1016/j.ocecoaman.2014.02.014>.

Sea cucumber stocks have been overfished in many countries. As a consequence, several species (*Holothuria polii*, *Holothuria tubulosa* and *Holothuria mammata*) are now caught in Turkish waters without adequate knowledge on their biology and ecology. Here, we address their morphometry, relationships among gutted length and weight, population dynamics, temporal evolution of catches, and we provide the first insights about technical aspects of their fisheries. The largest size classes of *H. polii* are missing from our sampling collection, possibly due to the heavy fishery pressure on this species. Significant differences in the eviscerated length and weight were found among the Turkish sampled localities for *H. polii* and *H. tubulosa*, respectively. These differences could be explained by higher food availability in some areas and/or differential fishery pressure. The size and weight of *H. tubulosa* specimens were smaller than those registered for the same species in Greek waters, where this species is not fished. All the studied species showed allometric growth. In the last two years, the sea cucumber fishery in Turkey has been increasing rapidly, reaching a total production of ca. 555 000 kg in 2012 (80% *H. polii* and 20% *H. tubulosa* plus *H. mammata*). For a correct management of these species, we recommend: 1) the re-establishment of species-specific closed fishery season according to the specific reproductive cycle; 2) the assessment of the exploited stocks from the Northern Turkish coasts with estimates of recovery time of their populations; 3) the reduction of fishery efforts, mainly on *H. polii* and *H. tubulosa* and 4) the establishment of protected areas (where sea cucumber fisheries are forbidden) to conserve healthy populations which will favour the recruitment on nearby areas.

Hernández-Flores, A., Condal, A., Poot-Salazar, A., & Espinoza-Méndez, J. C. (2015). Geostatistical analysis and spatial modeling of population density for the sea cucumbers *Isostichopus badionotus* and *Holothuria floridana* on the Yucatan Peninsula, Mexico. *Fisheries Research*, 172, 114-124 <https://doi.org/10.1016/j.fishres.2015.07.005>.

Spatial distribution of *Holothuria floridana* and *Isostichopus badionotus* was examined at two sites off the coast of Yucatan: Isla Arena, Campeche, and Dzilam de Bravo, Yucatan, at different times using geostatistics. By means of ordinary kriging, inverse distance weighted and spatial simulation; seven models representing spatial distribution were produced and compared: three for *H. floridana* and four for *I. badionotus*. Spatial continuity of population density was calculated using an experimental variogram. Five types of models were tested (spherical, exponential, linear, linear to sill and Gaussian). Three statistics were obtained to aid in model output interpretation: the proportion of spatial structure, the regression coefficient, and the residual sums of squares for each variogram. Ordinary kriging produced the models with highest goodness-of-fit, indicating that population density was a regionalized variable, especially when populations are at unfished levels. *H. floridana* and *I. badionotus* displayed spatial patterns including patchiness, with some patches covering more than 60km². Fishing changed the spatial structure or patchiness degree of population density. Spatial structure of virgin stocks was

better explained using exponential models; whereas spherical models better represented spatial structure after fishing impacts.

Krasnobaev, A., ten Dam, G., Boerrigter-Eenling, R., Peng, F., van Leeuwen, S. P. J., Morley, S. A., . . . van den Brink, N. W. (2020). Legacy and Emerging Persistent Organic Pollutants in Antarctic Benthic Invertebrates near Rothera Point, Western Antarctic Peninsula. *Environmental Science & Technology*, 54(5), 2763-2771 <https://doi.org/10.1021/acs.est.9b06622>.

Pollutant levels in polar regions are gaining progressively more attention from the scientific community. This is especially so for pollutants that persist in the environment and can reach polar latitudes via a wide range of routes, such as some persistent organic pollutants (POPs). In this study, samples of Antarctic marine benthic organisms were analyzed for legacy and emerging POPs (polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and organochlorine pesticides) to comprehensively assess their current POP concentrations and infer the potential sources of the pollutants. Specimens of five benthic invertebrate species were collected at two distinct locations near Rothera research station on the Antarctic Peninsula (67 degrees 35'8 " S and 68 degrees 7'59 " W). Any impact of the nearby Rothera station as a local source of pollution appeared to be negligible. The most abundant chemicals detected were hexachlorobenzene (HCB) and BDE-209. The highest concentrations detected were in limpets and sea urchins, followed by sea stars, ascidians, and sea cucumbers. The relative congener patterns of PCBs and PBDEs were similar in all of the species. Some chemicals (e.g., heptachlor, oxychlorane, and mirex) were detected in the Antarctic invertebrates for the first time. Statistical analyses revealed that the distribution of the POPs was not only driven by the feeding traits of the species but also by the physicochemical properties of the specific compounds.

López-Rocha, J. A., & Velázquez-Abunader, I. (2019). Fast decline of the sea cucumber *Isostichopus badionotus* as a consequence of high exploitation in Yucatan, Mexico. *Regional Studies in Marine Science*, 27, 100547 <https://doi.org/10.1016/j.rsma.2019.100547>.

Since 2010, the sea cucumber *Isostichopus badionotus*, has been heavily exploited by small-scale fisheries in the Yucatan peninsula, Mexico. Despite management efforts, in the northwest fishing zone of the peninsula, intense fishing pressure led to a decrease in the sea cucumber abundance and discouraged commercial fishing in the area. The objective of this manuscript was to evaluate the decline in the population and its condition after three years without fishing. The degree of decline in the population abundance during three fishing seasons (2010–2012) was assessed through estimates of density (ind ha⁻¹) and catch per unit effort (CPUE) (ind h⁻¹ person⁻¹). Furthermore, catchability (like indicator of relative vulnerability to fishing), and harvest rate were estimated by applying a depletion model. In order to determine the degree of recovery of the population after three years without fishing, density estimates were made in 2015. The results demonstrate a rapid decline in the abundance of sea cucumber. The CPUE diminished by 48% and there was an estimated 93% reduction in density. The rate at which abundance decreased was greater at low population levels with high harvest rates. Overall, the area was overfished and there was no recovery of population abundance, even after three years of no fishing. Illegal fishing and the lack of compliance and enforcement of the management measures could be the main causes of the population decline. Based on the results of this study, we recommend prioritizing the further creation of non-fishing zones and restocking as a priority to population enhancement.

Maniscalco, J. M., Springer, A. M., Counihan, K. L., Hollmen, T., Aderman, H. M., & Toyukak, M. (2020). Contemporary diets of walrus in Bristol Bay, Alaska suggest temporal variability in benthic community structure. *Peer J*, 8, 19 <https://doi.org/10.7717/peerj.8735>.

Pacific walrus (*Odobenus rosmarus divergens*) are a conspicuous and important component of the Bristol Bay ecosystem and human social systems, but very little is known about walrus ecology in this region, principally their feeding ecology. The present work provides contemporary data on the diets of walrus at four haulout locations throughout Bristol Bay between 2014 and 2018. Methods. We analyzed scat and gastrointestinal tract samples from these animals using quantitative polymerase chain reaction to amplify prey DNA, which allowed for diet estimates based on frequencies of prey item occurrence and on the relative importance of dietary items as determined from DNA threshold cycle scores. Results. Diets were highly diverse at all locations, but with some variation in composition that may be related to the time of year that samples were collected (summer vs. autumn), or to spatial variability in the distribution of prey. Overall, polychaetes and tunicates had the highest frequencies of occurrence and relative abundances in 2014-15, but a major change in diet appears to have occurred by 2017-18. While some sample sizes were small, diets in these later years contrasted sharply, with a greater prevalence of sea cucumbers and mollusks, and reduced importance of decapods and fishes compared to the earlier years. Prey identified in scat samples from one collection site also contrasted sharply with those reported from the same location in 1981. The apparent temporal shifts in walrus prey may represent a changing benthic ecosystem due to warming waters in recent decades.

Manuputty, G. D., Pattinasarany, M. M., Limmon, G. V., & Luturmas, A. (2019). Diversity and abundance of sea cucumber (Holothuroidea) in seagrass ecosystem at Suli Village, Maluku, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 339, 012032 <https://doi.org/10.1088/1755-1315/339/1/012032>.

Sea cucumber (Holothuroidea) is one of the marine resources that play an important ecology and economy roles. Sea cucumber has been reported to have high abundance in the seagrass ecosystem at Suli Village, however, its population has been reported to decline quite recently. It is speculated that this problem caused by environmental pressure due to human activity in form of marine tourism and also the change of physical properties of the coast due to abrasion. The aims of this study were to analyze the diversity and abundance of sea cucumber in the seagrass ecosystem of Suli Village. The study was conducted from September to October 2017. A sample of sea cucumber was collected through linear transect quadrat and identified down to species level through microscopic analysis of sea cucumber spicula shape. The number of species found then used to calculate some population ecology parameters. Our result showed that there are 14 species of sea cucumber found in the seagrass ecosystem of Suli Village that belong to 5 genera and 3 families. *Holothuria scabra* being the species with the highest density (0.0347 ind m⁻²) whereas *Stichopus chloronotus* has the lowest density (0.0004 ind m⁻²). Species with the highest abundance is *Holothuria scabra* (4,164 individuals) while the lowest abundance belongs to *Stichopus chloronotus* (53 individuals). In conclusion, the diversity of sea cucumber in Suli Village was considered high but its level of dominance was considered low.

Rawson, K., & Hoagland, P. (2019). Sea cucumbers in a pickle: the economic geography of the serial exploitation of sea cucumbers. *Ecology and Society*, 24(4), 7 <https://doi.org/10.5751/es-11150-240435>.

Serial exploitation comprises a pattern of the human exploitation of wild harvest fisheries, where previously untapped species or locations come under exploitation over both space and time. Unless managed sustainably, serial exploitation can lead to serial depletion of local fisheries, thereby adversely affecting local ecosystems, economies, and communities. Serial depletion is an archetypal problem of the Anthropocene, as its occurrence depends on trade linkages between consumers in one location and suppliers from sometimes geographically very distant fisheries. Invertebrates, especially echinoderms such as sea cucumbers, are subject to serial exploitation that is occurring now on a global scale. We found that the serial depletion of sea cucumbers was consistent with variability in the global mean price for sea cucumbers. When local fisheries are depleted, price tends to rise; a rising price signals previously unexploited fisheries to begin supplying the market. This cycle repeats itself, spreading from the regional to the global scale. Improved understanding of what drives serial exploitation may allow for more successful management of sea cucumber fisheries in the future.

Siegenthaler, A., Cánovas, F., & González-Wangüemert, M. (2015). Spatial distribution patterns and movements of *Holothuria arguinensis* in the Ria Formosa (Portugal). *Journal of Sea Research*, 102, 33-40 <https://doi.org/10.1016/j.seares.2015.04.003>.

Holothurian populations are under pressure worldwide because of increasing demand for beche-de-mer, mainly for Asian consumption. Importations to this area from new temperate fishing grounds provide economic opportunities but also raise concerns regarding future over-exploitation. Studies on the habitat preferences and movements of sea cucumbers are important for the management of sea cucumber stocks and sizing of no-take zones, but information on the ecology and behavior of temperate sea cucumbers is scarce. This study describes the small-scale distribution and movement patterns of *Holothuria arguinensis* in the intertidal zone of the Ria Formosa national park (Portugal). Mark/recapture studies were performed to record their movements over time on different habitats (sand and seagrass). *H. arguinensis* preferred seagrass habitats and did not show a size or life stage-related spatial segregation. Its density was 563 ind.ha⁻¹ and mean movement speed was 10m per day. Movement speed did not differ between habitats and the direction of movement was offshore during the day and shoreward during the night. Median home range size was 35m² and overlap among home ranges was 84%. *H. arguinensis*' high abundance, close association with seagrass and easy catchability in the intertidal zone, indicate the importance of including intertidal lagoons in future studies on temperate sea cucumber ecology since those systems might require different management strategies than fully submerged habitats.

Sitoresmi, D. A. N., & Pursetyo, K. T. (2020). The effect of concrete tanks for the breeding technique of the sand sea cucumber (*Holothuria scabra*). *IOP Conference Series: Earth and Environmental Science*, 441, 012054 <https://doi.org/10.1088/1755-1315/441/1/012054>.

Sea cucumber are one of the Echinodermata type that have nutritional value in high protein content and as the sea of commodities with high economical value. The attempts to Obtain sea cucumber are Increasingly declining. Based on the review above, it is noticed that the cultivation of sea cucumber are needed to fulfill the needs of the market and restore the wild population. Sand sea cucumber breeding begins with the preparation of the broodstock rearing media, the availability preparation of the broodstock, water quality management, the broodstock feeding, the broodstock selection for high quality broodstock, conducting the artificial spawning using the method of temperature shock, egg

incubation, hatching egg, and the larval rearing. The larvae were fed using the phytoplankton *Chaetoceros* sp. with a feeding frequency of once per day. The water quality parameters measured include temperature, DO, pH and salinity. The obstacles that were found on the sand sea cucumber breeding is the difficulty of getting the high quality of the broodstock, so the egg produced from spawning process are limited.

Sonnenholzner, J. I., Searcy-Bernal, R., & Panchana-Orrala, M. (2017). The potential for propagation of the commercial sea cucumber *Isostichopus fuscus* (Ludwig, 1875) by induced transverse fission. *Regional Studies in Marine Science*, 9, 35-42 <https://doi.org/10.1016/j.rsma.2016.10.006>.

This study evaluated the potential to propagate asexually the brown sea cucumber *Isostichopus fuscus* by induction of transverse fission, and its ability to survive, grow and regenerate body parts into a whole animal. Two independent experiments were performed. Experiment 1: sixty-two adult animals (18.8 ± 0.2 cm and 368.1 ± 7.2 g) were cut six centimeters from the rear, and during this process they eviscerated. Survival of body-parts (anterior and posterior) of animals and regeneration times were evaluated, until all individuals showed complete regeneration in terms of its morphology (lasted 13-wk). Animals were maintained in starved condition and had high survivorship (100%). Complete regeneration occurred within 84 to 95 days. Experiment 2: 48 completely regenerated posterior body-parts of *I. fuscus* (with mouth and anus well developed) were used (lasted 13-wk) and animals were fed ad libitum four diets in powder and two controls: diet A with *Ascophyllum nodosum* and *Sargassum* spp; diet B was a commercial shrimp feed with a mix of proteins from marine animals and vegetal material; diet C with *Padina durvillaei* and *Sargassum ecuadoreanum*; and diet D with a mixture of diet C with calcium citrate and Vitamin D. Two controls were used. Survival was not affected by diet but this significantly affected somatic growth rate in length and weight. The fastest growth rates (in length and weight) were for diet B (0.50 ± 0.10 cm month⁻¹ and 0.57 ± 0.11 g month⁻¹) and the lowest for diet A (0.15 ± 0.10 cm month⁻¹ and 0.11 ± 0.07 g month⁻¹). No growth was detected in controls. *I. fuscus* had a high potential for regeneration. Our results encourage further research to explore the feasibility of mariculture and/or restoration programs of wild sea cucumber populations in Ecuador, using asexual propagation techniques for *I. fuscus*.

Sotelo-Casas, R. C., Cupul-Magaña, A. L., Solís-Marín, F. A., & Rodríguez-Troncoso, A. P. (2016). Recruitment patterns of 2 sea cucumber species in a Central Mexican Pacific coral reef community. *Revista Mexicana De Biodiversidad*, 87(1), 86-91 <https://doi.org/10.1016/j.rmb.2015.09.020>.

Holothurians are nutrient recyclers, bioturbators, and prey for other taxa in diverse marine ecosystems; thus, they directly impact the distribution of organisms with which they are associated. However, little is known about annual changes in holothurian recruitment. Islas Marietas harbors a coral community with a rich assemblage of holothurians. From March 2011 to February 2012, bimonthly samplings were performed in order to identify the annual recruitment patterns of species *Pentamera chierchia* and *Neothyone gibber*. Density (indcm⁻²) was assessed for each of the 2 species, as was the micro-substrate abutting them. Both species had highest densities in the May and June period (*N.gibber*= 0.0903indcm⁻²; *P. chierchia*=0.0396indcm⁻²); densities<0.01indcm⁻² were documented over the remainder of the year. This is the first record of *P. chierchia* in the study area. Furthermore, no correlation between species density and substrate type was found ($s \leq 0.61$, $n=7$, $p > 0.05$). The study of seasonal recruitment fluctuations

of reef-associated holothurians and their relationship with factors such as reproduction and availability of coralline substrate may provide information on their life cycles, in order to initially understand some ecological patterns of these species that contribute to the maintenance of regional biodiversity. Wolfe, K., & Byrne, M. (2017). Population biology and recruitment of a vulnerable sea cucumber, *Stichopus herrmanni*, on a protected reef. *Marine Ecology*, 38(1), e12397 <https://doi.org/10.1111/maec.12397>.

Populations of tropical sea cucumbers, harvested for bêche-de-mer, are in a perilous state of conservation, yet there remains a paucity of information on the biology of many harvested species. We examined the population biology of the commercially important curryfish, *Stichopus herrmanni*, across 2 years on Heron Reef, a protected zone in the Great Barrier Reef (GBR) Marine Park. *Stichopus herrmanni*, a species recently listed as vulnerable to extinction, is a major target species for the fishery operating in the GBR. The size class distribution and density of *S. herrmanni* were documented for six sites across Heron Reef. There was distinct spatial variation in the size and density of *S. herrmanni* across sites, with no significant difference between the 2 years. The smallest individuals found were 10 cm long, some of the only juvenile *S. herrmanni* documented in nature. Juvenile and sub-adult populations were found along the leeward reef edge of Heron Reef, a habitat characterized by shallow channels of sand between inter-tidal coral reef and crustose coralline algae (CCA). Juvenile nurseries of sea cucumbers are rarely observed in nature, making this an important observation for understanding the recruitment and population biology of *S. herrmanni*. The presence of juveniles in the consolidated CCA habitat each year in autumn following the summer spawning period, and the absence of small individuals several months later in spring, suggests an ontogenetic migration or displacement of these individuals to adult habitat. The distribution of larger *S. herrmanni* suggests intra-reef connectivity and migration into deeper lagoon areas. This study contributes to understanding the population dynamics of this vulnerable species, a consideration for fisheries management in light of increasing global harvest.

Yanti, A., Tresnati, J., Yasir, I., Syafiuddin, Rahmani, P. Y., Aprianto, R., & Tuwo, A. (2020). Size at the maturity of sea cucumber *Holothuria scabra*. Is it an overfishing sign in Wallacea Region? *IOP Conference Series: Earth and Environmental Science*, 473, 012056 <https://doi.org/10.1088/1755-1315/473/1/012056>.

As the largest trepang producer in the world, Indonesian trepang product still depends on wild catches. This wild catch could cause overfishing. In many fishing areas, sea cucumber populations have decreased to the point where they can be considered as a rare species. The wild catch could lead to a negative impact on size at maturity. Biologically, there are two types of reproductive strategies at marine organisms, i.e. 'r-selection' and 'K-selection'. The 'r-selection' type was found in organisms that are dominantly controlled by their environmental factors and tend to reach physical maturation faster, while the 'K-selection' type was controlled more by biological factors, such as the presence of competitors. This study aims to analyze the size at the maturity of sea cucumber *Holothuria scabra* for different years to find out if the size at maturity can be used as a reference of the overfishing sign in the Wallacea region. The *H. scabra* or sandfishes were taken from the catches of fishermen at the Sub-district Liukang Tupabbiring Utara, Pangkep Regency, South Sulawesi, Indonesia. The Liukang Tupabbiring area is in the Spermonde Islands region, which is part of the Wallace line trajectory. Samplings were carried out for four years, from 2016 to 2019. The parameters measured were a total length (TL), total weight (TW), and gutted body weight (BW). The parameters observed were the color and stage of the gonad. The sizes at maturities were defined as the percentage of sexually mature, which were the sandfish with gonad stages of III, IV, and V. The study reveals that the size at maturity of

sandfish was reached at a smaller size than previously reported. Biologically, smaller sizes at maturity could be a sign that sandfish has overfishing. As one organism whose biological organ structure was still primitive, Sea cucumber probably maintains the continuity of its generation by adapting reproductive strategy “r-selection type”.

Section V: Conservation

Bell, J. D., Purcell, S. W., & Nash, W. J. (2008). Restoring small-scale fisheries for tropical sea cucumbers. *Ocean & Coastal Management*, 51(8), 589-593
<https://doi.org/10.1016/j.ocecoaman.2008.06.011>.

Overfishing threatens to extinguish local fisheries for valuable tropical sea cucumbers by reducing population densities to the point where reproductive success trails behind natural mortality (known as depensation or the ‘Allee effect’). Once this happens, conventional management measures alone, such as closed seasons/areas, size limits and gear restrictions, will usually fail to repair the damage. A different suite of active management interventions must be considered to restore the spawning biomass of severely over-exploited populations. These include: (1) restocking no-take zones with hatchery-reared juveniles; (2) aggregating remnant wild individuals in no-take zones; and (3) development of small enterprises to rear wild-caught sea cucumbers in simple sea pens, or dedicated sublittoral areas, to the size above sexual maturity that optimises earnings. The first intervention is currently limited to a few species of tropical sea cucumbers, whereas the second and third interventions can be applied to many species. The third intervention is particularly attractive – it allows fishers to add value to their catch, reverses the effects of fishing from damaging to improving the potential for replenishment by overcoming the Allee effect, and creates multiple groups of spawners to supply recruits throughout the range of the population(s) supporting a fishery.

Eriksson, H., Conand, C., Lovatelli, A., Muthiga, N. A., & Purcell, S. W. (2015). Governance structures and sustainability in indian ocean sea cucumber fisheries. *Marine Policy*, 56, 16-22
<https://doi.org/10.1016/j.marpol.2015.02.005>.

Good governance is paramount to the sustainability of fisheries, and inclusiveness of stakeholder groups has become the centerpiece in the ethos of managing small-scale fisheries. Understanding the effect of governance network structures on fishery sustainability can help guide governance to achieve desired outcomes. Data on resource users, fishing methods, governance networks and classifications of stock health were compiled for 17 sea cucumber fisheries in the Indian Ocean. The subjective influence of the actors and the complexity of governance networks on the health of wild stocks were analyzed. The fisheries differed widely in their resource users, fishing methods and governance networks. Little correspondence was found between the number of nodes in the governance networks and the health (exploitation status) of wild stocks. Government entities dominated the networks but neither their relative influence in the networks nor their proportionate contribution to the number of entities in the networks greatly affected stock health. These findings do not refute the benefits of inclusive governance, but rather suggest that multiple other factors (e.g. inadequate regulations, weak enforcement, high number of fishers) are also likely to play a role in influencing sea cucumber fishery sustainability. These factors must be tackled in tandem with good governance.

Eriksson, H., Thorne, B. V., & Byrne, M. (2013). Population metrics in protected commercial sea cucumber populations (curryfish: *Stichopus herrmanni*) on One Tree Reef, Great Barrier Reef. *Marine Ecology Progress Series*, 473, 225-234 <https://doi.org/10.3354/meps10054>.

The population ecology of the tropical bêche-de-mer sea cucumber *Stichopus herrmanni* (curryfish) was investigated on One Tree Reef, a no-take protected area in the Great Barrier Reef Marine Park. The size class frequency and density of this species at several sites were determined over 2 years: 2009 and 2011. There was a spatial separation of populations that differed in size and density, but these parameters did not change over the 2 yr of the study, indicating stable population metrics. The spatially heterogeneous population pattern has relevance for fisheries management, as current size limits protect animals with low fecundity that occur in shallow habitat, but make it legal to remove 85% of large, fecund animals in deeper areas. Data for 4 *S. herrmanni* populations were used to address 2 theories on the potential drivers of population structure: (1) adult migration and (2) phenotypic plasticity in growth with respect to habitat conditions. While connectivity through adult migration appears possible, the size structure and location of some populations indicate that population features are determined by post-recruitment growth in the habitat. The latter likely plays a major role in population dynamics and terminal growth of *S. herrmanni*. There was no day-night difference in density at fixed transects, indicating that data obtained in daytime surveys was representative. A frequency distribution profile of density data from manta tows is presented as an alternative to using mean density as an assessment indicator in sea cucumber fisheries. *S. herrmanni* showed a noticeable affinity for reef features, an important finding for improved resolution of spatial planning in management.

Gamboa-Álvarez, M. Á., López-Rocha, J. A., Poot-López, G. R., Aguilar-Perera, A., & Villegas-Hernández, H. (2020). Rise and decline of the sea cucumber fishery in Campeche Bank, Mexico. *Ocean & Coastal Management*, 184, 105011 <https://doi.org/10.1016/j.ocecoaman.2019.105011>.

The present work is the result of an extensive review related to the biological, fishing and management history of the sea cucumber fishery in the region known as Campeche Bank. It also examines the problems associated with its fishing, and the alternatives for sustainable use and its restoration. The following two periods of development of the sea cucumber fishery were analysed: (1) promotion fishing (2000–2012) and (2) commercial fishing (2013–2018). The promotion fishing period was characterised by operating without precautionary management measures and by concentrating unsustainable effort on the north and west coast of the Campeche Bank, which caused possible negative ecological effects. During the commercial fishing period, illegal catches were difficult aspect to control, the management measures developed were not respected and social conflicts worsened. In addition to the fishing record, the review offers basic biological information for the fisheries management of *Isostichopus badionotus* and unpublished material of sea cucumber seizures in the region. It is considered that the contributions of this review justify the need to develop new commercial, exploitation and restoration strategies for the sea cucumber fishery in the Campeche Bank, Mexico.

Meloni, D., & Esposito, G. (2018). Hygienic and commercial issues related to the illegal fishing and processing of sea cucumbers in the Mediterranean: A case study on over-exploitation in Italy between 2015 and 2017. *Regional Studies in Marine Science*, 19, 43-46 <https://doi.org/10.1016/j.rsma.2018.03.009>.

Seven species of sea cucumbers can be found in the Mediterranean Sea. In the last decades, the harvesting of sea cucumbers for “bêche-de-mer” has become increasingly important in the Mediterranean region due to increasing consumer demands in Asia as well as moratoriums in many producing countries, particularly from the Pacific Islands Region. In the European Union, the harvesting of sea cucumbers is authorized only in production areas classified by a Competent Authority. However, the over-exploitation of sea cucumbers is a concern and has contributed to low stocks of natural populations in some localities. Recently, illegal fishing of sea cucumbers has been reported with increasing frequency along the Italian coasts of the Mediterranean basin, accounting for 52,930 kg of seized products between 2015 and 2017. Moreover, illegal processing plants where sea cucumbers were being processed without the minimum hygiene requirements have been closed and product seized. In this case study, the main problems related to the illegal fishing, processing and marketing of sea cucumbers in Italy have been analysed through a lens of major sanitary and regulatory requirements.

Patankar, V. J. (2019). Attitude, perception and awareness of stakeholders towards the protected marine species in the Andaman Islands. *Ocean & Coastal Management*, 179, 104830
<https://doi.org/10.1016/j.ocecoaman.2019.104830>.

Examining stakeholder's knowledge, perception and attitudes are necessary for effective implementation of laws that are designed to protect and conserve marine biodiversity. In order to understand knowledge, awareness and perception about the law and the species that are protected under the Indian Wildlife (Protection) Act, 1972, I interviewed (N = 159) stakeholders (77 fishermen, 39 authorities and 41 middlemen/traders) in the Andaman Islands, India. Within respondents, mean awareness about different protected marine species was (80%) amongst authorities, followed by (63%) amongst traders/middlemen and (59%) amongst fishermen. The awareness about a few charismatic groups i.e., mammals, reptiles and cnidarians high; whereas awareness about elasmobranchs, fish, sea cucumbers and molluscs low amongst the respondent groups. Amongst several species traded in the islands, the sea cucumber, the trochus and the turbo are in high demand, and there is demand from middlemen and fishers to delist these species. Generalised model revealed that the years of fishing experience, occupation, annual income and age of respondents are important factors in determining awareness of locals towards protected species. Solutions suggested by stakeholders are strict enforcement of the law, education and awareness of protected species, a special task force for dealing with the Indian Wildlife Protection Act, need to curb poaching from foreigners etc. All fishers sell their catch to middlemen/traders who in turn send their catch to mainland India (Tamil Nadu and Kolkata). The knowledge about which government department is responsible for implementation and monitoring of the law is limited amongst all stakeholder groups. The study demonstrates that stakeholder's knowledge, perception and attitude can offer valuable insights towards strengthening the law that protects marine species. Similar studies should be carried out across different coastal states to understand the level of awareness of stakeholders towards protected marine species. Creating awareness, inclusiveness of local stakeholders in decision making, empowering authorities in monitoring can help in strengthening the existing law framework for protected marine species.

Purcell, S. W., & Kirby, D. S. (2006). Restocking the sea cucumber *Holothuria scabra*: Sizing no-take zones through individual-based movement modelling. *Fisheries Research*, 80(1), 53-61
<https://doi.org/10.1016/j.fishres.2006.03.020>.

The valuable sea cucumber *Holothuria scabra*, known as ‘sandfish’, has potential for restocking. However, there is little information available to determine the size of the no-take zones (NTZs) needed to protect the released animals so that they can form nucleus breeding populations. To do this, we measured short-term movement paths of released juvenile (1–105g) and wild adult (130–690g) sandfish in a seagrass bed in New Caledonia. We then developed an individual-based model (IBM) to predict long-term dispersal of sandfish released as juveniles (1–16g) at 1 individual m⁻² within a 1-ha area, drawing on distributions of speed and directionality and the relationship between speed and animal weight from field data. Movement was non-random at the sampling scale used, since animals tended to turn <90° at each 2-h time step. We examined high- and low-growth scenarios by applying 50% and 25% of the modelled growth rates of sandfish held in earthen ponds (where they are known to grow faster). The dispersal of released sandfish was predicted to be limited in the first 2 years, then markedly faster thereafter. After 10 years, 6–12% of surviving animals were predicted to remain in the original 1-ha release site. To protect surviving sandfish as nucleus breeding populations for 10 years, and accepting 10% spillover, square NTZs would need to be 19–40ha. The findings are useful for the management of restocking and pre-defining the size of sites for recapture surveys. Our model allows user-specified values for future releases and should be applicable for other sedentary marine invertebrates where basic data on movement and growth are available.

Renzi, M., & Blašković, A. (2020). Chemical fingerprint of plastic litter in sediments and holothurians from Croatia: Assessment & relation to different environmental factors. *Marine Pollution Bulletin*, 153, 110994 <https://doi.org/10.1016/j.marpolbul.2020.110994>.

This paper increases knowledge on litter transfer from sediments towards the trophic web throughout sea cucumbers, key protected benthic species. In October, sediment and holothurian samples from seventeen sampling sites from Croatian Islands characterized by different levels of protection (Silba n = 7; Telašćica MPA n = 10) were collected. Collected particles ranged in sediments within 113.4–377.8 items/kg d.w., and in holothurians within 0.6–9.4 items/animal, showing sizes within 1.4–10,493 µm. In holothurians, cellulose and cellulose acetate (non-synthetic materials) mean percentages were within 5.0–12.7% of the total amount of particles. Nylon fibres ranged within 0–26.7%; while PP, PE, PA, and PS% were more abundant than in sediments. Among factors of variability tested, “island group” and “level of protection” resulted to affect plastic composition in sediments. Otherwise, other environmental factors (i.e. orientation, morphology of sampling site, *P. oceanica*) were significantly related to chemical composition of microplastic ingested by holothurians.

Rodriguez-Barreras, R., Lopez-Morell, J., & Sabat, A. M. (2017). Effectiveness of two tagging devices in the sea cucumber *Holothuria (Halodeima) grisea*. *Marine and Freshwater Research*, 68(3), 563-567 <https://doi.org/10.1071/mf15473>.

A reliable and harmless mark-recapture method provides valuable information for the management of commercial sea cucumber species. Nevertheless, marking and tracking sea cucumbers is notoriously difficult and represents a serious challenge. In this study, we tested one external and one internal tag in the sea cucumber *Holothuria grisea*. A passive integrated transponder (PIT) tag was inserted into the coelomic cavity in one treatment, whereas a T-bar (external tag) was attached in the upper surface of the body wall in the other treatment; sea cucumbers were then followed for 17 weeks. The tagging procedure caused no evisceration in the experimental groups, nor was a significant difference in growth rate found between treatments. The retention of the PIT tag was low, with 100% lost by Week 9.

Retention of T-bars was higher, with 90% still attached by the end of the Week 8, but retention decreased thereafter as T-bar absorption increased. No relationship was found between initial weight and the number of weeks PIT tags ($r = -0.173$, $P = 0.781$) or T-bars ($r = -0.220$, $P = 0.652$) were retained. Neither the T-bar nor the PIT tags fulfilled the requirements of high retention required for long-term studies. However, we do recommend the use of T-bars for short-term studies for *H. grisea* under laboratory conditions or in a habitat with low substrate complexity.