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Short communication

# Growth and survival of California sea cucumbers (*Parastichopus californicus*) cultivated with sablefish (*Anoplopoma fimbria*) at an integrated multi-trophic aquaculture site

L. Hannah [a], C.M. Pearce [a,*], S.F. Cross [b,c]

[a] Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, British Columbia V9T 6N7, Canada
[b] University of Victoria, Department of Geography and Coastal Aquaculture Research & Training Network, Victoria, British Columbia V8P 5C2, Canada
[c] SEA Vision Group Inc., Courtenay, British Columbia V9N 9N8, Canada

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ABSTRACT

In a 12-month field trial we examined the growth and survival of California sea cucumbers (*Parastichopus californicus*) in suspended culture underneath net pens of sablefish (*Anoplopoma fimbria*) at an experimental integrated multi-trophic aquaculture (IMTA) site. We tested the effects of sea cucumber size (small: 7–99 g and large: 100–565 g whole wet weight) and stocking density (12, 17, and 21 ind $m^{-2}$) on growth and survival in a completely-crossed experimental design. We also compared growth and survival of experimental animals cultured directly under the fish pens with control sea cucumbers grown ~250 m away from the farm. The ability of the sea cucumbers to reduce total organic carbon and total nitrogen from the sablefish faeces was also examined. Small experimental animals grew significantly faster than large experimental individuals, the former increasing in whole wet weight by 27–56% over the 12 months and the latter decreasing by 10–33% over the same period. It was concluded that stocking densities of large animals were too high to produce net positive growth. Stocking density had a significant effect on growth of both size classes, lower densities producing higher growth rates, or less negative growth rates in the case of large animals. Small sea cucumbers suspended directly below the sablefish net pens grew significantly faster than control individuals grown ~250 m away from the farm, which had negative growth over the 12-month period. The small sea cucumbers cultured under the net pens had a high survival rate (mean: 99.5%) and their feeding reduced the total organic carbon and total nitrogen contents of the sablefish faeces by an average of 60.3% and 62.3%, respectively, demonstrating their potential as an important organic-reducing component in IMTA. Suspending sea cucumbers below fish net pens, as opposed to growing them on the seabed, makes their collection and monitoring easier and moves them away from potential seabed predators such as sea stars. This study demonstrated that *P. californicus* is well suited to utilise the heavy fraction of waste from a sablefish farm while providing an additional valuable harvestable product.



## 1. Introduction

There are growing concerns regarding the ability of the environment to sustain the expansion of intensive marine-finfish aquaculture and the effects of inorganic and organic wastes produced at fish farms (Brooks and Mahnken, 2003; Folke and Kautsky, 1989; Mayor and Solan, 2011; Pillay, 2004; Wu, 1995). Integrated multi-trophic aquaculture (IMTA) offers a natural means to utilise some of the waste material from finfish aquaculture as inputs into the production of lower-trophic-level crops of commercial value, increasing both the environmental and economical sustainability of the aquaculture operation by reducing waste output and increasing product diversity (Troell et al., 2009). A successful fully-integrated IMTA system closely mimics natural ecosystem function (Folke and Kautsky, 1992), utilising species at several trophic levels to consume different types of waste: dissolved nutrient fractions can be absorbed by macroalgae, fine particulates consumed by filter-feeding shellfish, and heavier particulates taken up by deposit feeders (Chopin et al., 2001).

Commercial-scale IMTA is established on the Atlantic coast of Canada, where blue mussels (*Mytilus edulis*) and kelp (*Saccharina latissima* and *Alaria esculenta*) are grown adjacent to Atlantic salmon (*Salmo salar*) (Neori et al., 2007; Reid et al., 2009; Ridler et al., 2007). On the Pacific coast of Canada, the pre-commercial-scale testing of IMTA with sablefish (*Anoplopoma fimbria*) in co-culture with Pacific scallops [an unconfirmed hybrid between the Japanese scallop (*Mizuhopecten yessoensis*) and the weathervane scallop (*Patinopecten caurinus*)], kelp (*S. latissima*), and sea cucumbers (*Parastichopus californicus*) has recently begun at a site

* Corresponding author at: Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, British Columbia V9T 6N7, Canada. Tel.: +1 250 756 3352; fax: +1 250 756 7053.
*E-mail address:* Chris.Pearce@dfo-mpo.gc.ca (C.M. Pearce).

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in Kyuquot Sound on the northwest coast of Vancouver Island, British Columbia (BC), Canada. An important part of these early IMTA endeavours on the Pacific coast is the initial testing of potentially suitable invertebrate species. The present study examined growth and survival of deposit-feeding California sea cucumbers (*P. californicus*) consuming heavier particulate fractions of sablefish waste.

Deposit-feeding sea cucumbers can recycle nutrients and bioturbate sediments (Uthicke, 1999), potentially limiting anaerobic bacterial growth and the formation of anoxic zones in highly enriched benthic environments, as may occur underneath shellfish and finfish farms. The majority of studies that have examined co-culture of sea cucumbers with other organisms have utilised shellfish species. In New Zealand, the Australasian sea cucumber (*Australostichopus mollis*) had high survival and growth rates when cultured below green-lipped mussels (*Perna canaliculus*) (Slater and Carton, 2007). In China, sea cucumbers (*Stichopus japonicus*) grew well when co-cultured with scallops (*Chlamys farreri* and *Argopecten irradians irradians*) and oysters (*Crassostrea gigas*) in both closed and open systems (Zhou et al., 2006). In BC, California sea cucumbers (*P. californicus*) suspended below Pacific oysters (*C. gigas*) grew well and had high survival rates (Paltzat et al., 2008), and in China, shrimp are commonly raised successfully in co-culture with sea cucumbers (Martinez-Porchas et al., 2010; Yaqing et al., 2004). Few studies, however, have utilised sea cucumbers to consume waste material at finfish farms. A recent study on juvenile sea cucumbers (*Apostichopus japonicus*) cultured below an open net pen containing red sea bream (*Pagrus major*), found high survivorship and significantly higher growth rate than in control individuals held away from the farm (Yokoyama, 2013).

The California sea cucumber, found from the Gulf of Alaska to Baja California (Brumbaugh, 1980), is a deposit feeder which collects organic matter with peltate feeding tentacles to which detritus adheres and is drawn into the mouth (Cameron and Fankboner, 1984). Feeding activity slows in October to November before visceral atrophy during aestivation in the winter. This process involves reabsorbing of the gut, gonad, respiratory trees, and circulatory system, resulting in an approximate 25% loss of body weight (Fankboner and Cameron, 1985). *P. californicus* is capable of consuming salmon net-pen fouling material, resulting in increased muscle development (Ahlgren, 1998), and has been shown to grow and survive well when suspended below cultured Pacific oysters (Paltzat et al., 2008). Results from both of these studies indicate that the California sea cucumber has potential as an organic-extractive species in IMTA. Sea cucumbers can also fetch a high market price, with a retail value in China of over US $400 kg$^{-1}$ for some species in 2004 (Chen, 2004; Hamel et al., 2001), and thus can contribute to the profitability of a fish farm as a secondary cash crop. There is already a proven Chinese market for *P. californicus*, with a rather lucrative wild fishery occurring in BC [landed value of CAN $3.36 million in 2011 (Fisheries and Oceans Canada, online commercial fisheries statistics)].

In the present study, we examined the effect of stocking density on growth and survival of small and large *P. californicus* suspended below, and consuming organic waste from, a sablefish farm in Kyuquot Sound, BC. Growth and survival of experimental sea cucumbers were compared with control animals cultured away from the sablefish farm. The ability of the sea cucumbers to reduce total organic carbon and total nitrogen from the sablefish faeces was also examined.

## 2. Methods

### 2.1. Description of site

The aquaculture site was located in Kyuquot Sound on the west coast of Vancouver Island, BC (50° 02′ 47.7″ N, 127° 17′ 48.6″ W) and comprised a single array of 12 anchored fish cages, each 15 × 15 × 20 m (L × W × H), in water ~30 m deep. At the beginning of the experiment, two cages were populated with 25,000 sablefish (*A. fimbria*) each. Fish biomass was maintained in each cage over the experimental duration with stocking density being reduced through size grading; by the end of the experiment there were five stocked cages. Fish size increased from ~500 g at the start of the experiment to ~1500 g at its completion. Fish were fed daily at approximately 5% of their body weight with "black cod" feed produced by Taplow Feeds (Vancouver, BC). Ingredients and concentration of various dietary components in the feed are given in Table 1. Also on site during the experiment was a 15-m wide array of Pacific scallops suspended in lantern nets which were 1 m apart, at 7 to 12 m depth, and located downstream and parallel to the fish cages. Downstream from the shellfish there was a grid of 20 lines of kelp (*S. latissima*), each line being 50 m in length with adjacent parallel lines spaced 1 m apart. Tidal circulation at the farm system drives a residual flow that moves water primarily in a direction across the system components, i.e. through the fish cages and then downstream to the suspended shellfish and then farther downstream to the kelp grid.

### 2.2. Collection of animals

Large (whole wet weight: 100–565 g) sea cucumbers were collected by scuba divers from a natural population in Cachalot Inlet, Kyuquot Sound (49° 59′ 54.0″ N, 127° 8′ 23.0″ W) on 13 November 2008. Small (whole wet weight: 7–99 g) sea cucumbers were collected by hand from a population that had settled on an abandoned shellfish farm structure in the same inlet. Due to their low density and cryptic behaviour, collecting sufficient small individuals in a more natural environment was not possible. Animals were placed in containers with ambient seawater, transferred to the IMTA site, placed in cages at approximately 15-m depth, and held for 5 days until experimental setup. A second collection of sea cucumbers was made in the same inlet on 11 March 2009 to furnish additional control cages which were added at this time.

### 2.3. Experimental setup and sampling

On 17 November 2008 sea cucumbers were transferred from their holding cages to a flow-through storage tank (L × W × H: 3 × 1 × 1 m), supplied with ambient seawater pumped from ~5-m depth, and held for 24 h to allow for acclimatisation and expulsion of gut contents. They were measured for whole wet weight (i.e. the entire wet weight of the intact sea cucumber), separated into small (<100 g) and large (>100 g) size categories, and allocated to experimental or control cages. Standard plastic oyster-culture trays (L × W × H: 57 × 57 × 21 cm, surface area: 1.13 m$^2$) were modified with mesh (20-mm and 5-mm mesh for large and small size categories, respectively) added under the lids to aid in sea cucumber containment and with

**Table 1**
Composition of "black cod" (sablefish, *Anoplopoma fimbria*) feed produced by Taplow Feeds, Vancouver, British Columbia, Canada. Sample from September 2007. Information is as listed on fish-feed bags.

| Dietary component | Concentration | |
|---|---|---|
| Crude protein | 46% | |
| Crude fat | 18% | |
| Crude fibre | 2% | Max |
| Moisture | 10% | Max |
| Ash | 10% | Max |
| Vitamin A | 8000 IU kg$^{-1}$ | Min |
| Vitamin D | 1000 IU kg$^{-1}$ | Min |
| Vitamin E | 175 IU kg$^{-1}$ | Min |
| Calcium | 1% | Actual |
| Sodium | 1% | Actual |
| Phosphorus | 0.65% | Actual |

Ingredients: Fish meal, organic wheat, fish oil, wheat gluten, calcium propionate.