MOVEMENT OF THE GIANT RED SEA CUCUMBER
PARASTICHOPOUS CALIFORNICUS

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MOVEMENT OF THE GIANT RED SEA CUCUMBER *PARASTICHOPUS CALIFORNICUS* IN SOUTHEASTERN ALASKA

A
Thesis

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Abstract

This thesis provides information on sea cucumber movement that could inform management of the growing fishery for the sea cucumber, Parastichopus californicus, in Southeast Alaska. Daily movement of individual P. californicus was quantified at six sites to assess spatial variation in movement, at three-month intervals over one year at one site to assess seasonal changes in movement, and densities were measured monthly at three depths over one year. Movements varied among seasons and sites ranging from 0 to 34.5 m·24 h⁻¹, and were highest in summer (mean ± SE = 4.6 ± 0.5 m) and lowest in fall (mean ± SE = 1.9 ± 0.3 m). Densities were highest in spring and summer and lowest in fall and winter. Recently tagged animals move, on average, 2 m more than animals tagged 72 h earlier, indicating that movement is best assessed 48 h after tagging. Stock assessments should be conducted in spring and summer to coincide with increased animal densities, with the fishery occurring in fall and winter to provide a possible refuge for a portion of the population. Overall, P. californicus demonstrate limited adult movement, indicating that populations are geographically limited with little possibility of animal migration or repopulation of adults in harvested areas.
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General Introduction


*Parastichopus californicus* (Phylum Echinodermata, Class Holothuroidea and Family Stichopididae) is distributed from southern California to the Gulf of Alaska, ranging from the intertidal to 249 m in depth, and is found on nearly all types of substrate and in most water current conditions (Lambert 1997). Sea cucumbers can fluctuate in size, weight and thickness by absorption, expulsion and regeneration of their internal organs and through water uptake. Holothurians have worm-like bodies with the mouth and anus at opposite ends and multiple rows of locomotory tube feet (Cox et al. 1969, Hyman 1955). Five muscle bands span the length of a slimy, leathery body wall, which contains microscopic, calcareous ossicles. *Parastichopus californicus* is visually distinguishable from other holothurians by its size, color, and fleshy spikes (papillae) that range in color from orange to dark brown, vary in size, and cover the dorsal side of the animal.
Most holothurians are dioecious and sexual identification from external features is impossible. Their reproductive system lacks a pentamerous arrangement unlike other echinoderms, containing a single gonad that is composed of long branched tubules (McEuen 1987). Temperate holothurians breed mainly during the spring and summer, possibly in response to increasing temperatures (Hyman 1955). *Parastichopus californicus* is a broadcast spawner that reproduces from late spring to August in British Columbia (Cameron and Fankboner 1986) and in July and August in Puget Sound, Washington (Hyman 1955).

*Parastichopus californicus* feeds by moving along the sediment and collecting deposits of detritus with sticky mucus covered tentacles (Cameron and Fankboner 1984). The cucumbers are able to selectively extract organic particles from sediment, which has low organic content and nutrient value (Ahlgren 1998). The specific ecological role of *P. californicus* is unknown, but sea cucumbers have been termed "bioturbators". They alter the sediment through feeding on detritus by either moving sediment to the surface of the benthos through feeding or by depositing sediment onto the surface through feces; thereby influencing the occurrence and abundance of other members of their ecosystems (Brenchley 1981). The sediment processing activities of *Parastichopus parvimensis*, a congener found along the California coast, may influence abundance and distribution of substrate inhabitants in the same habitat by altering the sediment through its feeding behaviors (Muscat 1983).

Perhaps coinciding with low food availability from September to March in British Columbia, *P. californicus* stops feeding, resorbs its internal organs, becomes inactive.
and goes into a hibernative state (Fankboner and Cameron 1985). The state of inactivity may be associated with oocyte and gonad development (McEuen 1987). During the inactive state, weight loss of up to 25% of summer body weight may occur and organs are absorbed mainly by phagocytosis and also possibly by endosymbionts (Fankboner and Cameron 1985). The internal tissues are regenerated several weeks to months later (2 to 4 weeks) (Fankboner and Cameron 1985).

Movement of *P. californicus* in Southeast Alaska has not been studied. Information on seasonal changes in movement and density are needed to: (1) determine timing of stock assessment surveys to provide accurate estimates of abundance, (2) provide data on population movement giving insight on potential of depleted areas becoming repopulated and (3) supply biological information on ideal fishing seasons. Average daily movement of *P. californicus* off the south coast of British Columbia during June through August was 3.9 m on bedrock substrate (Da Silva et al. 1986). Similar movement rates were observed for tropical sea cucumbers: *Holthuria mexicana* 4.5 to 5.5 m·day$^{-1}$, *Isotichopus badionotus* 4.0 to 4.4 m·day$^{-1}$ (Hammond 1982).

*Parastichopus californicus* has a depth distribution from the intertidal to 183 m in Barlow Cove, near Juneau Alaska, (Zhou and Shirley 1996) but extends as deep as 249 m (Lambert 1997). In Sitka, Alaska densities were greatest in shallow waters (above 20 m) in April; two-thirds of the population was found within diver depths (above 15-20 m) (Woodby et al. 2000). Depth distribution in Barlow Cove, near Juneau, Alaska may be constrained by substrate rather than depth (Zhou and Shirley 1996). *Parastichopus californicus* was more abundant on hard substrates than mud and silt in Sitka, Alaska.
Stichopus japonicus, a temperate species similar to P. californicus, has been observed from the intertidal to 100 m (Selin 2001). With its depth distribution explained by temperature (Choe 1963). Environmental factors may affect Echinoderm movement. Sexually mature individuals of Cucumaria frondosa were observed deeper than 20-40 m (normally occupied depths) during winter, and moved to shallow waters (< 20 m) exclusively for spring (Hamel and Mercier 1996). Similar seasonal movement behaviors have also been observed among sea urchin Strongylocentrotus droebachiensis (Drouin et al. 1985). Shifts in depth of P. californicus could also be due to negative phototaxis, which has been observed in the sea urchin S. droebachiensis (Adams 2001) and the sea star Asterias forbesi (Campbell 1984).

The Southeast Alaska sea cucumber fishery began in 1987 near Ketchikan, and in 1990 the Alaska Department of Fish and Game formalized a conservative management plan (Woodby et al. 1993). Within this plan fishing grounds are opened and closed to commercial harvest on a three-year rotation, and control areas are permanently closed to commercial fishing. The annual harvest rate for an area is calculated to take 15% of sea cucumber biomass once every 3 years, which equates to an average of 5% of the biomass harvested per year from assessed areas. In part, this rotation method is used because it costs less to survey one-third of the fishery area than the entire area every year. Stocks are assessed prior to the fishing season to generate guideline harvest levels (catch quotas). Biologists using scuba survey the number of sea cucumbers along a 2 m wide transect perpendicular to shore that runs from mean lower low water (MLLW) to 15 m in depth. Permanently closed areas are sampled in the same manner as fished areas to provide a

In Southeast Alaska, commercial fishing grounds are located near Ketchikan, Sitka, west of Prince of Wales Island (Woodby et al. 1993), and on the west coast of Admiralty Island in Hawk Inlet (Kyle Hebert, ADF&G, November 2002, personal communication). Commercial vessels are limited to two working divers but can have a maximum of three divers per boat and a trip limit of 907 kg per person (Larson et al. 2002). The commercial season runs from October 1 through March 31, with quotas usually being filled no later than December (Peter Hoechstoeger, Alaska Glacier Sea Food, Juneau Alaska, personal communication). The Alaska Commercial Fisheries Entry Commission set the maximum number of permits to 436 divers, although only 247 were active in 2002 (Larson et al. 2002). Ninety percent of sea cucumber tissue is marketable, including muscle bands, gonad, dermis and intestines, which may be eaten raw, boiled, dried, pickled, fried, or ground up and consumed in powder form (Hamel and Mercier 1999). Beche de mer refers to boiled and dehydrated sea cucumber dermis and is the most economically important product (Conand and Byrne 1993). Parastichopus californicus is of intermediate economic value compared to other commercially harvested sea cucumber species (Conand and Byrne 1993).

The total annual commercial catch of P. californicus for Southeast Alaska in 2001 was 716 t (approximately 3,252,000 cucumbers, value based on average weights) worth $2,500,000 exvessel. The average weight of a commercial sea cucumber in 2002 was about 0.20 kg (Larson et al. 2002). The exvessel price of eviscerated sea cucumber was
$0.69 per 0.4535 kg in 1990 and steadily increased to $2.40 per 0.4535 kg in 2000 (Larson et al. 2002) dropping to $1.27 per 0.4535 kg in 2002 and has since increased to $1.50 per 0.4535 kg in 2003 (Peter Hoechstoeger, Alaska Glacier Sea Food, Juneau Alaska, personal communication). The Southeast Alaskan fishery is growing by expansion of fishing grounds and increasing prices (Larson et al 2002). The 1990 world sea cucumber harvest was 120,000 t and valued at over US $ 60 million. In most countries, sea cucumber stocks are overexploited due to high demand and high prices, but stock enhancement projects are promising in some regions (Conand 1998).

The goal of my research is to study spatial and temporal variation in movement and provide improved methods of tracking sea cucumbers. This information could be beneficial to fisheries management and researchers by providing information which determines the best time to conduct stock assessments and harvests, the likelihood of sea cucumbers repopulating overexploited areas and provides methods to track individuals. The topics addressed by the study are divided into two chapters. Spatial and temporal variations in movement, depth distribution, orientation and seasonal density are discussed in Chapter 1, and tag performance and tagging effects on movements are addressed in Chapter 2.
Chapter 1

Temporal and spatial variation in movement of the sea cucumber *Parastichopus californicus* in Southeastern Alaska

1.1 Abstract

Movements of *P. californicus* were studied to aid management by providing insight into appropriate times for stock assessment, the fishery, and data on population movements. Daily (24 h) movement distances of *P. californicus* were recorded during four seasons from October 2002 to July 2003 near Juneau, Alaska. Summer had the highest daily movement median, 3.8 m and mean (mean ± SE = 4.6 ± 0.5 m), while fall had the lowest movement median, 1.3 m and mean (mean ± SE =1.9 ± 0.3 m). Densities were measured monthly at three depths, from July 2002 to August 2003. Highest densities shifted from 12.2 m depth to 7.6 m depth in spring, overall densities were comparatively higher in summer. Daily movements were compared among six sites (two each in Ketchikan, Sitka, and Juneau) during May and June 2003. Movements were highly variable among sites, with no regional patterns. The limited daily movement distances of *P. californicus* suggest the possibility that over-harvested areas may not be repopulated by adults, increasing chances of localized depletion.

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1.2 Introduction

The giant red sea cucumber, *Parastichopus californicus*, in the last two decades has become the center of a growing commercial fishery in Alaska, British Columbia and along the west coast of the continental United States (Lambert 1997). In Southeastern Alaska *P. californicus* is harvested mainly for its body wall and muscle bands. The fishery yielded an annual average of US$ 2.3 million exvessel value during 1998-2002 (Larson et al. 2002). Overall, Southeast Alaskan stocks appear healthy but management could benefit from information relating to adult recruitment, size-age relationships, distribution, life span, and movement (Cameron and Fankboner 1989). Movement information could allow managers to determine the likelihood of adults repopulating an area after harvest, the best time to perform a stock assessment, and the most appropriate time for the fishery to occur.

Individuals move based on their size, life history stage, geographic location, and habitat (Dingle 1996). Movement is defined as the displacement of an organism over time and leads to individuals immigrating to and emigrating from a population, thereby affecting species interactions, reducing genetic variability, and in some cases eliminating chances for localized depletion (Turchin 1998). Movement is a basic function that directly affects a populations size, and for most marine organisms, information on the subject is limited (Turchin 1998).

Movement of the sea cucumber *P. californicus* in Southeast Alaska has not been studied. Average daily movement for *P. californicus* off the south coast of British Columbia during June through August was 3.9 m on bedrock substrate (Da Silva et al.)
1986). Similar average daily movement distances have been observed among tropical sea cucumbers: *Holothuria mexicana* 4.6 m (±2.2 m) and 5.8 m (±2.7 m). *Isotichopus badionotus* 4.0 (±1.2 m) and 4.4 m (±2.4 m) (Hammond 1982). Periods of long-term movement for tropical sea cucumbers may not be random but movements for less than 24 h were random (Hammond 1982). However, *P. californicus* moves and feeds in a random direction with no influence from currents less than 4 km·h⁻¹ (Da Silva et al. 1986). The amount and quality of food are not limiting factors for deposit feeders, but during periods of apparent decreased food availability (end of plankton blooms) during autumn months, *P. californicus* stops feeding and moving (Fankboner and Cameron 1985), entering a state of torpor for several weeks to months.

Factors that determine sea cucumber distribution are substrate, predators, density of adult sea cucumbers, and light and temperature (Mercier et al. 2000). Echinoderm movement to deeper water may be initiated by behavioral modifications due to changes in water temperature, salinity or fresh water influences (Mercier et al. 2000). Fluctuations in salinity have been found to dramatically impact echinoderm populations, causing changes in abundance, population size structure and diversity of species (Drouin et al. 1985). The impact of salinity on *P. californicus* has not been explored.

Movement of *P. californicus* was studied to obtain information that relates specifically to management of its fishery in Southeast Alaska. The goals of this study were to examine spatial and temporal variation in movement. This study had three components: the effects of season on sea cucumber densities and daily (24 h) movement distances, variation of site on daily movement distances, and the effect of tagging on
daily movement. Movements were expected to vary among site and season as were densities, because echinoderms have been shown to exhibit responses to changes in temperature, sunlight, salinity and substrates.

1.3 Materials and Methods

1.3.1 Study Sites

All study sites were 50 by 50 m² in area, and were selected based on abundance of sea cucumbers and logistical reasons. Two sites near Juneau were used to study seasonal and site based differences in movement. The study site at Aaron Island (58° 26.532"N, 134° 49.686"W) in Lynn Canal, 33.8 km northwest of Juneau, Alaska was located on the east side of the island, and ranged in depth from 6 to 22 m (Figure 1.1). Rocky substrate with Laminaria sp. was sporadic, with in site and the predominant substrate was mud with a layer of fine silt to 25 m in depth. The site was shaped like a horseshoe with borders on both sides of large rocky outcroppings that extended to 13.7 m. The Amalga Harbor (58°28.939"N, 134°47.439"W) study site was 40.23 km from Juneau, and located on the eastern side of three small islands positioned at the mouth of the harbor (Figure 1.1). The site ranged in depth from 5 to 20 m. The substrate was mud, silt and pebbles, with clumps of Laminaria sp., and rocky outcroppings at 10 m. The site occasionally experienced high seas because of exposure to westerly winds, unlike the Aaron Island site.

Two sites near Ketchikan were used to study site based differences in movement. The Clover Island (55° 28' 46.6"N, 131° 48' 40.6"W) study site, 32.19 km from Ketchikan, was a small island located near Clover Passage. The site was located on the
northeast side of the island next to a shallow reef (Figure 1.1), with depth at the site no
deeper than 18.3 m. The majority of the site area was composed of vertical rock
outcroppings with one area of sediment flats, at 10.8 m. The exposure and position of the
island in the passage led to potentially strong tidal currents. The second study site was
33.8 km from Ketchikan. Pup Island (55° 29'01.8"N, 131° 49'38.3"W) was located at the
south end of Clover Passage, 2 km northwest of Clover Island (Figure 1.1), and ranged in
depths from 7 to 25 m. The substrate at the site was punctuated with medium sized rocks
on a bed of sandy silt, and Laminaria sp. dominated the substrate to 10 m. A noticeable
slope from shore flattened out to a large expanse at 15.2 m. Substrate overall was silty
with detrital deposits, and little water movement.

Two sites near Sitka were used to study seasonal and site based differences in
movement. The Starrigavan (57° 8.214"N, 135° 22.430"W) study site, 11.3 km north of
Sitka had continuous shoreline with Zostera sp. and Laminaria sp. in the shallows and
sandy silt from 6.2 to 12.2 m (Figure 1.1) and very little current. Located at the northern
end of Starrigavan Harbor, the depth of site area was no deeper than 12.2 m. Cedar Cove
(57°10.795"N, 135°19.943"W) was 8 km north of Starrigavan and about 25 km from
Sitka. The study site was at the south end of the Cove and contained large rocks that
punctuated the substrate at 7.6 m with the surrounding area composed of mud and silt.
The entire area of the site was shallower than 18 m.

1.3.2 Experimental Design and Field Methods

Daily movement distances were compared among seasons during four 4-6 day
periods over one year during October (fall) 2002, January (winter) 2003, April (spring)
2003 and July (summer) 2003 at the Aaron Island study site. Months were organized into four seasons: winter (December, January, February), spring (March, April, May), summer (June, July, August) and fall (September, October, November), and the measurements that occurred during any month within that category are labeled as that season. For each new measurement period, cement blocks (markers) were set parallel to shore in locations where 30 sea cucumbers could be tagged by two divers in 40 min. During the first measurement period, scuba divers located 30 animals and double tagged them \textit{in-situ} on the dorsal anterior end, using a Floy© double T-bar regular FD-94 tag and Dennison© tagging gun similar to tags used by Da Silva et al. (1986) and Muscat (1983). New animals were tagged each trial period. Sea cucumber locations were recorded every day over a 4 to 6 day period to quantify daily movement distances. However, in January, weather forced a break so that the measurements were not consecutively taken but were separated by a one week break. Twenty-four hours after initial tagging, divers relocated as many animals as could be found in 50-60 min and measured distance of the individual from both cement markers, orientation of the animal in relation to shore, depth of the animal, water visibility and temperature. Depth and water temperature were recorded with a Pivot Matrix Master™ (US Diver) dive computer. Water visibility was measured as the maximum horizontal distance visible to the cement block.

Daily movement distances were similarly quantified at study sites in Juneau (Aaron Island and Amalga Harbor), Ketchikan (Clover Pass Island and Pup Island) and Sitka (Starrigavan and Cedar Cove) (Figure 1.1) during May and June 2003 to determine
whether sea cucumber movements varied among sites and regions. Movements were measured with the same procedures described as for seasonal daily movement.

Densities were measured once a month from July 2002 to August 2003 at the Aaron Island site (Figure 1.1) to observe group movements among different depths. The density transects were located over 100 m from the "movement measurement site" at the Aaron Island study site and was similar in substrate and bathymetry. Two divers surveyed three replicate 3 by 25 m long transects at three different depths (7.8 m, 12.3 m and 18.4 m). Each row of three transects was parallel to shore.

1.3.3 Analyses

Sea cucumber movements were estimated using three straight-line measures: (1) the distance from the animal to the first anchor (AC); (2) the distance from the animal to the second anchor (BC); and (3) the distance between the two anchors, measured at the beginning of the movement period (AB) (Figure 1.2). The three measurements were used to estimate the linear movement distance (d) of an animal between time periods i and j as follows (Turchin 1998):

\[ d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \]

where \( x_i \) and \( y_i \) (or analogously for \( x_j \) and \( y_j \)) were computed as

\[ x_i = (AC_i^2 + AB_i^2 - BC_i^2) / 2AB \]

and

\[ y_i = \sqrt{AC_i^2 - x_i^2}. \]
where, \( x_i \) and \( x_j \) represent the locations along the x-axis (as defined by the line \( AB \)) of the animal at time periods \( i \) and \( j \), respectively, while \( y_i \) and \( y_j \) are the respective locations along the y-axis. Discrete movement distances (\( d \)) were estimated for each animal.

The movement data was not normal due to large individual movements that skewed the data. To obtain movement data that were normally distributed, movement distances (\( d \)) were transformed prior to fitting the ANOVA model using a logarithmic transformation:

\[
\tilde{d} = \log_e (d + \alpha),
\]

where \( \alpha \) was estimated using maximum likelihood, conditional on the ANOVA model (Venables and Ripley 1999). For ease in interpreting coefficients, a natural log (\( \log_e (d) \)) transformation was also explored. Results from both transformations were similar, with the same patterns and trends, but the standard log failed to produce normally distributed residuals, due to the data being heavily skewed. The maximum likelihood transformation resulted in normally distributed data. The Shapiro-Wilkes test was used to test normality of the residuals and random effects after transformation for all analyses in this study. The log maximum likelihood data were normal in every instance. The transformed data (\( \tilde{d} \)) were then used in the mixed effects repeated measures ANOVA models described below. Summary statistics used nontransformed data. Medians along with ranges and means were used to provide a clearer picture of typical animal movements, because when data is non-normal, medians represent a more “average” animal movement. All analyses and transformations were performed using S-plus® version 6.0.2.
We analyzed five aspects of this study: (1) comparison of daily movement across seasons, (2) comparison of daily movement across sites and regions, (3) changes in density throughout a year, (4) movement direction, and (5) the effects of tagging on sea cucumber movements. All movements were compared in each analysis using a mixed effects, repeated measures analysis of variance (ANOVA), which treated the effect of the subjects as random (Neter et al. 1996, Zar 1999). In all models, the measurement of depth was standardized to account for tides and the variation in site bathymetry. A “relative” depth was used, which was the depth of animal minus the average depth across all animals at a given site and time. Depth was treated as a cofactor in every analysis. We also addressed the possibility of a tagging effect in every model with factor t-effect. The t-effect factor reported the daily movement distance among different intervals from the time of initial tagging for determining possible tagging effects. Therefore daily movement distances were compared among the 0-24, 24-48, 48-72, 72-96, 96-etc. time periods. If factor t-effect was found significant a proportional effect of the measured distance was determined based on the model coefficients. Multiple comparison tests (Tukey or Sidak tests) were used to determine differences within factors (Zar 1999).

The initial model for seasonal daily movement included three factors and two interactions, which were hypothesized as potential influences on movement rates: season, t-effect, relative depth, season versus depth and season versus t-effect. Daily movement distances were compared among the three regions, each having two sites and occurring within the seasons of spring and summer. A factor, “region”, was created to identify sites as belonging to a particular region, Ketchikan, Sitka or Juneau. The model consisted of
three factors: region; t-effect, depth and two interactions, region versus t-effect and, region versus depth. Variability in movement among six sites and two seasons without the region component was also quantified by four factors: site, season, t-effect, depth and interactions: site versus season, site versus t-effect and site versus depth. An ANOVA was used on the seasonal density model, which had four factors: season, plot, depth and temperature; two interactions: season versus depth, and season versus plot. Tukey's multiple comparison test was used to compare depths (Zar 1999).

Circular statistics were used to determine if short-term and long-term movements were random, if direction of seasonal movement was random and if overall direction of movement at each site was random. The Rayleigh test determined the randomness of the distribution of data around the circle (Zar 1999). All circular tests were run using Oriana (V. 2) (Kovach Computing Services). All data utilized in this study were archived (Appendix 1.1).

1.4 Results

Seventy-nine percent (434/552) of all tagged animals measured for daily movement distance over the four seasons at Aaron Island were recovered. Fall had the largest recovery rate of 93% (Table 1.1). Daily movement varied significantly among seasons (df=3/78, F=9.1759, p<0.0001) at Aaron Island, with fall (df=94, t = -1.725, p=0.0878) and winter (df=83, t = -2.7140, p=0.0081) movements less (roughly half) than spring (Fig. 1.3). There was no difference between spring and summer or fall and winter. Movement was highest and most variable in summer, with median and mean (± SE) movement distance of 3.8 m and 4.6 (± 0.5) m, and lowest and least variable in fall, 1.2 m
and 1.9 (± 0.3) m (Table 1.1). Winter had the single largest daily movement distance of 20.2 m, and fall represented the season with the smallest range of movements. 0.1 to 6.9 m (Table 1.2). Animal 111/112 (tag number) (Figure 1.3) was identified as a possible outlier; however removing it had little effect on results.

During comparisons of movement at different sites in May and June, we recovered 72% (772/1077) of all tagged animals, over all sites. Recovery rates varied among sites from 62 to 81% (Table 1.2). No regional effect was apparent due to high variability among sites. Movement varied among sites (df=5/240, F=10.346, p=<0.0001) and tagging affected movements through 48 hours (df=5/240, F=7.56, p=0.0064). Using the Sidak multiple comparison test, Pup Island and Starrigavan differed significantly (p=<0.05) from Aaron Island, Amalga Harbor and Cedar Cove (Table 1.2). Pup Island had the largest daily median and mean (± SE) movement distances of 7.5 m and 9.4 (± 0.9) m. Amalga Harbor and Cedar Cove tied for the smallest daily median and mean (± SE) movements of 3.0 m and 3.9 (± 0.4) m (Table 1.2). Daily movements at Pup Island were 2.1 (CI: 1.5-3.1) times greater than movements at Aaron Island. Among all sites, Starrigavan in Sitka had the single largest daily movement distance of 34.5 m (Table 1.2).

The largest 48 h movement was 35.1 m at Clover Island, with the smallest 48 h movement occurring at Amalga, 0.1 m (Table 1.3). Overall, 48 h movements were 20% greater than daily movements. Starrigavan had the largest mean (± SE) 48 h movement distance of 11.6 (± 1.1) m and median of 7.2 m but Pup Island had the largest median movement of 9.3 m and mean (± SE) of 8.8 (± 1.5) m (Table 1.3).
Density varied significantly among depth (df=2, SS=31.3, F=13.720, p=0.0000) and depths within seasons (df=6. SS=21.78, F=3.182. p=0.0068). The shallower transect (7.6 m depth) had noticeable increases in density during April and declines in density during November, December and January. The 12.2 m transect increased during September and December and steadily declined from January to April. The deepest transect, 18.3 m had increases in December and July but remained consistent for the remainder months (Figure 1.4). Seasonally, the 12.2 m transect had the highest densities for summer, fall and winter and the 18.3 m transect had the lowest for spring, summer and winter. In general, monthly density increased in September, until an equally dramatic decrease in November and June (Figure 1.4). Overall, the highest densities were recorded in summer, 33% of total animals, and fall had the lowest with 18%, and spring and winter, with 24% and 25%, respectively. From April to June an 8° C temperature increase occurred; temperatures in remaining months were consistent (Figure 1.5). Water visibility was lowest in summer at Aaron Island, visibility at each site was highly variable (Figure 1.6).

The randomness of animal movement direction was compared among season, and short-term movements and long-term movements were examined for each site. Movement direction at Aaron Island was randomly distributed for spring (p>0.05) (Figure 1.7), summer (p>0.05) (Figure 1.8) and winter (p>0.10) (Figure 1.9). Fall was not randomly distributed (Figure 1.10). Short-term movements (24 and 48 h) were random in direction, (p= 0.261 and p=0.175) (Figure 1.11) but movement direction at 144 h was not random at Aaron Island (Figure 1.12). Starrigavan and Aaron Island were the
only two sites that did not have randomly distributed movement directions (p=0.007 and p=0.003) (Figures 1.13 and 1.14). Orientation at Cedar Cove (Figure 1.15), Amalga Harbor (Figure 1.16), Pup Island (Figure 1.17) and Clover Island (1.18) were randomly distributed around the mean overall time periods.

1.5 Discussion

Variation in movement distance was observed among sites and seasons for 24 h and 48 h movements. Movements at Aaron Island, Amagla Harbor and Cedar Cove varied from movements at Starrigavan and Pup Island. Clover Island movements were not different from any site. Differences in each site’s bathymetry may be reason for the variation in movement. Site variation in movement has been observed occurring among tropical species (Hammond 1982). Seasonal daily movement distances were similar between spring and summer, and fall and winter, probably due to temperatures being fairly similar during each two sets of seasons.

Overall, recovery rates were good. Spring and summer had lower rates of recovery due to poor water visibility and increased animal movements; together those variables increased chances of animals being undetected within the search area or for animals emigrating from the search area. Winter also had a low recovery rate, which was possibly due to the break in sampling periods (e.g. a week passed between the second and third day of measurements). The animals not recovered (28% of the total) during the site-based movement study for all time periods could be due to the extreme movements of individuals beyond the site borders or possibly due to being cryptic enough to go undetected during relocation searches. Pup Island and Starrigavan study sites had the
lowest animal recoveries, the Pup Island site was flat, mainly silt substrate, providing few places to hide and more likely animals moved beyond the site borders, and the Starrigavan site was dominated by *Laminaria sp.* and *Zostera sp.* providing animals with more opportunities to be cryptic. Extreme movements for sea cucumbers seem possible, but were not observed for more than a few animals and those were not moving more than 35 m in a day.

*Parastichopus californicus* moved to shallow water (7.6 m) in spring and remained at 12.2 m for other seasons. Densities at all depths decreased after September. The transect surveys suggested the majority of animals stayed around 12.2 m. Woodby et al. (2000) found two-thirds of *P. californicus* populations remained above 20 m in submersible surveys done to 100 m in depth in Southeast Alaska during spring. Seasonal densities at all depths to 33 m decreased in the shallow subtidal for *Parastichopus parvimensis* in September and October (Muscat 1983). Adult *Cucumaria frondosa* also move deeper in fall which coincides with rapidly decreasing water temperature and food availability, going offshore in winter and returning in spring (Hamel and Mercier 1996). At the Aaron Island site, the majority of *P. californicus* remained around 12.2 m; possibly to avoid competition for resources from *Synallactes challenger*, which occupied the 18.3 m transect and maintains a deeper distribution (20-366 m) than *P. californicus* (Lambert 1997). *P. parvimensis* and *P. californicus* ranges overlap along the California coast, however where they overlap *P. californicus* occupies the deeper habitat (Muscat 1983), and it is possible that competition structures these distributions as well. In Oregon and Washington *P. californicus* is found in shallower water than it is in Southern
California. Overall, density data indicates that the population at Aaron Island does not experience large fluxes in numbers and suggests a closed population that is limited in geographic area.

The harvesting for the sea cucumber fishery in Southeast, Alaska occurs in fall, which coincides with the lowest densities found in this study, which may provide unintentional refuge for some animals. Typically, commercial divers harvest above 15 m (Larson et al. 2002), which allows divers the potential to harvest the majority of the animals in an area, as two-thirds of a population were found above 20 m in Sitka, Alaska (Woodby et al. 2000). If one third of the population remains below diver depths during the fall fishery, there is potential for a deep water refuge. We found *P. californicus* primarily within 11 to 13 m depths regardless of site and season, with the exception that in spring the majority were found shallower. Shallower movements in the spring may coincide with spawning times. As a broadcast spawner, *P. californicus* may increase its chances of success if it aggregates around spawning times (Cameron and Fankboner 1986). The seasonal pattern of movement distances had highest movements in spring and summer, possibly due to increases in metabolic activity, increasing water temperatures, and reproductive activity but lowest movements in fall and winter coinciding with the time of gut reabsorption and seasonal evisceration (Fankboner and Cameron 1985).

Animal direction was random over 24 h periods and not random for longer periods (144 h) at most sites. Periods of movement less than one day were random for *Isostichopus badionotus, Holothuria mexicana, Meoma ventricosa,* and *Plagiobrissus grandis* in Discovery Bay Jamaica (Hammond 1982). Movements over 10 days were not
random possibly due to natural boundaries that prevent movements for *I. badionotus* and *H. mexicana* (Hammond 1982). Orientation of *P. californicus* on horizontal substrate was random over many days in British Columbia (Da Silva et al 1986). The substrate and current did appear to be a factor in orientation for this study, as *P. californicus* has demonstrated a preference for hard substrates (Woodby et al. 2000). There were no noticeably strong (> 4 km·h⁻¹) tidal currents occurring during the sampling and substrates were mainly mud and silt for all sites.

Tagging affected movement distances within 48 h from the time of initial tagging. After 48 h no effect was observed, and no mortality or increased predation to individuals was recorded. Previous to this study, many tags and methods have been attempted for monitoring individual sea cucumbers: photo-identification, coded wire tags, stains, various Floy© tags, chemical markers, branding, self-adhering tags, and sonic tags (Conand 1983, Hammond 1982, Lokani 1992, Raj 1998, Graham and Battaglene 2004, Chapter 2); few have been successful. The Floy© double T-bar tag used here allowed successful identification and high retention as observed in tagged field animals twenty-four months after initial tagging (personal observation). The tag affects movement initially, but has no measurable affect on movements after 48 h.

This movement information will help managers to determine the likelihood of adults repopulating an area after harvest, the best time to perform a stock assessment, and the most appropriate time for the fishery to occur. The fishery should not be conducted in the summer or late spring during spawning season. Fall or winter are the most appropriate seasons, because fewer animals seem to be available for harvest due to
decreases in densities. Stock assessments should occur in late spring because animals move shallower and are at peak densities. Spring provides a more accurate estimate of the population in a given area than other times, and animals are more readily available in shallow water. Based on the results of this study, new adults of equal size appear unlikely to migrate to and repopulate an area that has been depleted by harvesting, although fishermen have reported returning to areas they considered “well harvested” and seeing adults. One possibility for this occurrence is that the fishermen did not clean out the area entirely and the sea cucumbers have since moved around, giving the appearance that new animals have moved into the area. The daily movements of *P. californicus* were substantial in comparison to no movement at all, but the likelihood of animals being able to move to repopulate other areas or into other populations seems to be an unlikely possibility. All results for this study were based on short-term measurements but observations of animals possibly exhibiting site fidelity were seen at Aaron Island over the course of a year, in that tagged individuals from previous movement periods were seen year round. Individuals move relatively small distances, exhibit site fidelity and appear to move in circular paths (Appendix 1.2, Appendix 1.3), suggesting, over fished areas are unlikely to be repopulated by adults, increasing the chance for localized depletion to occur. Future research should focus directly on the possibility of localized depletion when fishing an area and determine how long or if harvest grounds can be repopulated naturally.
1.6 Acknowledgments

Thanks to B. Pyper for analytical assistance, K. Shotwell for ArcView knowledge and giving up her free time to dive, S. McMurray for countless dives and my advisor G. Eckert for overall project guidance. A special thanks to my boat and life tenders M. Cieciel and D. Greenwell. This study was funded by the University of Alaska Southeast and the Alaska Department of Fish and Game.
Figure 1.1. Locations of sampling sites in Southeast Alaska. The site based movement study was conducted at Aaron Island, Amalga Harbor, Pup Island, Clover Island, Cedar Cove and Starrigavan in 2003. The seasonal movement study and density study were conducted at Aaron Island only in 2002 and 2003.
Figure 1.2. Method used to estimate linear movement distance for *P. californicus*. At each time period and for each individual, distance was recorded for: AB, the distance between the two anchors, measured at the beginning of each movement period, AC, the distance from the animal to the first anchor and BC, the distance from the animal to the second anchor. Numerals one and two represent the cement anchors.
Figure 1.3. Seasonal movement distance data (m) with possible outliers. Daily movement distances (non-transformed data) of *Parastichopus californicus* during four seasons at Aaron Island, near Juneau, Alaska. Medians denoted by triangle with line, outliers are solid circles with horizontal lines, lines perpendicular to rectangle are the interquartile range and the rectangle top and bottom are the 25th and 75th percentiles.
Figure 1.4. Monthly (mean ± SE) density for *P. californicus* at Aaron Island. Densities were measured near Juneau, Alaska from July 2002 to August 2003. Densities were not measured in October. The three different transect depths are denoted by different shapes.
Figure 1.5. Monthly (mean ± SE) temperature and overall (mean ± SE) densities for *P. californicus*. Densities were measured at Aaron Island near Juneau, Alaska for July 2002 to August 2003. Densities were not measured in October. Temperature was recorded from the 12.2 m transect, density observations were made at the 12.2 m transect.
Figure 1.6. Water visibility distance (m) for 2002-2003 movement distance study. A. Visibility distance for all seasons at Aaron Island, near Juneau Alaska. B. Visibility distance for May and June 2003 at sites in Juneau, Sitka and Ketchikan.
Figure 1.7. Spring movement orientation at Aaron Island. A. Distance and direction moved for all time periods, and B. Frequency of direction observations for all time periods. The line radiating from center is mean angle and the line outside of the plot is the SD of the mean. The shore is represented by 0° for both plots. Missing data indicates no movement direction calculated for individual.
Figure 1.8. Summer movement orientation at Aaron Island. See Figure 1.7 for details.
Figure 1.9. Winter movement orientation at Aaron Island. See Figure 1.7 for details.
Figure 1.10. Fall movement orientation at Aaron Island. See Figure 1.7 for details.
Figure 1.11. Movement direction frequencies at 24 and 48 h for all seasons for *P. californicus* at Aaron Island near Juneau, Alaska. The line radiating from center is mean angle and the line outside of the plot is the SD of the mean. The shore is represented by 0° for both plots.
Figure 1.12. Movement direction at 144 h for all seasons for *P. californicus* at Aaron Island near Juneau, Alaska. See Figure 1.11 for details.
Figure 1.13. Starrigavan orientation directions over all time periods. A. Distance and direction moved. B. Frequency of direction observations. See Figure 1.7 for details.
Figure 1.14. Cedar Cove orientation directions over all time periods. A. Distance and direction moved. B. Frequency of direction observations. See Figure 1.7 for details.
Figure 1.15. Aaron Island orientation directions over all time periods. A. Distance and direction moved. B. Frequency of direction observations. See Figure 1.7 for details.
Figure 1.16. Amalga Harbor orientation directions over all time periods. A. Distance and direction moved. B. Frequency of direction observations. See Figure 1.7 for details.
Figure 1.17. Pup Island orientation directions over all time periods. A. Distance and direction moved. B. Frequency of direction observations. See Figure 1.7 for details.
Figure 1.18. Clover Island orientation directions over all time periods. A. Distance and direction moved. B. Frequency of direction observations. See Figure 1.7 for details.
Table 1.1. Summary statistics for daily movement distances (m). Sample size n, mean, standard error, median, range and recovery rate for daily movements (m) of *P. californicus* at Aaron Island near Juneau, Alaska, during four seasons, 2002-2003. All values are based on non-transformed data.

<table>
<thead>
<tr>
<th>Season</th>
<th>n</th>
<th>Mean</th>
<th>Standard Error</th>
<th>Median</th>
<th>Range</th>
<th>Recovery Rate (%)</th>
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<tbody>
<tr>
<td>Spring</td>
<td>60</td>
<td>4.1</td>
<td>0.3</td>
<td>3.7</td>
<td>0.0—12.1</td>
<td>80</td>
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<tr>
<td>Summer</td>
<td>62</td>
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<td>0.5</td>
<td>3.8</td>
<td>0.1—15.2</td>
<td>71</td>
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<tr>
<td>Fall</td>
<td>27</td>
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<td>1.2</td>
<td>0.1—6.9</td>
<td>93</td>
</tr>
<tr>
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<td>41</td>
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<td>0.7</td>
<td>1.6</td>
<td>0.1—20.2</td>
<td>73</td>
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Table 1.2. Summary statistics for site-based daily movement distances (m). Sample size n, mean, standard error of the mean, median, range and percent recovery rates for 24 h movements (m) of *P. californicus* per site in Alaska. All values are based on non-transformed data, and all data were collected over two seasons in 2003, spring (1) and summer (2) Significant differences (p<0.05) among sites are indicated with a and c but no difference exists for b.

<table>
<thead>
<tr>
<th>Season</th>
<th>n</th>
<th>Mean</th>
<th>Standard Error</th>
<th>Median</th>
<th>Range</th>
<th>Recovery Rate (%)</th>
</tr>
</thead>
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<tr>
<td>Aaron Island a</td>
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<td>62</td>
<td>4.6</td>
<td>0.4</td>
<td>3.8</td>
<td>0.1-15.2</td>
</tr>
<tr>
<td>Aaron Island a</td>
<td>1</td>
<td>60</td>
<td>4.1</td>
<td>0.3</td>
<td>3.7</td>
<td>0.0-12.1</td>
</tr>
<tr>
<td>Amalga Harbor a</td>
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<td>3.9</td>
<td>0.4</td>
<td>3.0</td>
<td>0.2-16.3</td>
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<tr>
<td>Clover Island b</td>
<td>1</td>
<td>42</td>
<td>5.9</td>
<td>1</td>
<td>4.6</td>
<td>0.3-34</td>
</tr>
<tr>
<td>Pup Island c</td>
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<td>49</td>
<td>9.4</td>
<td>0.9</td>
<td>7.5</td>
<td>1.0-30.6</td>
</tr>
<tr>
<td>Cedar Cove g</td>
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<td>3.0</td>
<td>0.1-19.5</td>
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<tr>
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<td>8.9</td>
<td>1.1</td>
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<td>0.1-34.5</td>
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Table 1.3. Summary statistics for site-based 48 h movement distances (m). Sample size (n), mean, median, standard error of the mean and range for *P. californicus* per site in Alaska. All values are based on non-transformed data, and all data were collected over two seasons in 2003, spring (1) and summer (2)

<table>
<thead>
<tr>
<th>Site</th>
<th>Season</th>
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<th>Mean</th>
<th>Error</th>
<th>Median</th>
<th>Range</th>
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<td>4.1</td>
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<tr>
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<td>0.6</td>
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<td>1.5</td>
<td>4.8</td>
<td>0.1-18.1</td>
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<tr>
<td>Pup Island</td>
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<td>26</td>
<td>8.8</td>
<td>1.5</td>
<td>9.3</td>
<td>0.5-18.5</td>
</tr>
<tr>
<td>Clover Island</td>
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<td>8.7</td>
<td>1.7</td>
<td>7.0</td>
<td>0.8-35.1</td>
</tr>
<tr>
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<td>5.1</td>
<td>1.3</td>
<td>5.3</td>
<td>0.3-11.6</td>
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<tr>
<td>Starrigavan</td>
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<td>10</td>
<td>11.6</td>
<td>1.1</td>
<td>7.2</td>
<td>2.6-31.0</td>
</tr>
</tbody>
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1.7 Literature cited


Raj, 1998. Photo-identification of Stichopus mollis. SPC Beche-de-mer Information


Appendix 1.1. Location of archived data. Data from this study is archived online in the Knowledge Network for Biocomplexity (KNB). http://knb.ecoinformatics.org/index.jsp.
Appendix 1.2. Sample plots of five animals for 4 to 6 days. Spring and summer movement path plots for *P. californicus* at Aaron Island near Juneau, Alaska.
Appendix 1.3. Sample plots of five animals for 6 to 12 days. Fall and winter movement path plots for *P. californicus* at Aaron Island near Juneau, Alaska.
Chapter 2

Tag retention and effects of tagging on short-term movement
of the sea cucumber *Parastichopus californicus* in Southeastern Alaska

2.1 Abstract

Sea cucumbers are notoriously difficult to tag, however the identification of individuals is useful for growth, movement, and other biological studies. In this study, retention rates of six different tags were examined, and the effect of tagging on movement was determined for *P. californicus* near Juneau, Alaska. The Floy© single T-bar had the highest retention rate of 70% after 4 months and 20% after 8 months. The movements of animals were monitored during five 24 h trials in August 2003 to assess the effect of tagging on sea cucumber behavior. Treatments consisted of 1) handling and relocating five animals; 2) tagging each of five animals twice *in situ* with Floy© double T-bar tags; and 3) five animals without any treatment, the control. Short-term movements were measured for each group after 1 h, 6 h, and 24 h. Tagged animals moved, on average, 2 m further than control animals within 24 h of tagging. Floy© tags are inexpensive, easily attached, and successfully retained, however short-term behavior may be affected by tagging. It is recommended that, when using Floy© tags, handling is minimized and researchers wait 24 h after tagging before making observations.

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2.2 Introduction

The giant red sea cucumber, *Parastichopus californicus* supports a US$ 2.2 million per year (average from ex vessel values for 1998-2002) dive fishery in Southeast Alaska (Larson et al. 2002). The harvestable components of the sea cucumber are the body wall, longitudinal muscle bands and viscera (Conand and Byrne 1993). However, in Southeastern Alaska sea cucumbers are harvested for their body wall and muscle bands only (Woodby et al. 1993), because the viscera atrophies during the fall season when the fishery occurs (Fankboner and Cameron 1985).

Sustainable fishery management requires knowledge of basic life history information but little is known about adult recruitment, size-age relationships, life span and movement of the giant red sea cucumber (Cameron and Fankboner 1989). Studies of movement require the identification of individuals. Sea cucumbers are difficult to tag and monitor because their size, weight and dermal thickness fluctuate, and they go through yearly physiological changes of absorption and regeneration of their internal organs and muscles (Hyman 1955). Hammond (1982) attempted injection and application of vital stains which proved unsuccessful and led to a tropical sea cucumber, *Euapta lappa*, autotomomizing body sections. Photo-identification was successfully used for individual identification of tropical species *Actinopyga mauritiana* and *Stichopus mollis* (Graham and Battaglene 2004). Animals had to possess individually distinctive markings for successful individual identification (Graham and Battaglene 2004). Genetic identification methods have also been explored. DNA fingerprinting based on amplified fragment length polymorphism has been shown as highly reliable and requires little effort.
compared to other DNA techniques, however only a limited number can be identified in this process, and there is no way to identify individuals in the field (Uthicke and Benzie 2002). Muscat (1983) was successful in tagging *Parastichopus parvimensis* with ½” long Floy® garment tags with a T-bar on the end. Tags were retained in animals up to 44 months later with no adverse effects (Muscat 1983). Conand (1983) found Floy® T-bar tags had low retention rates in the lab and recapture rates under 25% after 3 months for seven sea cucumber species, however several recaptured individuals in the field were found to retain tags over a year.

We performed a laboratory study to determine which of six different tags had the highest retention rates in *P. californicus*. My tagging procedures were based on methods used by Muscat (1983) and Da Silva et al. (1986). Da Silva et al. (1986) used Floy® T-bar tags to investigate orientation and movement of *P. californicus* in British Columbia. They waited 24 hours after tagging before recording measurements and observed no behavioral anomalies from tags, but behavioral observations were not quantified. In a field study to determine the effects of tagging on movement, we used a Floy® double T-bar tag (a tag with two T-bars) and tagged each subject with twice to minimize loss of animals due to tag loss.

The study objectives were to estimate retention rate and ease of attachment for six different tags in the lab and to estimate potential effects of tagging on movement rates of *P. californicus* in the field. We expected T-bars to out perform the cinch, banner, fingerling, and coded wire tags but equals the garment tag in retention rates based on previous tag studies where individuals were monitored using Floy® tags. (Muscat 1983,
Knowledge about tagging effects is important to interpreting results from the year-long movement study described in Chapter 1. To quantify the effect of tagging on movement rates, we conducted an experiment in which we hypothesized the movements of 75 animals, either tagged, handled or control would not differ during August 2003 at a site near Juneau, Alaska.

2.3 Methods

2.3.1 Tag Retention Study

In August 2000, thirty sea cucumbers were tagged with six different tags, to determine which tag had the highest retention rate in *P. californicus*. Tags tested were the cinch tag (Floy© FT-4C), garment tag (Floy©), banner tag (Floy© FTSL-73), coded wire tag (CWT) (Northwest Marine Technology), fingerling tag (Floy© FTF-69) and single T-bar tag (Floy© FD-94) (Figure 2.2). Animals were collected from the field and maintained in flowing seawater under laboratory conditions. Each tag required a different method of application. Cinch tags were attached by piercing a hole with a blunt metal probe through a pinched portion of dermis near the anus on the dorsal side, and the tag was threaded through the newly made hole. The tag was cinched down until flush with the skin, and the tail was trimmed. The garment tag, used successfully by Muscat (1983), was numbered prior to tagging with a waterproof marker. The number was covered in hot melt glue, so that it would not wear off. Garment tags were inserted on the dorsal side, near the anus and midway between the outer dermis and the muscle bands, with a Dennison© tagging gun. Banner tags are streamers attached to a metal needle, which were sewn into the animal and tied off with an overhand knot. The tags were
placed near the midsection of the body with some placed through papillae. CWT tags were injected into the animal using a modified spring-loaded syringe. The metal tag was hand loaded into the tip of the needle and injected at an angle through the body wall into the muscle bands. The CWT was placed on the dorsal anterior end; and tag presence was determined by a metal detector (Handheld Wand Detector U.S. Patent #5,134,370). Fingerling tags were sewn on dorsally into the dermis, at the midsection of the body. Tags were sewn in a z-shaped pattern; attempts were made to penetrate the muscle with the plastic thread. The z-pattern was tied off with a surgeon’s knot, and the ends were trimmed. Tag retention was monitored daily during the first two weeks from initial tagging, and then weekly until no tags remained in the subjects. Animals were checked for presence of tag and any adverse signs caused by tagging including, death, sores, and or discoloration.

2.3.2 Tagging Effect Study

The tagging effect study was conducted in the field, 40.23 km north of Juneau, Alaska at Amalga Harbor (58° 28.939”N, 134° 47.439”W) (Figure 2.1). At this location, we established three 10 m square plots, 20 m apart and separated by prominent rock boundaries. Each plot contained two cement markers, 10 m apart at 8 to 10 m in depth, which were used as reference points for measurement of movement (described in detail below). A rebar post was used to mark the center of each plot, as a reference for placing handled animals. The substrate in and around each plot was similar and consisted of large rocks on a bed of silt and Laminaria sp., and changed to silt and mud around 10 m.
We conducted five replicate movement trials over a two week period between August 4 and August 18, 2003, to determine whether movement rates of sea cucumbers were affected by tagging and handling. Trials were initiated between 0900 and 1100 hours and continued for 24 h. Two divers measured the initial location of each animal, at 0 h, 1 h, 6 h and 24 h. Fifteen animals were followed in each trial: five control animals, five “handled” animals and five “tagged” animals. In the handled treatment each animal was squeezed approximately ten times and moved to the center of the plot. For the tagged treatment each animal was tagged twice *in-situ* on the dorsal anterior end with Floy double T-bar regular FD-94 tags injected by a Dennison tagging gun (Da Silva et al. 1986, Muscat 1983) (Figure 2.3). No tagged animal was ever moved or handled in any way other than being contacted by the needle of the tagging gun. Control animals were not manipulated. To track the control and handled animals, 105 animals were tagged in the study area one month before the study. Methods of tagging were the same used for the tagging treatment. By tagging a month prior to the study, we assumed that any residual effects of tagging on movement would be negligible. Similar procedures were used in California for *P. parvimensis*, in which no effects of tagging on movement were noted over a two-week interval (Muscat 1983). New animals were used for each trial, and no animal was ever reused for another trial under a different treatment.

In the first trial, each of the three treatments was randomly assigned to one of three plots, and treatments were reassigned by rotation to the three different plots in each of the four subsequent trials (Table 2.1). Regardless of treatment, plot 3 was always measured first, and plot 1 was measured last due logistical constraints. Scuba divers
located animals during each measurement period, recorded their distance from both
cement markers, and recorded depth using a Pivot Matrix Master™ (US Diver) dive
computer. In addition, water temperature (measured with a dive computer) and water
visibility were recorded at the cement markers in plot 2 during a given dive session.
During each trial the setup dive during which we tagged, measured and relocated animals
required about one hour. The end of the setup dive was established as time 0h. At 1 h, 6
h, and 24 h later, animals were relocated and their position surveyed. Subsequent dives
for periods 1 h, 6 h and 24 h lasted between 22 to 50 min depending on ability to relocate
animals and air consumption.

2.3.3 Analyses

Sea cucumber movements were estimated using three straight-line measures of
distance recorded at each time period and plot: (1) the distance from the animal to the
first anchor, denoted $AC$; (2) the distance from the animal to the second anchor ($BC$); and
(3) the distance between the two anchors ($AB$), which was always 10 m, as noted above
(Figure 2.4). These measurements were then used to estimate the linear movement
distance ($d$) of an animal between time periods $i$ and $j$ as follows (Turchin 1998):

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}.$$

where $x_i$ and $y_i$ (or analogously for $x_j$ and $y_j$) were computed as

$$x_i = \frac{(AC_i^2 + AB^2 - BC_i^2)}{2AB}$$

and

$$y_i = \sqrt{AC_i^2 - x_i^2}.$$
Here, $x_i$ and $x_j$ represent the locations along the x-axis (as defined by the line $AB$) of the animal at time periods $i$ and $j$, respectively, while $y_i$ and $y_j$ are the respective locations along the y-axis. We estimated three discrete movement distances ($d$) for each animal, corresponding to the 0-1 h, 1-6 h, and 6-24 h movement periods. To examine movement distances over a 24 h period, we calculated two additional measures of movement for each animal. The first was a “cumulative” 24 h movement distance, which was the sum of the three discrete movements (0-1, 1-6 and 6-24 h movements). The second was a “relative” 24 h movement, which was the linear distance an animal moved in 24 h relative to its initial position at time 0 (i.e., from period $i = 0$ h to period $j = 24$ h).

Two sets of analyses were used to estimate the effects of handling and tagging on sea cucumber movements. First, we compared movements for the 0-1, 1-6, and 6-24 h movement periods using a repeated measure analysis of variance (ANOVA) that treated the effect of subjects as random and the other factors as fixed effects (Neter et al. 1996). In the initial model, four factors were included, movement period, treatment, trial, plot, depth of the animal’s location and two interactions: movement period versus treatment and trial versus treatment. Movement period (0-1, 1-6, 6-24 h) was the daily time interval that began when tagging occurred, and treatment was the three manipulations used on the test subjects: handling, tagging and the control. The movement data was not normal due to large individual movements that skewed the data. To obtain movements that were normally distributed, we transformed the movement distances ($d$) using a standard log transformation:

$$\tilde{d} = \log_e(d + 0.05),$$
where 0.05 (representing the addition of 5 cm of movement to remove zero movement measures) was added to all distances. The transformed data \( \tilde{d} \) were then used to estimate the random effects model. We tested for outliers and ran analyses on data sets with and without the outliers to compare possible effects. The Shapiro-Wilkes test was used to test normality of the residuals and random effects after transformation for all analyses in this study. The log maximum likelihood data were normal in every instance. Medians and average movement distances were reported due to extreme skewedness of data set prior to transformation. Medians along with ranges were used to provide a clearer picture of typical animal movements, because when data is non-normal, medians represent a more “average” animal movement. All summary statistics are reported for non-transformed data.

In the second set of analyses, “cumulative” and “relative” movement distances were compared using the similar procedures described above, but a basic ANOVA model was used in place of the repeated measures ANOVA. In this case, the factor “movement type” replaced “movement period” (cumulative versus relative), and other factors included treatment, trial, and plot. No interaction effects among factors were considered due to the possibility of factor confounding. All data utilized in this study has been archived (Appendix 2.1).

### 2.4 Results

In the tagging retention study the single T-bar tag had the highest retention rate. Seventy percent were retained after four months with no observed mortality, and after eight months, the single T-bar and the CWT were the only two tags remaining, with
retention rates of 20% and 17% (Figure 2.4). All other tags were retained for shorter periods. The banner tags had the lowest retention rates and were completely expelled from the subject in less than a month (Figure 2.4).

In the movement effect study, 75 animals were monitored over five trials, however each individual was not always relocated. Overall, 257/285 successful measurements were made, for a 90% recovery rate. Animal recovery varied with movement period (df=2/115, F=45.1645, p<0.0001). The 0-1 h period was highest (100%) and lowest for the 6-24 h period (82%) (Table 2.2). Movements ranged from 0 to 12.5 m, with a tagged animal having moved the farthest (12.5 m) during the 6-24 h movement period (Table 2.2). Treatments (df=2/66, F=11.6234, p<0.0001) were significantly different. Handled animals had the highest median movements for two of the three periods, 0-1 h 0.84 m and 6-24 h 4.90 m, while control animals had the lowest median movements for all time periods 0.4 m, 1.17 m and 1.10 m (time periods 0-1 h, 1-6 h and 6-24 h) (Table 2.2). Animals receiving the handled treatment had the highest averages for all time periods, while control animals had the lowest averages (Figure 2.5). There were significant differences among trials (df=4/66, F=4.6825, p=0.002). In a comparison (Sidak test) of all trials, Trial 5 showed significant variation (p<0.05) with Trial 1, Trial 3 and Trial 2. Trial 1 had the lowest movement distances over all time periods, 50% smaller ± 20%. In a comparison (Tukey test) of treatment, the handled and tagged treatments differed significantly from the control (Figure 2.6). Across all time periods the handled treatment had movements 2.6 times greater than the control (95% confidence interval: 1.7-3.8), while the tagged treatment had movements 1.9 times
greater (CI: 1.4-2.7). Depth distribution was from 9 to 21 m, with most animals between 11 and 13 m. The 0-1 h interval varied significantly from the 1-6 h interval and the 6-24 h interval with the Tukey test (Figure 2.6). Compared to the 0-1 h movement period for all trials and treatments, 1-6 h movements were 2.6 times greater (CI: 2.0-3.3) and 6-24 h had 3.5 times greater movements (CI: 2.6-4.7). Depths (df=1/115, F=5.9393, p=0.013) were shown to vary.

The two movement types cumulative and relative movement differed significantly (df=1, SS=4.290, F=12.6681, p=0.0006). Treatments (df=2, SS=17.1527, F=25.324, p<0.0001) varied significantly; handled treatments had the highest average movement distance (5.4 m), control treatments had the lowest (2.1 m) and tagged treatments had the largest range (0.8-14.3 m) (Table 2.3). Compared to the control animals, tagging resulted in an additional 2 m movement for the relative distance, and the cumulative distance effect was 3.1 m. Movements continued to increase into the 6-24 h period for all treatments, including the control, but at different rates. From the 1 h to 6 h measurement period, the tagged movements increased by 259%, having the highest percent increase in movement distance, followed by the control with 150%, and handled with an increase of only 82%. But from the 6 h to the 24 h period, handled movements increased 151%, while control and tagged movements only increased by 17% and 15%. There was variation among trials (df=3, SS=13.6339, F=13.419, p<0.0001). Water visibility distance (m) was variable for the five trials (Table 2.4).

Two outliers in the relative distance data (9.2 and 14.3 m) had a possible influence on the tagged treatment results (Figure 2.7). The untransformed average
distance for tagged treatment with the outliers removed was 3.1 m, median was 3.2 m and the range was 0.8-6.2 m. Upon removal of the outliers and reanalysis solely with the relative distance data, the effect of the tagged treatment was no longer significant in comparison to the control.

2.5 Discussion

Tag retention was affected by tag design, attachment procedure, and health of the animal. The best performing tag was the single T-bar that was easily attached, had the highest retention rates, and caused no mortalities. Some open sores were found on the dermis around the base of the tag for seven out of 30 animals. For this reason, double T-bar tags were assessed in field studies. The second T-bar on the tag prevents the tag from moving around in the animal and causing sores. Banner tags were hard to apply, because they appeared delicate and tore easily. Fingerling tags were nearly impossible to attach in large quantities, and sewing was difficult with cold hands. Cinch tags were easy to attach, but they affected health of the animals, as sores developed after two months and caused skin to slough off. The cinch tag would eventually fall out, and death resulted in two cases. CWT tags moved from the point of injection and were difficult to load in single shot syringe. Also, CWT tags could only be recovered by sacrificing the animal, which is not practical for when individuals need to be identified multiple times in a study. Garment tags were easily attached but lacked a numbering system for individual identification. Tag loss for all tags due to poor initial attachment was a problem, which was mainly due to operator inexperience. Operator inexperience can only be eliminated
with practice. Based on the literature and my experiences, the best all purpose tags for tagging sea cucumbers were the Floy® T-bar tags.

Average daily movements of *P. californicus* were 1.8 m based on control animals and 3.6 m for tagged treated animals. Da Silva et al. (1986) determined a daily movement average of 3.9 m for *P. californicus* in British Columbia. Slightly higher daily movement rates have been observed among tropical sea cucumbers: *Holothuria mexicana* moved 4.5 to 5.5 m, and *Isotichopus badionotus* moved 4.0 to 4.4 m (Hammond 1982). The tropical averages are slightly higher than daily averages for *P. californicus*. Tropical species may move more because nutrients are limiting in tropical environments or warmer temperatures increase metabolism and activity (Stambler 1999), however sea cucumber movements in the tropics do not appear to be moving that much more than temperate species. For adult *Cucumaria frondosa* a decrease in water temperature leads to a migration to deeper (>40 m) waters (Hamel and Mercier 1996). If temperature could cause sea cucumbers to go deep, it may also affect movement distances. Based on abundance estimates in Southeast Alaska, *P. californicus* may migrate seasonally to and from depths below 18 m (Woodby et al. 1993).

Daily movement averages were computed from relative distances, not cumulative distances because most other studies record movement on 24 h intervals. Cumulative distances were larger than relative distances, because they were the total of multiple measurements throughout a day. *Parastichopus californicus* does not move in linear paths but rather convoluted paths, and as a result daily movements cannot be simply multiplied to get multi-day movement distances. Cumulative distance gives a more
accurate measurement for purposes such as determining bottom speed and estimating detrital feeding coverage, when it is on the appropriate time scale.

Recapture rates varied at different time intervals and trials. Thirteen animals were not recovered over all time periods. During trial 2, an equipment failure resulted inability to collect data for the 6-24 h period. The majority of those animals that went missing were in trial 3. Animals could have been lost for a variety of reasons: tag loss, water visibility and animals moving outside of our search area. The probability (sum of lost tags/total number of tags) that an animal lost one of its tags was 8.5%. Double tagging results in a 0.7% ((probability of losing one tag)^2) chance that an animal would lose both of its tags. Water visibility averaged 3.6 m and differed among trials. Trial 5 had the lowest visibility of 1.5 m. Animals that moved beyond the 50 x 50 m^2 plot would not be measured, and therefore extreme movements were not followed. However, only 1 % of animals moved more than 20 m for all time periods, indicating that the study captured most sea cucumber movements. Dive search times for animal relocations were from 22 to 50 min long depending on diver air consumption, depth, visibility (longer dives during poor visibility), and diver experience. During trial 5, significantly smaller movements were measured, along with poorer water visibility and a noticeably large fresh water lens on the surface. Echinoderms have been recorded as being very sensitive to changes in salinity, which could explain smaller movements during that trial (Drouin et al. 1985).

In the study, tagging and handling treatments significantly affected movements in comparison to the control, increasing movements by 1.9 and 2.6 m within a 24 h period. Handling had a greater effect which was probably due to being physically handled, and
moved in close proximity to other animals. Floy tags did have an effect on movement when inserted \textit{in-situ} into \textit{P. californicus} and the effect lasted for at least 24 hours. This tag can be successfully used because of its ease of attachment, high retention rate, and low cost, however behavioral studies should wait at least 24 h from initial tagging before making observations.

\textbf{2.6 Acknowledgments}

Thanks to B. Pyper for statistical assistance and assistance, K. Shotwell for Arcview aid and diving, S. McMurray for scuba assistance, M. Cieciel and D. Greenwell for topside assistance and my advisor G. Eckert for help with many project details. My gratitude to my funding sources and providers of equipment, University of Alaska Southeast and Alaska Department of Fish and Game in Juneau, Ketchikan and Sitka.
Figure 2.1. Location of Amalga Harbor sampling site within Southeast Alaska for August 2003 tagging effect study. Study area within Amalga Harbor, sampling plots outlined for August 2003 tagging effect study. Locations of cement markers are identified, map is to scale.
Figure 2.2. The six tags used to tag *P. californicus* in a lab based tag retention study begun in August 2000. The Tags were 1) garment tag (Floy©), 2) cinch tag (Floy©, FT-4C), 3) Fingerling tag (Floy© FTF-69), 4) single T-bar (Floy©, FD-94), 5) banner tag (Floy©, FTSL-73) and 6) coded wire tag (Northwest Marine Technology) (loaded in syringe tip).
Figure 2.3. Photograph of tagging gun and tag. Dennison® tagging gun and Floy® double T-bar FD-94 tag, used to tag *P. californicus* in a tagging study conducted during August 2003 in Amagla Harbor, near Juneau, Alaska.
Figure 2.4. Distance measurement method for sea cucumber used *in-situ*. Depiction of the three line measurements used to estimate linear movement distance for *P. californicus*. At each time period and plot and for each individual, distance was recorded for: line AB, the distance between the two anchors; line AC, the distance from the animal to the first anchor; and, line BC, the distance from the animal to the second anchor. Numerals 1 and 2 represent the cement anchors.
Figure 2.5. Proportion of tags retained by *P. californicus* in the laboratory during August 2000 through April 2001.
Figure 2.6. Average distances (± SE) (m) of *P. californicus* movement. Means and their 95% confidence intervals were computed.
Figure 2.7. Treatment data plotted to identify outliers. Non-transformed relative movement distances (m) for each treatment. Medians denoted by triangle with line, outliers are solid circles with horizontal lines, lines perpendicular to rectangle are the interquartile range and the rectangle top and bottom are the 25th and 75th percentiles.
Table 2.1. Treatment assignments per plot, for the five trials, during the August 2003 tagging effect study.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
</tr>
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<td>1</td>
<td>Tagged</td>
<td>Control</td>
<td>Handled</td>
</tr>
<tr>
<td>2</td>
<td>Handled</td>
<td>Tagged</td>
<td>Control</td>
</tr>
<tr>
<td>3</td>
<td>Control</td>
<td>Handled</td>
<td>Tagged</td>
</tr>
<tr>
<td>4</td>
<td>Tagged</td>
<td>Control</td>
<td>Handled</td>
</tr>
<tr>
<td>5</td>
<td>Handled</td>
<td>Tagged</td>
<td>Control</td>
</tr>
</tbody>
</table>
Table 2.2. Summary statistics of movement distances for three movement treatments at Amalga Harbor, Alaska. Sample size n, mean and median movement distances (m), and recovery rate (%) for three treatments and time periods for *P. californicus* in 2003.

Treatments consisted of control, handled and tagged animals.

<table>
<thead>
<tr>
<th>Periods</th>
<th>n</th>
<th>Mean</th>
<th>Standard Error</th>
<th>Median</th>
<th>Range</th>
<th>Recovery Rate (%)</th>
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<tr>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>0.1</td>
<td>0.4</td>
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<td>1-6 h</td>
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<td>0—6.3</td>
<td>96</td>
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<tr>
<td>6-24 h</td>
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<td>0.4</td>
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<tr>
<td>0-1 h</td>
<td>25</td>
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<td>0.2</td>
<td>0.8</td>
<td>0.3—4.2</td>
<td>100</td>
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<td>96</td>
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<tr>
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<td>1.0</td>
<td>0.2</td>
<td>0.7</td>
<td>0.1—3.8</td>
<td>100</td>
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<tr>
<td>1-6 h</td>
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<td>2.8</td>
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<td>0.6—8.5</td>
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<td>6-24 h</td>
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<td>2.9</td>
<td>0.7—12.5</td>
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Table 2.3. Summary statistics of movement types at Amalga Harbor, Alaska in 2003.

Sample size n, means, standard error, median, and range based on non-transformed 24 h movement distances (m) for *P. californicus*, cumulative (total distance traveled) and relative distance (net movement). Treatments consisted of control, handled and tagged animals.

<table>
<thead>
<tr>
<th></th>
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<th>Standard Error</th>
<th>Median</th>
<th>Range</th>
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<td>Periods</td>
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<td>Mean</td>
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<td>0.6</td>
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<td>2.1</td>
<td>0.4</td>
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<td>1.4</td>
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<tr>
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<td>4.3</td>
<td>0.9</td>
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Table 2.4. Water visibility distance (m) at Amalga Harbor, August 2003. Visibility was measured as part of a tagging effects study. Multiple dots within a trial signifies a change in visibility during a 24 h measurement period.

<table>
<thead>
<tr>
<th>Period</th>
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<th>6-24 h</th>
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2.7 References


Appendix 2.1. Location of archived data. Data from this study is archived online in the Knowledge Network for Biocomplexity (KNB). http://knb.ecoinformatics.org/index.jsp.
General Conclusions

*Parastichopus californicus* is the only commercially harvested sea cucumber in Southeast Alaska. The fishery started in 1987 and has grown due to decreases in tropical stocks and increasing local fishing areas (Larson et al. 2002, Woodby et al. 1993). Management of *P. californicus* is difficult because of the lack of information on longevity, recruitment, nocturnal activity, and movement (Cameron and Fankboner 1989). Not only is biological information lacking, but agreement on whether individuals can be successfully monitored and tagging procedures have been in question. Many researchers have tried several tagging methods with little or mixed success, with little consensus for the best method (Hyman 1955, Hammond 1982, Conand 1983, Muscat 1983, Da Silva et al. 1986, Graham and Battaglene 2004).

We evaluated different methods for observing and tracking individual sea cucumbers in the field and used these methods to record individual movement distances and to measure the movement of a population for one year. The information provided from this study could be beneficial to sea cucumber management and researchers by providing information on: (1) a method for tracking individuals; (2) appropriate times for the fishery and stock assessment surveys to be conducted; and (3) the possibility of adults repopulating an over harvested area. The project was divided into two chapters. Chapter 1 examines spatial and temporal variation in movement and density, and Chapter 2 evaluates different methods used to track individuals and their movement distances. Daily movement rates were large for an animal considered to be sedentary, but not substantial enough to indicate large scale movements. Movements occurring over 48 h
were only 20% higher than 24 h movements indicating that animals do not move linearly over time. Densities (number·m$^{-2}$) at different depths varied among seasons, but the total number of animals remained fairly constant. The majority of animals were found at one depth range within typical commercial diver depths. Seasonal movements varied, with largest movements occurring during summer and smallest movements occurring during fall. Tagging was shown to have a measurable effect on daily movement rates right after initial tagging. The effect of tagging increased movement distances by 2 m within the first 24 h of initial tagging and may last up to 48 h. After 48 h no effect of the tag was measured, indicating that Floy© tags can be used successfully to study sea cucumber movement.

The likelihood of sea cucumbers being able to repopulate depleted areas seems unlikely due to their small and circular movements. This study also indicated that surveys conducted in late spring or mid-summer had higher densities potentially because individuals aggregated during the spawning period (Cameron and Fankboner 1986). Fishing in the fall and winter may provide a refuge due to lower densities available for harvesting. Based on my observations, sea cucumbers appeared to remain within a fixed area; many of the tagged individuals were observed at the study site throughout the year. These results indicate that sea cucumbers may exhibit site fidelity, which creates a high potential for over-harvesting and localized depletion of an area.

The duration of this movement study was only a year, which provides a brief snapshot of information. It would be beneficial to setup a multi-year project to monitor movement and density and provide a long-term picture of population trends and
characteristics. Along with monitoring long-term movement, an investigation into the nocturnal movement activities would provide a clearer picture into the movement behaviors of the sea cucumber, as studies of tropical species during nocturnal periods have found that movements increased during the night. Future research projects should also examine whether adults move into harvested areas and how long it takes to repopulate a depleted area.
Literature cited


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