

**The susceptibility of California's wild and cultured abalone
to the ectoparasitic snail (*Evalea tenuisculpta*)**

by

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ABSTRACT

Purpose of the Study:

Ectoparasites in the family pyramidellidae have been known to have negative impacts on mollusk fisheries by causing shell malformation, reduced growth, transmission of disease, and mortality. Although common pests in fisheries worldwide, little is known about these pyramidellids in western fisheries. A study done in 2011, showed <40% of wild red abalone from Sea Ranch, California had this parasite and anecdotal evidence suggests these parasites are found in heavy infestations in aquaculture. Currently, nothing is known about the prevalence or infection intensity of *Evalea tenuisculpita*. The high infection rates and parasite loads on abalone, combined with abalone's conservation status and market value begs additional investigations into the basic ecology of this host-parasite relationship. As abalone aquaculture continues to expand, parasite infestations may impact sustainability justifying contamination prevention from an economical and ecological perspective. Knowing the baseline distribution and infection intensity may benefit sustainability of aquaculture, the recovery of endangered species, and the health wild populations. The information we discover may not only be applicable to the abalone, but to scallop, clam, and mussel fisheries also. The purpose of this study is to understand the prevalence, ecology, and size frequency of the pyramidellid parasite, *Evalea tenuisculpita*, which infects abalone in California.

Procedure: We used SCUBA surveys, aquaculture surveys, and fisherman interviews to access the prevalence, infection intensity, and size structure of *E. tenuisculpita* in the wild and aquaculture.

Findings: The parasitic snail *Evalea tenuisculpita* was commonly found in aquaculture and in the wild throughout California. While there was a slightly higher prevalence of this parasite in the wild, larger parasites were found under culture conditions. Abalone captured from the wild and raised in aquaculture on non-treated water had the highest parasite loads of all abalone sampled.

Conclusions: While we don't believe *E. tenuisculpita* is invasive in the wild, aquaculture conditions may facilitate outbreak of these parasites. We hypothesize the introduction of infected wild abalone into aquaria may facilitate explosion and parasite growth and recommend quarantining abalone and removing parasites before abalone are introduced to aquacultured populations. More investigations are needed on this parasite to address potential removal methods for this parasite.

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The susceptibility of California's wild and aquacultured red abalone *Haliotis rufescens* to the parasitic snail *E. tenuisculpita*.

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A B S T R A C T

We examined the ecology, abundance and size frequency of the ectoparasitic vampire snail, *Evalea tenuisculpita*, on the host red abalone *Haliotis rufescens* to inform fishery managers and the industry. This study is the first to document this parasite in the family pyramidellid infesting red abalone in aquaculture. We found *E. tenuisculpita* on abalone at 4 of 5 aquaculture sites and 11 of 13 wild sites in California in 2014-2015. At all sites with *E. tenuisculpita* present, parasites were aggregated in their distribution within crevices on the hosts shell. In aquaculture, the average infection prevalence was 32% with a mean infection intensity of 10 parasites per host. In the wild, the average infection prevalence was 41% with a mean infection intensity of 8 parasites per infected host. The highest prevalence and intensity was seen at one aquaculture site, with 68% of abalone infected and one abalone had 484 parasites. Average parasite size was larger in

aquaculture sites than in the wild. In aquaculture, abalone with the highest parasite prevalence and intensity were those collected from the wild and maintained in untreated sea-water. In the wild, parasites were more prevalent and exhibited higher infection intensities at deeper depths and at sites with higher host densities. In surveys of fisherman's catch, host size (specifically shell width) and the presence of parasitic boring sponge *Cliona celata* had a significant positive affect on parasite prevalence and intensity. Lastly, for the first time we document *E. tenuisculpita* on wild and aquacultured pink abalone in southern California. These results suggest that the collection of wild abalone may be a potential mechanism of parasite infestation for aquaculture. We recommend comprehensive shell inspections for pyramidellid parasites coupled with aggressive parasite and egg mass removal, to enhance red abalone aquaculture production.

1. Introduction:

As wild marine fisheries continue to decline (Hutchings, 2000; Mullan, 2005; Pauly et al. 2003; Worm et al., 2006; FAO 2015) aquaculture has been expanding worldwide (Eng and Tech, 2002; FAO, 2010). Currently, aquaculture practices provide 43% of all food fish, increase the sustainability of ornamentals, and provide stock for endangered species (FAO, 2015; Tlusty, 2002). And in the past 30 years, fish production from aquaculture has been increasing on average 8.3% per year to meet demand (FAO, 2012). While aquaculture may lessen the strain of fishing efforts, rapid expansion may lead to an increase in undocumented parasites that may threaten the efficiency of culture efforts (Naylor et al, 2001). In aquaculture,

fish are often confined in large numbers for many years so parasite eggs and larvae can become dense and the number of parasites per adult host can be devastating, (Lafferty, 1993; Murray and Peeler, 2005; Roberts and Janovy, 1996; Krkošek et al. 2007). These parasite outbreaks can lead to biological and economic losses not only through mortality, but also by causing poor meat quality, undesirable aesthetic changes, and reductions in host reproductive potential, (Couch and Fournie, 1993; Sorensen and Minchella, 1998). While reducing parasites in the wild may not be practical, strategic parasite control could enhance aquaculture productivity and sustainability.

Mollusk culture is one of the fastest growing food sectors, second only to freshwater fish production, however shell-dwelling parasites often go undocumented in aquaculture. Ecotoparasites in the family pyramidellidae are known to have significant impacts on mollusk fisheries impacting shell formation, growth, transmission of disease, and mortality (Cumming 1994; Wilson 1999; Wilson 1988; Ward et. al 1986; White 1984). They have been shown to impact both wild and aquacultured populations, as well as ornamentals, (Boglio and Lucas, 1998; White et. al., 1988; Govan, 1994; Abbe 1986; Bullock et. al. 1971; Handcock 1959; Hori,1999; Powel et. al 1987). These small snails (generally <5mm in length) live and reproduce on their hosts' shell using a proboscis and piercing stylet to feed on host hemolymph (Fretter and Graham 1949). These blood-sucking snails are generalists on multiple commercially important mollusk species worldwide, yet there are only a few studies on pyramidellids in the western hemisphere. Evidence from bivalve culture shows pyramidellids can not only halt growth, but clam culture

suggests a pyramidellid load of 20 snails is sufficient to be lethal (Carol and Finelli, 2015; Cumming, 1994). These parasites may have significant impacts for shellfish aquaculture.

There are three species of pyramidellids that are found to infest shellfish in California (Harbo et al, 2012). The most common pyramidellid found is the fine-sculptured odostome snail, *Evalea tenuisculpta*, which has been observed in intertidal and shallow subtidal habitats from Alaska to Baja California (Abbott 1974; Carpenter 1864; Maguire and Rogers-Bennett, 2013). *E. tenuisculpta* infects a wide array of molluscs including scallops, chitons, clams, mussels, and abalone (Harbo et al. 2012). Substantial infestation rates (>50%) and parasite loads (up to 57 per abalone) of *E. tenuisculpta* were found on wild red abalone during subtidal transect surveys and on abalone caught in the fishery in northern California (Maguire and Rogers-Bennett 2013), but nothing is known about these parasites on abalone in aquaculture.

Hosts that may be particularly vulnerable to *E. tenuisculpta* infestations are California's abalone such as the red abalone, *Haliotis rufescens*. Wild red abalone harvests peaked in 1957, but since then overfishing, algal blooms, disease and poaching have led to the depletion of California's red abalone and the closure of the fishery south of San Francisco (Gordon and Cook 2004; Karpov et al 2000; Moore et al. 2002). Given the limited fisheries for abalone and sustainability of mollusk culture, abalone farming is increasingly valuable for abalone as food and for restoration purposes (Hooker and Morse 1985; Karpov et al 2000; Naylor et al

2000). Since 1980, California's number of abalone farms have increased threefold and California's abalone stock is now shipped worldwide (Mcbride, 1998; Oakes and Ponte 1996). Although abalone aquaculture brings in \$9 million dollars annually, culture is time and labor intensive. In an aquaculture setting it takes 3-5 years for red abalone to reach market size and any reduction in growth rates or increases in mortality by parasites could be adding considerable costs to culturing these mollusks (Oakes and Fields 1996).

In this work, we examine the distribution and abundance of *E. tenuisculpita* in the wild and in aquaculture facilities. We examine the baseline abundance of *E. tenuisculpita* and the relationship between host abundance and parasite abundance. A number of environments are examined to determine which are more likely to have the highest parasite infestations. To understand the potential energetic cost of parasites in aquaculture we looked at average parasite prevalence, intensity and size. In aquaculture, we quantify abalone origin, culture location, and water treatment. Finally, we use this information to make recommendations for strategies aquaculture managers may adopt to decrease the prevalence of parasites in their facilities thereby enhancing productivity.

2. Methods

2.1. Locations

We surveyed 18 sites in California to understand more about *E. tenuisculpita's* prevalence, infection intensity, size frequency and ecology in 2014-2015. Parasite prevalence is described as the percentage of abalone infected with 1 or more parasites. Abalone were recorded as having parasites present or absent.

Infection intensity is described as the number of parasites on an infected host and mean intensity is the average number of parasites per infected host. We sampled 5 aquaculture sites used for research and commercial purposes that were land and ocean based (Figure 1). We sampled 13 wild sites in and outside the recreational abalone fishery throughout California. We determined location use culture method, and average water temperature at each wild site (Table 1).

2.2. Sampling procedures

2.2.1. Aquaculture Surveys

In May-November 2014, we surveyed one research aquaculture facility in Bodega Bay, two mariculture facilities in Monterey Bay, and two land based aquaculture facilities, one in Davenport and one in Goleta. We define mariculture facilities as those cultivating abalone directly in the ocean. On these surveys we recorded parasite prevalence, parasite intensity, parasite length, host length and life history. We also assessed culture conditions that could affect parasite survival such as water treatment and culture method.

2.2.2. Interviewed recreational abalone fisherman and surveyed catch

In April-June of 2014, we sampled abalone caught by recreational fishermen at 10 wild sites in Sonoma and Mendocino county, northern California. All abalone sampled were greater than 179mm which is the minimum legal size in the fishery. We sampled a minimum of 100 abalone from Todds Point, Sea Ranch, Salt Point, Point Arena, Caspar cove, Moat Creek, Caspar Cove, Van Damme, Hardy Creek, and Mackerricher State Park. At these sites we noted *E. tenuisculpita* prevalence,

infection intensity, host length and width and presence of another parasite the *Cliona celata* sponge.

2.2.3. Transect surveys within California recreational fishery in the wild

In August and September 2014, we performed surveys along 22 band transects (30m) on SCUBA at three different depth intervals in Mendocino county, California. The depth intervals were A (0-15ft), B (16-30ft), and (30-45ft). At these depths, we noted abalone density per square meter, abalone length, presence and absence of *E. tenuisculpita* on each abalone (prevalence), and number of *E. tenuisculpita* on each abalone.

2.2.4. Fisheries independent surveys in the wild

In May-July of 2015, we performed swim surveys on SCUBA in Monterey bay, Catalina Island, San Miguel Island, La Jolla Cove. These sites are thought to have lower abalone densities and are not open to fishing so a different sampling method was needed to survey these sites. For these surveys, divers swam randomly selected compass headings and surveyed each abalone seen for parasites. We recorded parasite prevalence, parasite intensity, parasite length, and host length.

2.3. Data analysis

All statistical analyses were performed in JMP version 12.1.0. Group comparisons of *E. tenuisculpita* prevalence were made using contingency tables or nominal logistic regressions. The relative contribution of different factors affecting parasite intensity were determined using one or two-way ANOVA's. Tukeys tests were used to compare individual differences within models. Letters that do not match indicate significant differences. In instances where model residuals did not appear normal,

counts of *E. tenuisculpita* were logarithmically transformed. All applicable models were checked for equal variances and colinearity.

3. Results

3.1. Description of infection and awareness

In aquaculture and in the wild *E. tenuisculpita* is mostly seen on the shell of its abalone host. Less than 1% of the time we saw *E. tenuisculpita* on the reef within 8 inches of its host or on tank/cage walls. Parasites were cryptic and often found in crevices on the shell, covered in their own mucus or egg masses. Crevices in the abalone shell were likely made by boring sponge or clam damage. On undamaged shells, parasites were often found next to the respiratory pores of the abalone or on the ventral margin of the shell. In instances of high parasite load, parasites were found covering the entire shell of its host. Parasites attached themselves to the host shell with an elastic mucopolysaccharide string. 0 of 8 abalone aquaculturists and 1 of 13 abalone biologists knew that pyramidellids could infect fisheries and aquaculture in California.

3.2. Summary of population structure

E. tenuisculpita parasites were found in an aggregated or contagious distribution on aquacultured and wild abalone (Figure 2). In aquaculture, average infection prevalence was 32% (range 0% to 67%) with an average of 10 parasites per infected host (Table 3). In the wild, average infection prevalence was 41% (range 0 % to 64%) with an average 8 parasites per infected host (Table 3).

3.3 Parasitism on aquacultured abalone hosts

We surveyed the prevalence and infection intensity of *E. tenuisculpita* at five aquaculture sites in the northern, central, and southern California. During 2014 aquaculture surveys, the prevalence of *E. tenuisculpita* was correlated with aquaculture site (Figure 3). Because infection intensities differed by orders of magnitude we log transformed infection intensity. Log *E. tenuisculpita* infection intensity was significantly different by aquaculture site. A tukeys multiple comparisons test indicates differences between sites. We saw the highest intensity at a laboratory facility in Bodega Bay, the second highest was seen at the mariculture facilities in Monterey and the lowest prevalence was seen in land-based commercial aquaculture in Davenport and Goleta (Figure 3).

We surveyed red abalone hosts in aquaculture to understand whether host origin (raised in aquaculture/wild), culture location (land-based/ocean based), and water treatment (untreated/UV treated) influence parasite prevalence and intensity. We ran a nominal logistic model. When controlled for site, the presence of *E. tenuisculpita* parasites is correlated with host origin, aquaculture location, and water treatment. The prevalence of *E. tenuisculpita* parasites in aquaculture is associated with host origin. Wild caught abalone maintained in aquaculture are associated with a higher prevalence of parasites as compared to abalone raised completely in aquaculture. The occurrence of *E. tenuisculpita* parasites in aquaculture is associated with aquaculture location, with a higher prevalence of parasites in mariculture. The occurrence of *E. tenuisculpita* parasites in aquaculture is associated with water treatment, with a lower prevalence of parasites found in UV

treated water (Figure 4). Because *E. tenuisculpita* infection intensity fluctuated by orders of magnitude, a log transformation was used. The type of water treatment, location of culture, and host origin all had a significant affect on *E. tenuisculpita* counts. Site is not significant when included in the model, so site was removed. After the log transformation, model residuals were normally distributed. A tukey's multiple comparisons test shows, *E. tenuisculpita* counts were significantly higher on abalone imported from the wild than on abalone raised their full life span in aquaculture; *E. tenuisculpita* counts we significantly higher on abalone held in flow through conditions than those in UV treated water; and *E. tenuisculpita* counts were significantly higher in mariculture than land based aquaculture (Figure 4).

A one-way anova suggests abalone collected from the wild were significantly larger than abalone raised in aquaculture from larvae. We looked at whether abalone length had an influence on log *E. tenuisculpita* infection intensity separately. On 2014 aquaculture surveys, log *E. tenuisculpita* counts increased significantly with increasing red abalone host length (Figure 5).

3.4. Parasitism on wild red abalone hosts

We surveyed the prevalence and infection intensity of *E. tenuisculpita* at 13 wild sites on the northern, central, and southern California coast (Table 2). During 2014-2015, a contingency analysis shows the presence of *E. tenuisculpita* is associated with wild site locality (Figure 3). During 2014 wild abalone surveys, log *E. tenuisculpita* infection intensity was significantly different by wild site. Residuals of the model appear normally distributed. A tukeys multiple comparisons test indicates differences between sites and counties with adjusted means for the model.

Monterey county, in central California, had the highest infection intensity of parasites, Sonoma and Mendocino County sites in northern Ca had the second highest, and the lowest were seen in Santa Barbara, Southern California (Figures 4 and 5).

During 2014 transect surveys, we examined the impacts of abiotic and biotic conditions on *E. tenuisculpita* prevalence and infection intensity in Mendocino county. We found that the prevalence of *E. tenuisculpita* was associated with host depth (Figure 7). Using a one-way anova, *E. tenuisculpita* log infection intensity increased significantly with deeper depth type. Residuals appear normally distributed.

During 2014 surveys of recreational abalone catch, we looked at the association of shell boring parasites and abalone shell morphometry with *E. tenuisculpita* prevalence. We performed a two-way nominal logistic model to examine these associations. The presence of *E. tenuisculpita* was associated with wider abalone host widths and presence of boring clionid sponge parasites, ($\chi^2 = 127.74$, $DF=20$, $p<0.0001$) when controlling for survey site. The presence of *E. tenuisculpita* parasites in the wild is associated with red abalone width ($\chi^2_{7,953}=15.87$, $p=.0263$). The presence of *E. tenuisculpita* parasites in the wild is not associated with the presence clionid sponge ($\chi^2_{7,953}=12.82$, $p=.0671$). The presence of *E. tenuisculpita* parasites in the wild is associated with the interaction of red abalone width and the presence of clionid sponge ($\chi^2_{6,953}=33.87$, $p<.0001$). During 2014 fisherman surveys, we used a one-way Anova to determine whether red abalone shell morphometry and parasites had a significant affect on *E. tenuisculpita*

infection intensity. Because *E. tenuisculpita* counts fluctuated by orders of magnitude, a log transformation was used. The presence of shell parasites (boring sponge) and width of legal sized abalone were correlated with *E. tenuisculpita* infection intensity ($F_{2,372}=9.29$, $p<.0001$). After the log transformation, model residuals were normally distributed. *E. tenuisculpita* infection intensity in the wild is significantly higher on wider legal red abalone ($F_{1,372}=5.19$, $p=.024$). *E. tenuisculpita* infection intensity was significantly higher on abalone infested with clionid sponge ($F_{1,695}=7.54$, $p=.0064$).

3.5 Parasite size in aquaculture mariculture and wild.

We examined whether host location affected parasite size. In June of 2014, we collected *E. tenuisculpita* parasites from infected wild red abalone, red abalone in mariculture, and abalone in land based aquaculture and recorded individual parasite sizes. *E. tenuisculpita* standard length is significantly affected by culture location with the largest parasites in land-based aquaculture (average=6.03mm) and smallest parasites in the wild (average= 4.47mm). Model residuals are normally distributed. A one-way anova was run to see if location affected host size. Residuals appeared normally distributed so no transformations were needed. Red abalone *standard length* is significantly affected by culture location. A tukeys multiple comparisons test shows the differences.

4. Discussion

4.1 Abundance, distribution, and ecology

The ectoparasitic snail, *E. tenuisculpita*, was found throughout California in the wild and, for the first time, in aquaculture. *E. tenuisculpita* was detected at 4 of 5

aquaculture localities and 11 of 12 wild localities. Of all the abalone biologists and aquaculturists interviewed, only one was aware *E. tenuisculpita* could infect abalone, likely due to a lack of literature on this parasite. Overall, we found a lower average parasite prevalence across aquaculture sites (33%) compared to wild sites (41%), but higher infection intensities on aquacultured red abalone (Avg. 10 parasites, range 1 to 483) compared to the wild (Avg. 8, range 1 to 178). At all sites, we found *E. tenuisculpita* was distributed in an aggregated or contagious pattern. That is, most of the parasites are on relatively few hosts while the majority of abalone hosts were lightly infected or not infected at all. This aggregated distribution is typical of macroparasite populations, where the parasite is large and has dispersive stages, (Crofton 1971; Roberts and Janovy, 1996).

Most of the time, parasites were found on the shell of their abalone host. In cases of heavy infestations, we found parasites left the host abalone shell and surrounded the foot, showing these parasites can survive off the host shell. Parasites found were cryptic and often covered in their own mucus or eggs on the host shell. We often found parasites living in holes and crevices on the abalone shell, if available. These crevices were likely related to shell damage, boring clams and boring sponges. We may see more parasites on abalone with boring sponge infestations because this provides cryptic habitat for the parasite. In aquaculture, we saw many more abalone with clean shells with minimal growth, unless they had originally been collected from the wild or were immersed in wild waters. On abalone shells with few other epibionts parasites were found on all locations of the shell, but most often found close to the respiratory pores. This may be because this is

one location of parasite feeding. Parasites attached themselves to the shell with an elastic mucopolysaccharide string, sometimes making parasite removal difficult.

4.2. Parasite prevalence and ecology in aquaculture

In aquaculture, the research facility in Bodega Bay had the highest parasite prevalence and infection intensities of all aquacultured sites, mariculture sites had the second highest parasite prevalence and infection intensity in aquaculture, commercial land-based aquaculture had the lowest prevalence and infection intensity. In aquaculture, the highest prevalence (67%) and infection intensity (avg. 16 parasites per abalone, range 1-483) was seen at a land-based research institution in Bodega Bay, Ca. There was a lot of variance in *E. tenuiscuplita* abundance at this site by culture condition. This was the only aquaculture facility that had abalone raised their whole life in aquaculture and previously wild abalone that were being kept under segregated culture conditions. The influx of wild abalone into aquaculture may be the reason for parasitic outbreaks at this site (Figure X). Studies have shown that the influx of parasites from the wild to aquaculture can lead to economically disastrous outbreaks (Murray and Peeler, 2005; Costello 2006; McVicar 1997). We saw the second highest infection intensities in mariculture. In aquaculture, one land-based site in Goleta was parasite free. At this site, all individual abalone were raised at the culture facility, and none had encountered wild abalone. These abalone had the cleanest shells of all the aquacultured abalone at the other sites.

4.3. Parasite prevalence and ecology in the wild

In the wild, the highest prevalence (62%) and highest infection rate (avg. 34 parasites per abalone, range 1-78) was seen in Monterey, Ca (Central California). This site is central to the parasite's range, where there is no recreational fishery, otters, and moderate densities of abalone. We found no *E. tenuisculpita* parasites on abalone in La Jolla, Ca and Catalina, Ca. At the La Jolla site, red abalone densities were so low it was hard to find red abalone resulting in a low sample size at this site. The low densities may have made it hard for the parasite to find its host or the low sample size may have given us a false negative. At the Catalina site, we were unable to find any red abalone to sample and no parasites were found.

Creel surveys showed that increasing abalone width and presence of the clionid parasitic sponge on had a positive impact on *E. tenuisculpita* infection. Large abalone with clionid sponges may provide better habitat for parasites. Other studies have suggested that larger hosts may have more behavioral movement than smaller hosts and therefore encounter more parasites (Mohr, 1961; Lo et. al, 1998). Also, hosts that act as larger islands that provide more food resources surface area for parasite reproduction and feeding and therefore suffer the highest mortality costs (Grutter and Poulin 1998; Poulin, 1999; Cable and Van Oosterhout, 2007). Lastly, studies have shown that the microenvironment associated with their host can affect the host selection, (Loye and Carroll, 1998). In the wild small abalone are often more cryptic and hidden where adults are more out in the open and typically have more shell growth.

In Mendocino county (within the recreational fishery), there were more parasites on larger abalone at deeper depths. Survival of a parasite often depends on a parasite's ability to infect appropriate hosts, (Rhode, 1993), and areas of higher densities may provide better food resources and increase the chances of recruits finding a host. Deeper depths may be a refuge from wave turbulence and fishery removal. If these parasites have the potential to negatively affect abalone, the abalone fisherman may be helping to remove parasites on large abalone but may be leaving a sink of parasites at deeper depths (Barabas et al. 2004; Härkönen et al. 2010).

4.3 Parasite size and host size

We saw a disparity in parasite size on aquacultured, maricultured and wild abalone. On average, we found the largest parasite to host size ratio in land-based aquaculture (6.1/135.78), the second largest in mariculture (4.1/111), and the smallest in the wild (3.4mm/195). This suggests that *E. tenuisculpita* may have its largest physiological impact on aquacultured abalone. In land based aquaculture, there was a lack of natural predators, high host densities, and calm waters. In mariculture, there are still high host densities and but animals are subject to higher water flow and predators. These environments may provide more favorable conditions for a parasite to grow larger and faster. We found the largest *E. tenuisculpita* individuals on abalone that were originally taken from the wild and raised in captivity. Large parasites may not only directly exhaust their host's resources. Large parasites may also have increased reproductive capacity, studies have shown that larger parasites produce exponentially more offspring (Honek,

1993; Waage and Ming, 1984). We directly witnessed this with this species in 2012, where we saw that larger adults produced more egg masses with more eggs per mass (Maguire and Rogers-Bennett, 2013).

4.4 Implications for management

This work suggests that abalone culturists carefully track *E. tenuisculpita* parasites on their farm. This may be particularly important whenever stock is brought in from the wild, it should be quarantined from parasite free stock. Meticulous abalone husbandry practices need to be adhered to in order to prevent the spread of parasites from the wild to the farms. Because abalone raised in aquaculture are often much smaller than wild abalone, high numbers of large parasites may be more detrimental to shellfish health on the farms than in the wild. We would suggest that the smallest abalone with the highest infection intensity and largest parasites are likely to be impacted the most. While removal of parasites in the wild may not be warranted, control of parasites in aquaculture may contribute to the sustainability of culture efforts.

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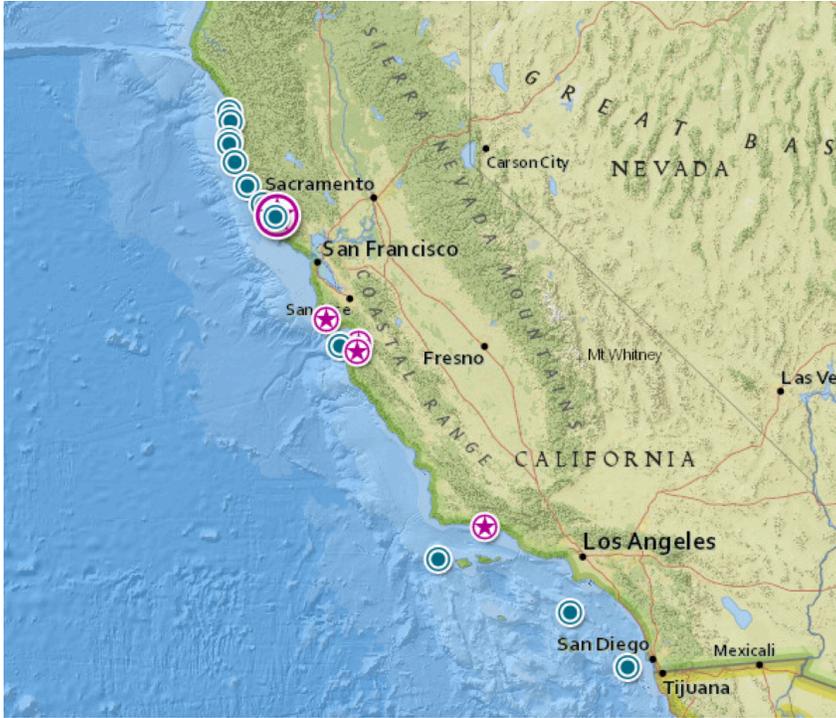


Figure 1. Map of sites where red abalone were surveyed for *E. tenuisculpita*. Aquaculture sites are indicated by stars and wild sites are indicated by bullseyes.

Wild Sites						
Location	County	Fishing	Lat.	Long.	Avg. temp 2014	Survey type
Hardy Creek	Mendocino	Yes	39.714	-123.808	10.0	Creel
MacKerricher	Mendocino	Yes	39.516	-123.780	10.0	Creel
Todds point	Mendocino	Yes	39.424	-123.818	10.0	Creel
Caspar Cove	Mendocino	Yes	39.361	-123.817	10.0	Transect
Van Damme	Mendocino	Yes	39.273	-123.791	10.0	Creel/ Transect
Point Arena	Sonoma	Yes	38.914	-123.710	10.6	Creel
Moat Creek	Sonoma	Yes	38.881	-123.674	10.6	Creel
Sea Ranch	Sonoma	Yes	38.699	-123.440	11.1	Creel
Salt Point	Sonoma	Yes	38.565	-123.333	11.1	Creel
Hopkins	Monterey	No	36.622	-121.903	12.8	Swim
San Miguel	Santa Barbara	No	34.037	-120.401	12.8	Swim
Catalina	Los Angeles	No	33.446	-118.498	14.4	Swim
La Jolla	San Diego	No	32.817	-117.299	14.4	Swim

Table 1. Locations and descriptions of wild sites where red abalone were surveyed for *E. tenuisculpita*.

California aquaculture

Site	Location	Type	Culture	Lat.	Long.	Life history Grown in:	Temp (C)
Lab, Bodega Bay	Research	Land- based	Flow through and/or UV treated	38.317	-123.071	Wild and culture	11.1
American abalone, Davenport	Commercial	Land- based	Flow through, untreated	37.023	-122.214	Culture	12.2
Abalone Company, Monterey	Commercial	Ocean	Ocean based	36.603	-121.890	Culture	12.8
Abalone Barge, Monterey	Commercial	Ocean	Ocean based	36.607	-121.890	Culture	12.8
Cultured abalone, Goleta	Commercial	Land- based	Flow through untreated	34.440	-119.963	Culture	13.9

Table 2. Aquaculture site locations and descriptions where red abalone were surveyed for *E. tenuisculpita*.

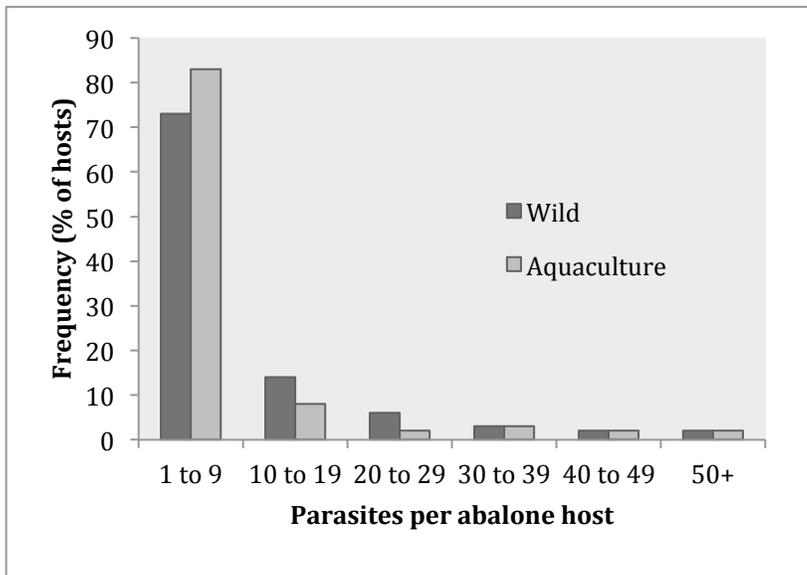


Figure 2. Distribution of abalone parasites on wild and aquacultured abalone.

Location	Avg. prevalence (%)	Range (%)	N (sites)	Avg. infection intensity (#)	Range (#)	N
Wild	41	0-62	12	8	1-178	422
Aquaculture	32	0-67	5	10	1-483	202

Table 3. Average *E. tenuiculpita* prevalence and infection intensity between 18 wild and aquacultured sites.

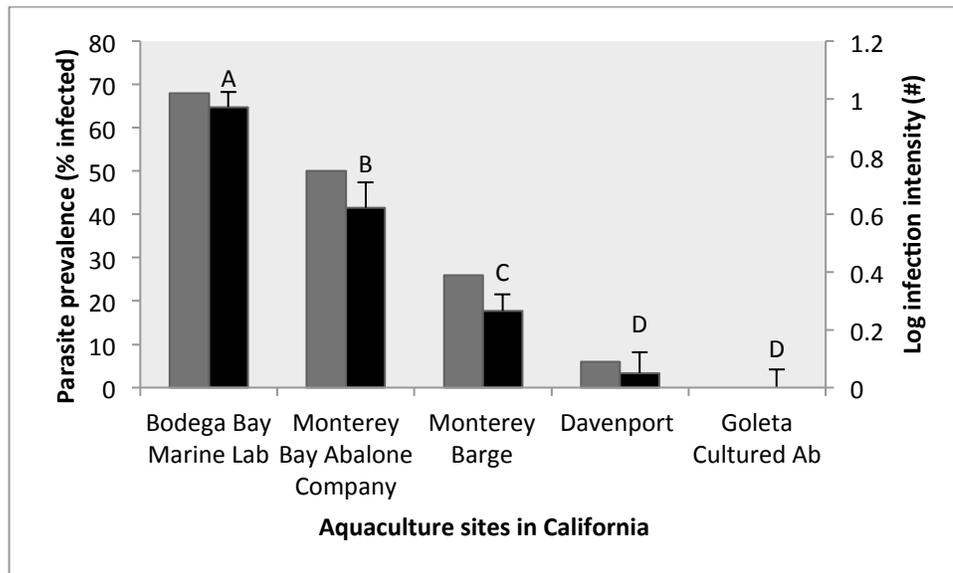


Figure 3. Left axis shows a one-way anova of the prevalence of *E. tenuiculpita* by aquaculture site ($\chi^2=271.94$, $DF=4$, $p<0.0001$). Right axis shows a one-way anova of the parasite infection intensity by aquaculture site ($r^2=.21$, $F_{4,695}=47.71$, $p<.0001$). Sites are in geographic order of northern to southern California. Error bars are \pm standard error. A tukeys analysis indicates significant differences. No red abalone were found in Catalina.

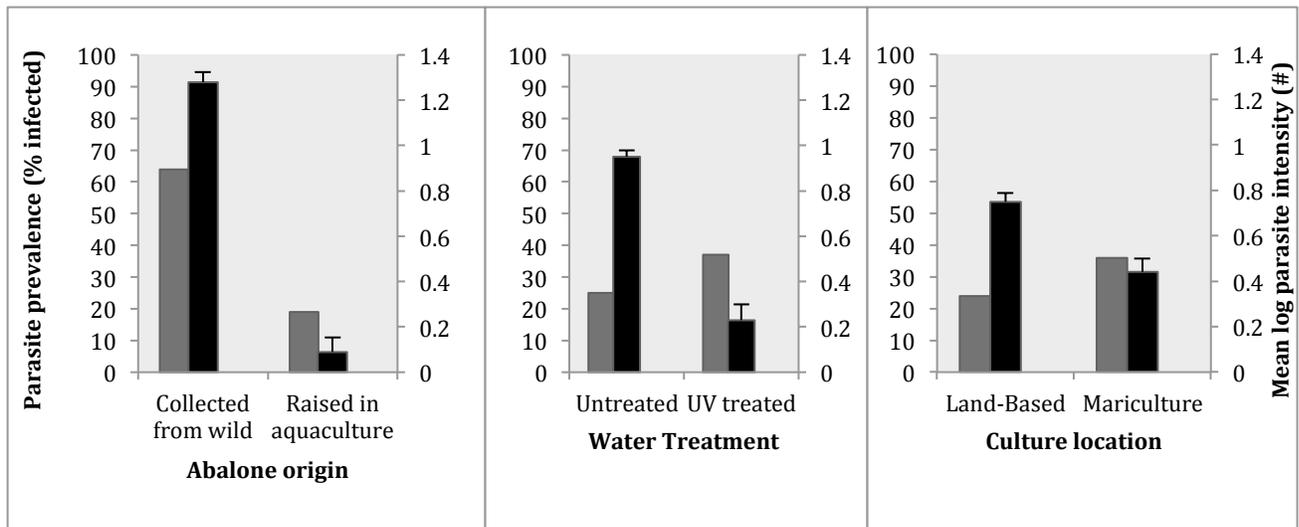


Figure 4. The prevalence and log infection intensity of *E. tenuisculpita* by California aquaculture site. The mean prevalence of *E. tenuisculpita* by aquaculture method ($r^2 = .34$, $X^2_{3,695} = 281.33$, $p < .0001$). The prevalence of *E. tenuisculpita* parasites in aquaculture is associated with host origin ($X^2_{1,695} = 268.87$, $p < .0001$), water treatment ($X^2_{1,695} = 115.73$, $p < .0001$), and culture location ($X^2_{1,695} = 36.22$, $p < .0001$). The mean log infection intensity by culture method ($r^2 = .37$, $F_{3,695} = 137.22$, $p < .0001$). The prevalence of *E. tenuisculpita* parasites in aquaculture varies with host origin ($F_{1,695} = 393.48$, $p < .0001$), water treatment ($F_{1,695} = 83.27$, $p < .0001$), and culture location ($F_{1,695} = 24.93$, $p < .0001$). Adjust means for the models are displayed. Error bars are \pm standard error.

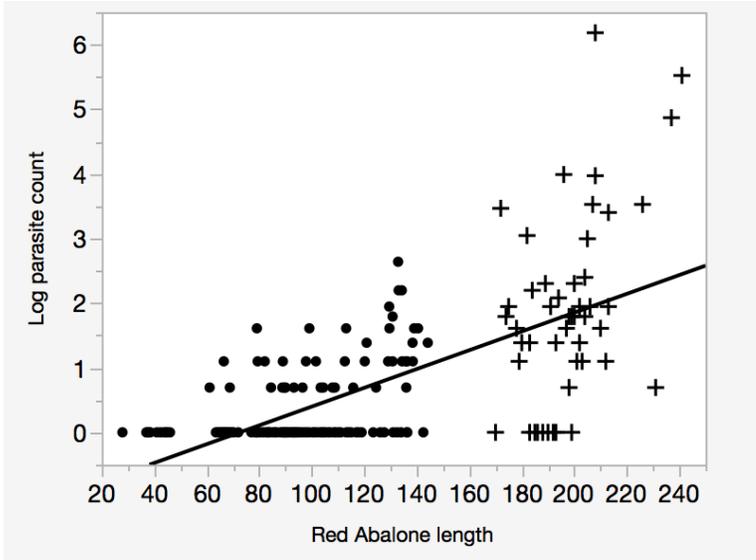


Figure 5. Log infection intensity by host length ($y = 0.0145414(\text{Red Abalone length}) - 1.05534$, $r^2 = 0.46$, $F_{1,224} = 185.18$, $p < .0001$). Plus symbols for abalone collected/measured in the wild and dots are for abalone collected/measured in aquaculture.

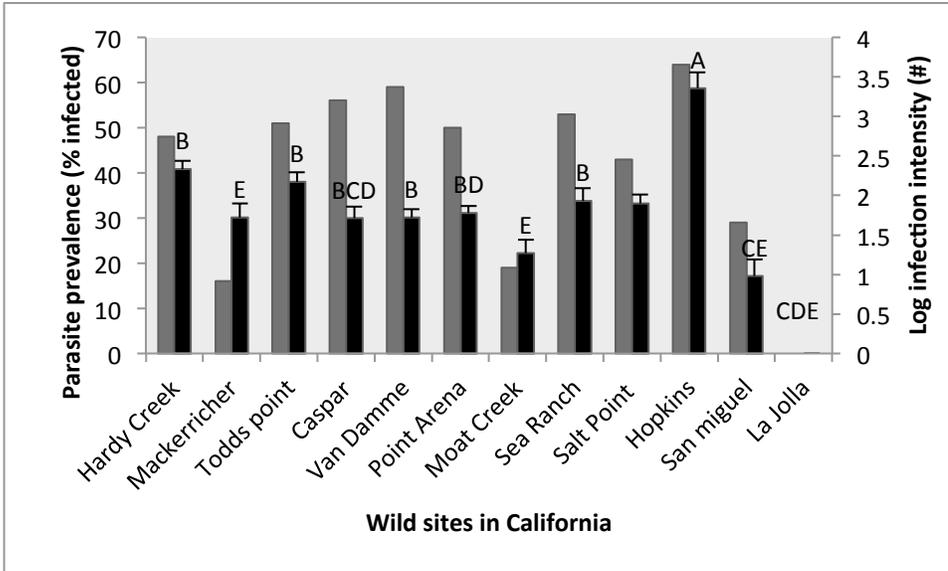


Figure 6. Left axis shows a one-way anova of prevalence of *E. tenuisculpita* by wild site ($\chi^2 = 194.26$, $DF = 11$, $p < .0001$). Right axis shows a one-way anova of the parasite infection intensity by wild site ($r^2 = .18$, $F_{10,617} = 13.13$, $p < .0001$). Sites are in geographic order of northern to southern California. Error bars are \pm standard error. A tukeys analysis indicates significant differences. No red abalone were found in Catalina, California.

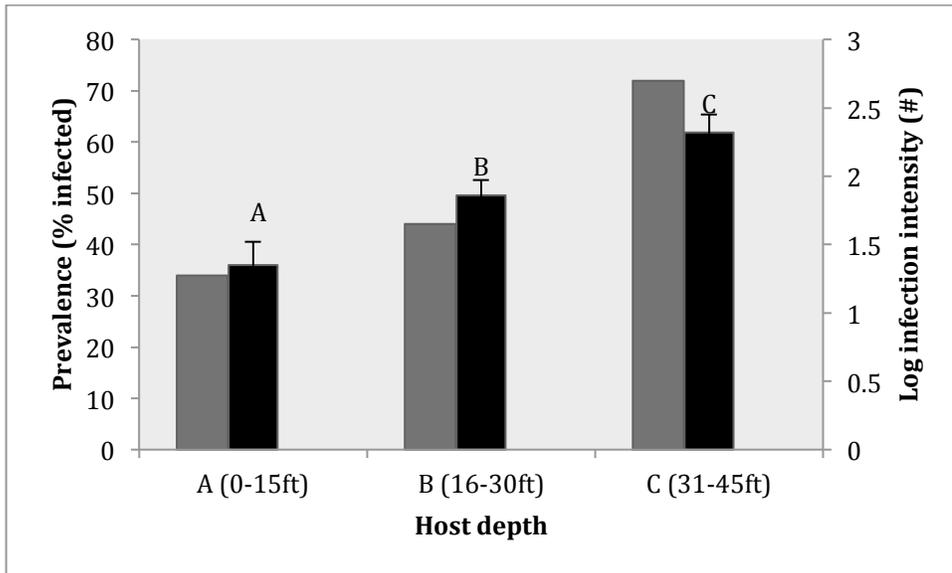


Figure 7. Left axis shows a one-way anova of prevalence of *E. tenuisculpita* on red abalone by depth ($X^2_{3,91}=127.04$, $p<.0001$). Right axis shows a one-way anova of infection intensity of *E. tenuisculpita* by depth ($r^2= 0.20$, $F_{2,91}=10.67$, $p<0.0001$). Error bars are \pm standard error. Tukeys test indicates significant differences.

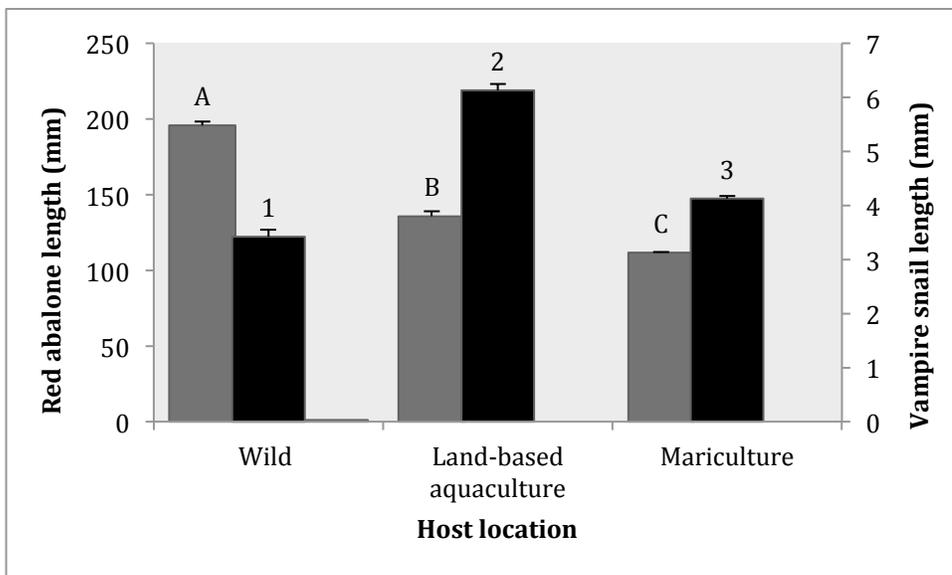


Figure 8. Red abalone (*Haliotis refuscens*) standard length is significantly different by culture location ($r^2=.40$, $F_{2,1675}=545.49$, $p<0.0001$) (Bars are in grey, analysis signified by letters). *E. tenuisculpita* standard length is significantly affected by culture location ($r^2=.39$, $F_{2,1059}=340.99$, $p<0.0001$). (Bars are in black, analysis signified by numbers). Error bars are \pm standard error.

