Title

Management and Risk Assessment of Sabellid Polychaete Infestations in Abalone Mariculture Facilities

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Introduction

In October 1993, growers at some commercial abalone mariculture facilities (AMFs) in Southern California brought an interesting sabellid polychaete to our attention. The worm infested shells of cultured red abalone, *Haliotis rufescens*. Heavily infested abalone ceased growth. Their shells exhibited domed teratology often lacking respiratory holes. The worms appeared to bore into the shell.

We discovered that all AMFs in California were infested; several were so heavily infested that domed specimens were abundant. The objectives of our study were to describe the worm (Associate principal investigator, K. Fitzhugh, Los Angeles County Museum of Natural History), investigate transmission to abalone, its mechanism of attachment and the cause of shell damage. We also examined the host specificity among common intertidal molluscs. In the course of our research we discovered that a natural rocky intertidal site at Cayucos, California had become infested. Here we sought to investigate how the worms had escaped into the adjacent facility, determine whether the worms had become established there, quantify transmission at that site and devise and supervise an eradication plan.

Life History

The newly recognized pest is a sabellid polychaete. Fitzhugh and Rouse (unpublished results) have described the worm placing it in a new genus. It is a simultaneous hermaphrodite brooding its young to a late, nonfeeding larval stage. Released larvae lack the branchial crown characteristic of adult sabellids and crawl over the benthos until they settle on the apertural margin of susceptible gastropods. Benthic larvae of the sabellid pest are able to locate abalone in experimental aquaria by moving both with and against the current (Kuris and Culver, unpublished results). Within a few hours after settlement, the worms secrete a mucous sheath at the growing margin of the abalone shell. Activity of the worm at the margin of the shell apparently prevents its dislodgement and also blocks deposition of nacre over the aperture of the tube. The ability of the abalone mantle to prevent settlement of fouling organisms at the shell margin is foiled by the sabellid. The possible mechanisms used by the sabellid to evade anti-fouling defenses are under our continuing investigation.

Worms will not settle on dead (empty) shells or on hermit crab-occupied gastropod shells (Culver and Kuris, 1997). They will settle on glass and plastic surfaces when an appropriate host is not present (C. Culver, personal observation).

Shell Damage

The abalone, failing to dislodge the recently settled sabellid worm, responds by secreting a laminar layer over the tube (Kuris and Culver, unpublished results). Thus, in the immediate vicinity of each newly settled worm, the abalone mantle is temporarily retracted so that prismatic deposition at the growing margin of the aperture is prevented. After a period of time, the nacreous layer over the worm tube is sufficiently thick that the worm cannot be seen through the laminar layers of shell, nor can the raised worm tube be readily detected by touch with a fingernail or probe. At this point the abalone will renew prismatic deposition. Thus, growth of the shell is most visibly perturbed in the new shell below the worm. The more worms settling at one time, the more evident the growth check mark on the outer (accretionary) surface of the shell. If worms continue to settle over a longer period of time, the abalone takes on a teratological, domed, appearance. The shell is porous (because of many worm tubes) and relatively fragile. Without continued linear extension of the shell, the abalone ceases to grow. Although the process of shell damage is obviously dependent on the intensity and duration of the infestation, the actual intensity-dependent and time- dependent relationships remain to be investigated.

The respiratory pores of the abalone are also sabellid infestation sites. These holes can become completely clogged by worm tubes. In heavily infested shell, formation of new respiratory holes at the margin of the shell is often impaired. Since no new holes are formed, and the old ones are heavily fouled, the function of these holes is probably less effective.

Some preliminary comparative observations have been made on shells of the common upper intertidal zone snail, *Tegula funebralis*. This information was needed because these snails are very rarely found in abalone mariculture facilities (AMFs). Thus, recovery of infested *T. funebralis* shells in nature is convincing evidence that transmission of the introduced sabellid is occurring in native habitat. Within two weeks, the tubes of newly settled sabellids have been so rapidly covered with nacre that they are no longer detectable by tactile examination, and prismatic shell deposition has been renewed. Thus, detection of sabellid worms on these shells requires very careful inspection of the accretionary, as well as depositional, surfaces; worm tube apertures can be recognized by the microscopic deflection of nacreous shell below the aperture of the worm tube.

Host Specificity

Table 1 summarizes our initial studies of host specificity. Most prosobranch gastropods exposed to the worms become infested. The Archaeogastropods (limpets, abalone, trochids) seem most susceptible. A comprehensive evaluation of host specificity using cafeteria choice experiments and a comparison with South African species is in progress.

Although we have been able to infest abalone (*Haliotis rufescens*) as small as 2-mm long, certain small species of gastropods are not susceptible to sabellid settlement (Culver and Kuris, 1997). These include species of *Littorina* and *Mitrella*. Cowries (whose outer surface are laminar rather than prismatic shell) are also not susceptible. The few species of bivalves exposed are unsuitable hosts (although the occasional worm can become established on rock scallops in the presence of very heavily infested abalone).

Spread of Sabellids in the Natural Environment

We surveyed most of the California AMFs for sabellids (Culver and Kuris, 1998). We were particularly interested in the presence of infested shells in the discharge drains or in the natural habitats near the water discharge outflows. Some facilities include suspended infested abalone in cages in situ in the environment. Others release small numbers of escaped abalone, dead abalone shells and, most particularly, numerous infested individuals of *Tegula montereyi* and *T. brunnea*. These snails enter certain AMFs in large numbers, as they are present on kelp used for abalone food. These snails can exit in the drains. Although the former is normally a fully subtidal species, and large individuals of the latter are lower intertidal zone inhabitants, both were recovered in large numbers below the drains of some infested AMFs.

In March 1995 at Cayucos, California, we detected cultured red abalone (source evident from the pale green color of cultured red abalone), *Tegula brunnea* and *T. montereyi* released from the AMF into the upper and mid-intertidal zones. All were infested, often with high intensity worm burdens. A follow-up survey found that many of the native *T. funebralis* were also infested at this site. In September 1996 we successfully conducted a sentinel snail experiment that demonstrated that the infestation was established in the *T. funebralis* population.

Following our recommendations, the AMF agreed to initiate an eradication program. The program consisted of three components: (1) installation of a screen to block the egress of live snails and shell debris from the facility; (2) removal of infested and healthy hosts and empty shells that had been released from the facility into the intertidal site and, (3) removal of all *T. funebralis* (over 15-mm shell length) from the intertidal area around the discharge. The screen was initially installed in late November 1996. Shell debris and live red abalone, *T. brunnea* and *T. montereyi* were removed from the adjacent intertidal zone beginning in November 1996, and on several other occasions in 1997 and 1998. Removal of *T. funebralis* is ongoing and began in July 1997. Results have been encouraging. By April 1998, new infestations (on the margin of the outer lip of the aperture) could no longer be detected in a sample of 180 snails. The rate of new infestations in July 1997 had previously reached over 10% (N = 500). Thus, debris screening and removal of susceptible hosts appears to have dropped the threshold of transmission below the level to sustain the epidemic spread of the worm at Cayucos. It may have reduced the transmission rate below the level required for the worm infestation to persist at the site. Further studies are ongoing with sentinel *T. funebralis* at this site. If eradication of the sabellid from this established site is attainable, it will represent the first successful eradication of a marine pest. At this location, release from the AMF of large numbers of adult reproductive worms on live gastropods and shell debris appears to have been responsible for this outbreak. This conclusion is supported by the fact that few benthic larvae could be detected in water discharge samples. Additionally, it seems unlikely that many larvae could survive the marine cascade of several meters in height from the outflow pipe.

The contamination incident at Cayucos greatly elevated environmental concerns about the impact of the sabellid pest on the California native molluscan fauna. Research on host specificity and on habitat and host range of the sabellid in its native range in southern Africa will enable us to assess risk of establishment and spread of the sabellid in California. Concern over the sabellid led to it being one of the focal topics of the recent Third International Abalone Symposium at Monterey, California, convened by the California Sea Grant College System.

Accomplishments

Our research has greatly altered feeding, water management and animal handling procedures in California AMFs. Most of these recommendations are detailed in Culver et al. ,1997. We have recommended, and industry has adopted, antiseptic procedures in the transfer of animals between parts of AMFs. Hands and equipment are rinsed in freshwater. Transfer of abalone and kelp between tanks is minimized and pathways of stock movement through facilities are recorded. The presence of kelp-associated gastropods (especially *Tegula brunnea* and *T. montereyi)* in AMFs is minimized. Escaped abalone, other gastropods and shell debris are removed from drains. Outflows to environmentally sensitive areas are screened. An important practical concern was the recognition that infection dynamics and risk assessment of onshore tank AMFs were substantially different from offshore cage (barrel) facilities. We provided separate recommendations appropriate to these two types of AMFs.

To effectively and promptly convey our findings to the industry and the California Department of Fish and Game (CDF&G), an Abalone Sabellid Advisory Committee (ASAC) was formed with industry, CDF&G representatives and the principal investigator. The Sea Grant trainee, C. Culver, also actively participated in these meetings.

Table 1. Host Specificity of Sabellid Polychaete

Species	Infestations from Facility Tanks	Infestations from Experimental Tanks
Snails		
Acanthina spp.	—	Yes
Astrea undosa	—	Yes
Calliostoma annulatum	Yes	—
Calliostoma canaliculatum	Yes	—
Cypraea spadicea	—	None
Haliotis corrugata	Yes	—
Haliotis cracherodii	—	Yes
Haliotis fulgens	Yes	—
Haliotis rufescens	Yes	Yes
Kelletia kelletii	—	Yes
Littorina planaxis	—	Yes (rare; only one case)
Mitrella spp.	None	None
Norrisia norrisi	Yes	Yes
Nucella emarginata	—	Yes
Olivella biplicata	—	Yes
Tegula aureotincta	Yes	—
Tegula brunnea	Yes	—
Tegula eiseni	Yes	Yes
Tegula funebralis	Yes	Yes
Tegula montereyi	Yes	—
Limpets		
Crepidula adunca	Yes (uncommon and isolated cases)	—
Fissurella volcano	Yes	—
Lottia gigantea	Yes	Yes
Lottia pelta	Yes	Yes
Lottia digitalis	Yes	—
Lottia limatula	Yes	—
Macclintockia scabra	Yes	—
Bivalves		
Crassadoma gigantea	None	Yes (rare; only one case)
Crassostrea gigas	—	None
Mytilus galloprovincialus	None	None

Based substantially on our work, CDF&G Director Schafer (personal communication) required all abalone aquaculture facilities to develop a sabellid eradication plan because all were considered infested. These plans are reviewed by CDF&G and the risk at each facility is assessed based on the principles of infestation dynamics developed in our laboratory. Approval of these plans and progress towards eradication are required for Aquaculture Registration renewal.

Subsequent actions by CDF&G include sabellid-free certification for transfers between facilities. Initially (1996) inspection of stock for out-planting was required. Later, all outplantings were banned to prevent further infestations in the wild.

We initiated training of CDF&G personnel to enable them to recognize lightly infested abalone. This was critical as prior to that time the industry and CDF&G were only able to detect the teratologic domed specimens that were very heavily infested. Detection of lightly infested stock is key to the approach of eradication in contaminated AMFs. We also demonstrated these detection procedures to many industry facility managers and scientists. Using these procedures to detect infested stock, reduce transmission rates, and harvest infested abalone, growth rates of abalone stock have returned to pre-sabellid infestation norms at many AMFs.

Our information on detection, host specificity and environmental contamination was transmitted to the ASAC of CDF&G on March 22, and November 6, 1996. An important outcome of these meetings was the establishment of a Sabellid Advisory Subcommittee (SAS) chaired by Robert Hulbrock, the CDF&G Aquaculture Coordinator. The final report of the SAS contains the Sabellid Worm Cleanup Plans of all AMFs and a detailed status evaluation and risk assessment.

Our discovery of the infested natural site at Cayucos galvanized several environmental organizations and individuals to call for more careful regulation of introduced marine species in general and the sabellid pest in particular. This information has been used at permit hearings before the California Coastal Commission and CDF&G Commission.

Scientific advancements include the discovery of a new type of worm with the unique ability to settle at the growing margin of the aperture of abalones and other gastropods and stimulate the mantle to secrete new laminar shell so as to form a tube for the worm. This guidance of the mantle by the worm or its tube has implications for the study of molluscan shell deposition. The worm may provide a new assay for the study of biomineralization and the development of novel biomaterials. Use of the sabellid as an experimental probe has been initiated in our laboratory in conjunction with Drs. Daniel Morse (University of California, Santa Barbara) and Rob Day (University of Melbourne, Australia).

Benefits

The following abalone aquaculture companies were informed about methods to detect sabellids, reduce infestations, prevent release of sabellids into the environment and quarantine infested stock. Farms receiving onsite training or informational slide presentations are indicated by an asterisk.

Abalone Acres*; The Abalone Farm Inc.; Abalone International*; Bodega Farms*; Carlsbad Aquafarms*; The Cultured Abalone; Monterey Abalone Company*; Pacific Abalone Farms; Pacific Mariculture Inc.*; Proteus Seafarms; U.S. Abalone*; Jacobsbaii Aquaculture (South Africa),

In addition, CDF&G has used our information on worm biology to detect sabellid presence and to develop a sabellid-free certification program for outplanted abalone. CDF&G has used our information on transmission and host-specificity to develop regulatory policies to block spread of sabellids among facilities and to reduce or eliminate spread to our native gastropods in natural habitats.

The California Coastal Commission used our information to evaluate permitting of an abalone culture facility.

Cooperating Organizations

California Department of Fish and Game
Centre for Research on Introduced Marine Pests, CSIRO, Hobart, Tasmania
The Abalone Farm, Cayucos, California
The Cultured Abalone, Goleta, California
The HMAS *Sterling*
University of Cape Town, South Africa
Western Australia Fisheries Department

References

Culver, C.S., A.M. Kuris, and B. Beede. 1997. Identification and management of exotic sabellid pests in California abalone aquaculture. California Sea Grant College System. Publication No. T-041.

Culver, C.S. and A.M. Kuris. 1998. Eradication of a newly introduced species: Mission possible? *Fisheries*. In press.

Publications

Fitzhugh, K. 1996. A polychaete threatens California's abalone culture industry. *Terra*. 33:(4):4–5.

Presentations

Culver, C.S. and A.M. Kuris. Characteristics of cultured abalone infestations by an introduced sabellid polychaete. Presented at the Abalone Workshop II: An Educational Workshop on Current Developments in Abalone Enhancement Projects and the Aquaculture Industry, Bodega Marine Laboratory, Bodega Bay, California, December 2, 1995.

Culver, C.S., A. Kuris, and C.S. Friedman. Abalone aquaculture, health, management and sabellid polychaetes. Fish Health Session, Canadian Aquaculture Society Annual Meeting, 1996.

Culver, C.S. and A.M. Kuris. Sabellid polychaete pest of cultured abalone: Current exotic pest, future introduced species? Presented at the California Sea Grant Nonindigenous Species Workshop, San Francisco, California, October 18–19, 1996.

Culver, C.S. and A.M. Kuris. The case of the sabellid worm: implications for future nonindigenous species introductions. Presented at the Western Society of Naturalists, 77th Annual Meeting, La Paz, Mexico, January 8–11, 1997.

Culver, C.S. and A.M. Kuris. Introduction of a new molluscan shell pest: Not just another "boring" organism. Presented at the American Malacological Union of the Western Society of Malacologists Annual Meeting, Santa Barbara, California. June 22–27, 1997.

Culver, C.S. and A.M. Kuris. Eradication of a newly introduced species: Mission possible? Presented at the American Fisheries Society Annual Meeting, Monterey, California, August 24–28, 1997.

Culver, C.S. and A.M. Kuris. An introduced polychaete pest of California cultured abalone: current status and environmental concerns. Presented at the 3rd International Symposium on Abalone Biology, Fisheries and Culture, Monterey, California, October 26–31, 1997.

Culver, C.S. and A.M. Kuris. Status of the introduced sabellid pest of abalone and other gastropods in California. Presented at the Eighth International Zebra Mussel and Aquatic Nuisance Species Conference, Sacramento, California, March 16–18, 1998.

Lectures

C.S. Culver. Infestation of cultured abalone by the nonindigenous sabellid worm. Invited lecture. Sea Grant Extension Program Staff Training Meeting, San Francisco, California, September 13, 1995.

C. Culver, and K. Fitzhugh. A new genus of sabellid and its impacts on California gastropods. Invited lecture. Los Angeles County Museum of Natural History, Los Angeles, California, December 7, 1995.

C. Culver. Status of the sabellid worm in California. Invited lecture. California Department of Fish and Game senior biologists staff meeting, Southern California Region, Santa Barbara, California, April 30, 1997.

A. Kuris. Invited lecture. Tasmania Department of Fisheries, Taroona, Tasmania, June, 1997.