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The Introduction of the South African Worm: Biology, History, and Implications for Management

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ABSTRACT: In the early 1990's, California cultured abalone unknowingly became host to an undescribed polychaete pest. Several years later, it was determined that the worm was a non-indigenous species. By this time, the pest had been spread throughout the industry. Native to South Africa, it has been assigned to a new genus within the family Sabellidae. Initial research efforts were aimed at understanding the effect of the pest on abalone, as well as a means for controlling it within the facilities. However, with the determination that the worm was non-indigenous, research efforts shifted to the assessment of ecological issues. The primary concern was the release and establishment of the sabellid in California habitats. Biological and physiological characteristics of the pest are well suited for establishment in California. In fact, one established sabellid population has been found in an intertidal area near Cayucos, California. Eradication efforts are ongoing and appear to be effective. However, additional surveys of other potential release sites are badly needed. The events surrounding the introduction of this pest are complex. Understanding the biology, as well as the history of the introduction, is critical to assess appropriate management strategies. These features and their implications for management are discussed.

This paper has been developed as part of a panel discussion on controlling the release of the South African worm from California abalone aquaculture facilities. Recently, much attention has been focused on the evaluation of the management response to this introduction. For one to assess the adequacy of the response, certain information is needed. In this paper, we summarize general information on the biology of the exotic species and the history of the introduction. In addition, we provide basic management recommendations and we discuss implications of this introduction for future introductions. A more thorough description of these topics is covered in Culver *et al.* (1997).

BIOLOGY OF THE SABELLID

Prior to the introduction of the sabellid into California, this worm was unrecognized even in its native habitat. It has since been described and named by Dr. Kirk Fitzhugh of the Los Angeles County Museum of Natural History (Fitzhugh and Rouse 1999). It is a member of the family Sabellidae, a group collectively known as fan worms. It lives in a tube in a mollusc shell. A simultaneous hermaphrodite, sperm are broadcast out of the tube, while eggs are fertilized and brooded within the tube (Oakes and Fields 1996; Culver *et al.* 1997; Kuris and Culver 1999; Fitzhugh and Rouse 1999). Unlike the majority of marine organisms, this pest does not have a planktonic larval stage. Instead, a benthic larva develops directly within the parental tube. Transmission occurs when the larva crawls out of the tube and settles at the growing edge of either the parental host or a different host. Once settled it produces an elongate mucus sheath. The host then calcifies this transparent, fragile sheath. Thus, the worm obtains a tube as a result of the host's response. This process of

establishment is unique among shell-inhabiting parasites, which normally bore directly into the host shell using mechanical or chemical methods (Haigler 1969; Blake and Evans 1973; Zottoli and Carriker 1974). In addition, although a living host is required for establishment of this pest, empty shells can retain live sabellids that became established while the host was alive.

Another important biological feature of this sabellid is that it has broad host specificity. This pest infests many different gastropods, not just abalone (Culver *et al.* 1997; Kuris and Culver 1999). Bivalves appear to be unsusceptible, although few species have been tested. Host specificity issues, including the role of habitat, host behavior, host size, host defense, and sabellid host preference, are currently being studied.

Infestations of this sabellid directly impact the growth of the host, altering both the rate and type of shell deposition. The impact is intensity dependent. For example, if only a few worms are present, the host may be virtually unaffected by the worm because growth is only temporarily interrupted. In contrast, high worm intensity causes prolonged impacts to shell deposition and structure. In the worst case, growth ceases and the shell becomes very brittle and abnormally shaped. Further, respiratory pores are often lacking. These direct impacts on growth can also have indirect affects on the host. Growers have reported increased mortality associated with heavy infestations (Oakes and Fields 1996). Given the lack of respiratory pores and the abnormal growth of heavily infested abalone, these mortalities are likely due to prolonged stress. In addition, preliminary laboratory experiments indicate that heavy infestations increase a host's susceptibility to predators (Culver and Kuris unpub. data). Further, as size is affected by sabellid infestations, fecundity is also presumably affected.

HISTORY OF THE INTRODUCTION: CALIFORNIA ABALONE AQUACULTURE FACILITIES

This pest appears to have arrived into California with a shipment of South African abalone being used for commercial research purposes. At this time, the existence of the worm was unknown to science. Initially, worm-infested abalone were simply characterized as having domed shells, often lacking respiratory pores. However, it was later learned that these abnormalities only occurred in animals with high worm intensities. In contrast, animals with low numbers of worms appeared normal. The failure to recognize low infestation levels allowed the continued spread of the pest throughout the industry. By 1995, all California abalone farms were infested with the sabellid. Although this pest did not affect the meat of the abalone, nor did it cause direct mortality, growers suffered because the animals were not reaching market size. Production levels plummeted.

Initially, control of this pest in the aquaculture facilities was a primary research focus. Thus, we attempted to identify potential sabellid predators for use as biological control agents (Kuris and Culver 1999). We were unsuccessful. Other control methods such as exposure to freshwater, to extreme temperatures, and to various chemicas were tried, but they too failed. The only treatment that provided some beneficial effect was coating the shell surface with wax or a non-toxic shellac. This technique effectively plugs the tubes and smothers the worms. Following this treatment growth resumes. However, this means of control is not currently used because it is extremely labor intensive and requires reapplication. Presently sabellid infestations in aquaculture facilities are controlled through isolation of infested stocks, use of antiseptic procedures and sale or destruction of infested stock.

The economic impacts have been devastating to the industry. Some companies have gone out of business, while those surviving have experienced production delays of up to two years. Currently, all growers are working toward eradication of the pest from their facilities. Some have already achieved this goal.

HISTORY OF THE INTRODUCTION: CALIFORNIA NATURAL ENVIRONMENT

Concern over the environment increased with the recognition that the sabellid is a non-indigenous species. Our research efforts evaluated the likelihood that the sabellid had been released into the environment. We identified several avenues of release including:

- Aquaculture facilities (both onshore and offshore);
- Enhancement projects (outplants);
- Live fish markets and distributors;
- Research and educational facilities (*e.g.* universities, aquariums, bioassay labs).

Our investigations of release of the sabellid began with onshore aquaculture facilities. These facilities had endured the heaviest infestations and contained the largest number of infested abalone. As onshore facilities discharge their effluent directly into the environment, we began by examining areas around discharge sites. At several sites, escaped animals and empty shells were being released from the facilities. Often these animals and shells contained reproductively active adult sabellids. In some areas, hundreds of adult sabellids were living in these shells.

It became obvious that the sabellid was being released into the environment through the discharge of infested animals and shell debris. Thus, we began taking samples of the native gastropods from around the discharge sites. Because we knew some animals were becoming infested in the facilities and then discharged, we targeted species that were not found in the facilities. At one site, the sabellid was found to occur frequently in a snail species, *Tegula funebralis*, that is rarely found in the facilities. However, the infestations were of low intensity. To further illustrate that infestations were occurring in nature at this site we conducted a mark and recapture study. New infestations were detected at the first recapture date, two weeks after release. Currently, eradication efforts are ongoing, infestation levels have sharply declined and eradication seems possible.[1]

Despite the swift action to eradicate the one known established sabellid population, additional surveys are critically needed. We have only been able to conduct intertidal surveys around onshore facilities. We have recommended that subtidal surveys also be conducted around these facilities. Further, we have recommended that the other avenues of release be assessed. Preliminary surveys around some offshore cage facilities have been conducted and no established sabellid populations have been detected. However, these surveys looked primarily at animals collected directly below or close to the cages. As it is likely that the larval worms are carried away from the cage areas by water currents, additional information on current patterns and broader surveys are needed. Similar surveys are also critically needed in areas where potentially infested abalone may have been outplanted.

MANAGEMENT OF THE SABELLID

Throughout the course of the sabellid introduction we have provided both the industry and CDFG with our research findings as they have become available. We have also provided recommendations about management of the problem (Culver *et al.* 1997). In general, we agree with some

[1] NOTE ADDED IN PRESS: The eradication efforts were successful (Culver and Kuris 2000).

of the policies that have been developed. However, we also feel that some aspects of the introduction have been under-regulated, while others have been over-regulated.

When assessing sabellid management strategies, one should consider the history of the introduction, as well as the biology of the organism. Important dates surrounding the sabellid introduction include:

1981: Known importation of South African abalone to California.
1987: First observation of abnormal abalone in California.
1993: Identification of the pest as an undescribed sabellid.
1994: California research begins.
Mechanism of shell deformation determined.
Recognition that the pest is an introduced species from South African.
1995: Recognition that the pest is widespread in California aquaculture facilities.
Broad host specificity demonstrated.
1996: Established wild population of the pest detected in California.
1998: Examination of the pest in South African habitats.

Given this timeline, it is likely that the sabellid has been in California for a minimum of 11 years. However, it has only been a few years since it has been recognized as an introduced species. In addition, only recently did we detect an established population in nature.

Because this sabellid was a completely unrecognized and undescribed species, its basic biological characteristics were unknown. The following biological characteristics of the sabellid have been identified:

- It is a simultaneous hermaphrodite.
- It has broad host specificity.
- It lives in habitats in South Africa similar to those available in California.
- It has a benthic crawling larval stage.
- It directly affects shell deposition and growth of host species (and indirectly affects survivorship and fecundity).

These features suggest that this pest has a strong potential to successfully invade Californian habitats. However, its benthic larval stage suggests that dispersal will be limited. Further, the impacts of the sabellid on its host are perceived by some as benign; this pest does not pose any human health risk and it does not kill any organisms outright. Development of a management scheme requires consideration of all of these factors, as well as the impact of such a strategy on affected entities (*e.g.* the abalone farming industry). Thus, depending on perception of the risks, different management strategies could be proposed.

IMPLICATIONS FOR FUTURE MANAGEMENT OF NON-INDIGENOUS SPECIES

Like all introductions, lessons can be learned from the introduction of the sabellid. In general, we must face the reality that importation, no matter how regulated, allows for the potential introduction of non-indigenous species. In the case of the one known importation of South African abalone, all animals were inspected and quarantined. However, the existence of the sabellid was unknown. The effectiveness of an inspection and quarantine system will be limited for organisms that have never been studied. The sabellid is not the first, and likely will not be the last, unknown species that is discovered after it has been introduced elsewhere.

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