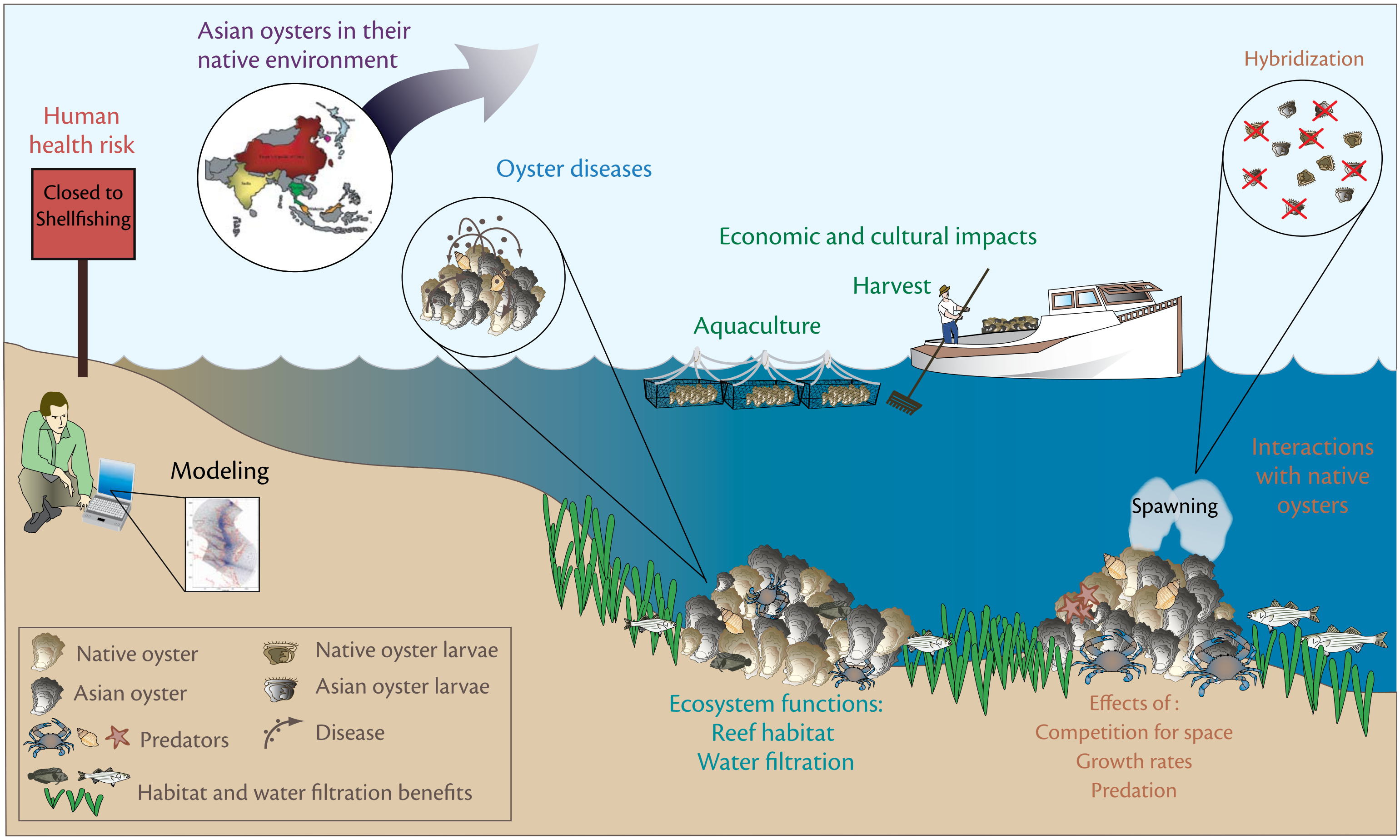
ASIAN OYSTERS:
SCIENCE TO INFORM POLICY DECISIONS

The dramatic decline of Chesapeake Bay's native oyster — the Eastern oyster, *Crassostrea virginica* — has led to the collapse of a formerly productive fishery and loss of important ecological functions such as reef habitat formation and water filtration. Historic overharvesting, habitat loss, poor water quality, and two oyster diseases, MSX and Dermo, have contributed to the decline and continue to hinder oyster restoration efforts. One potential solution being considered by the State of Maryland and Commonwealth of Virginia is to introduce an oyster species from Asia – the "Suminoe" oyster, *Crassostrea ariakensis**. This particular species was selected because initial tests showed fast growth and greater resistance to MSX and Dermo. Concerns about the possible risks associated with a non-native introduction have resulted in a cautious approach, which includes several years of focused research to answer key questions about the Asian oyster.

Therefore, federal and state agencies are preparing an Environmental Impact Statement (EIS) to examine the risks and benefits of introducing the Asian oyster, as well as seven alternative actions that individually or in combination could increase oyster stocks to achieve the desired economic and ecological benefits. A draft EIS is expected to be released for public review in 2008. Since 2004, the National Oceanic and Atmospheric Administration (NOAA) has supported a research program to provide scientific information for the EIS. State agencies have also provided funding for many projects. The research agenda has been guided by recommendations and priorities identified by local, national, and international science advisory groups[1-3].

This overview presents the major research topics under investigation (see figure below). The research includes more than 50 studies conducted by scientists at 15 academic institutions, government research laboratories, and environmental consulting firms. More information on this research and the Environmental Impact Statement can be found at the websites listed on the back page.



Research to support the EIS covers a broad range of topics, including: performance of Asian oysters in their native environment; whether Asian oysters could provide key ecosystem functions; the likely outcome of interactions with native oysters; whether the Asian oyster might influence the dynamics of established or new oyster diseases; human health risks associated with consumption of Asian oysters compared with native oysters; and economic and cultural impacts. Research results and modeling predictions will be used to evaluate the proposed introduction and alternatives in the EIS.

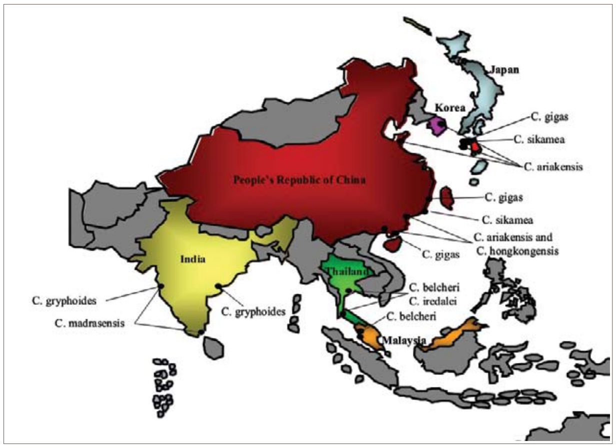
* *referred to as the Asian oyster throughout this newsletter*

ASIAN OYSTERS IN THEIR NATIVE ENVIRONMENT

Knowing where the Asian oyster naturally occurs and how it coexists with other species can help us predict how it might perform and interact within Chesapeake Bay and other Atlantic coast ecosystems. At least seven different oyster species in Asia have been commonly misidentified as *C. ariakensis*. Scientists are working to resolve this confusion in order to determine the actual distribution and ecology of this species in its native environment.

The specific strain of *C. ariakensis* proposed for introduction derives from a dozen or so individuals that were propagated following their unintended arrival at an Oregon oyster hatchery via a shipment of other live oysters from Japan in the early 1970s. Due to the small number of individuals used to establish the "Oregon strain", reduced genetic diversity is a concern.

Researchers are studying the genetics of *C. ariakensis* populations in Asia and comparing genetic diversity between wild populations and captive hatchery strains. This information will help clarify whether the Oregon strain is the one best suited for introduction, and how significant the genetic bottleneck issue may be in successfully establishing new populations of this oyster in the Chesapeake region.



Jan Cordes (VIMS)

ECOSYSTEM FUNCTIONS

Ximing Guo (Rutgers)

The native oyster is a prolific builder of reefs that provide important habitat for many other species. Not all oyster species are reef-builders — some are referred to as "rock oysters" because their flat growth form hugs the surface of rocks and other substrates. Through experiments in the United States and observations of wild populations in Asia, scientists are exploring whether the Asian oyster could fill this important ecological role in the Chesapeake region.

Another critical ecosystem function that oysters perform is water filtration, which removes excess phytoplankton and sediment and improves water clarity. All oysters are filter feeders, but species vary in filtration rates and the sizes and types of particles they remove from the water. Researchers are gathering data on how Asian oysters filter feed, and are using the data in models to estimate the water quality improvements that can be expected from native and Asian oysters at various population sizes.

Might a successful introduction of the Asian oyster provide too much of a good thing? Fouling of docks, boats, buoys, and water intake structures can have significant economic costs, as in the case of non-native zebra mussels in the Great Lakes. Research on Asian oyster biology and ecology will provide insight on the potential for this species to become a fouling nuisance if it is introduced.

INTERACTIONS WITH NATIVE OYSTERS

If larvae of native and Asian oysters prefer similar substrates for settlement, it is likely they would eventually co-occur and compete for the severely limited amount of hard bottom habitat presently available in Chesapeake Bay. Generally faster growth and lower disease mortality may give the Asian oyster a competitive advantage over the native oyster in the long term. On the other hand, the Asian oyster's weaker shell may make it more vulnerable to some common oyster predators like crabs. Field and laboratory studies are providing information that we can piece together for insight on whether one species might out-compete and eventually eliminate the other over time.

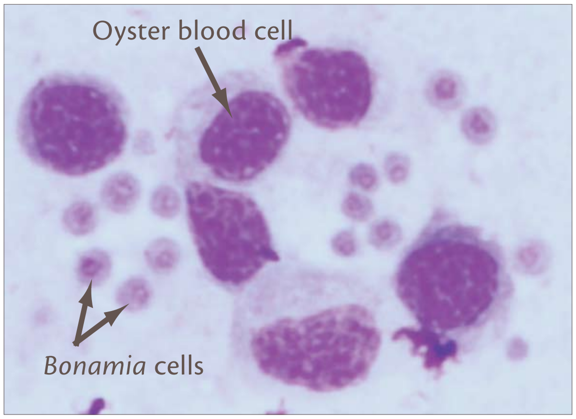
Al Curry (VIMS)

During reproduction, native and Asian oysters can cross-fertilize, but the hybrid larvae die after several days. Production of inviable hybrids creates a "gamete sink" — the loss of gametes that could otherwise produce healthy, single-species offspring. Scientists are determining the likelihood that native and Asian oysters would co-occur and spawn at the same time, and examining how hybridization could negatively affect the reproductive success of both species.

OYSTER DISEASES

Although Asian oysters seem to suffer less mortality than native oysters from Dermo and MSX, we also need to understand whether their introduction might worsen the impact of these diseases on native oysters. Scientists are conducting experiments to learn whether Asian oysters can serve as a disease reservoir or transmission vector (source or sink) for a range of oyster pathogens.

Bonamia, an oyster pathogen not previously known to occur in the mid-Atlantic region, recently caused mass mortalities of young Asian oysters in controlled field trials conducted in North Carolina. Although *Bonamia* infections have not been documented in Chesapeake Bay and the pathogen does not appear to affect native oysters, it is possible that *Bonamia* could spread to the Chesapeake if a suitable host were present. Researchers are studying the geographic distribution and environmental tolerances of *Bonamia* in North Carolina in order to understand how the Asian oyster may be limited by this disease at salinities and temperatures characteristic of Chesapeake Bay and other Atlantic coast waters.



Ryan Carnegie (VIMS)

HUMAN HEALTH RISK

Judy Kleindinst (WHOI)

As filter feeders, oysters can concentrate toxins and pathogens such as bacteria, protozoans, and viruses within their tissues at levels much higher than those of the surrounding water. Human illness from the consumption of raw oysters is a risk that is proactively managed by food safety practices including water monitoring, closure of contaminated shellfish harvest areas, and post-harvest handling standards. These regulations and standards have been developed from research and experience with shellfish species already present in the United States.

Economic revitalization of the oyster fishery is one of the reasons for the proposed introduction of the Asian oyster. In controlled taste tests consumers rated the taste, appearance, aroma, and texture of Asian oysters as favorable, and many participants indicated they would buy Asian oysters if available at a competitive price.

Thus, a key question is whether existing water quality and product handling standards will be sufficiently protective of human health in the case of this new species. Will the Asian oyster pose a greater, lesser, or similar risk for human health compared with the native oyster? Scientists are answering this question by comparing the rates of accumulation, depuration (clearance from tissues), and post-harvest decay of human pathogens in native and Asian oysters.

ECONOMIC AND CULTURAL IMPACTS

Oysters were once the most economically important fishery of Chesapeake Bay, and today remain a cultural icon reflecting the unique flavor and maritime heritage of the Chesapeake region. Income from fall and winter oystering is critically important for communities struggling to maintain the traditional waterman's way of life. In addition to harvest, the ecological functions that oysters perform also have economic value (e.g., recreational fishing, nutrient removal, habitat creation).

The EIS will evaluate economic and cultural impacts of the proposed introduction and alternatives such as expansion of native oyster restoration efforts, a harvest moratorium, and aquaculture of native oysters or triploid (reproductively sterile) Asian oysters. Economists and cultural anthropologists are studying factors including: native oyster restoration costs compared with Asian oyster introduction; effectiveness of past fishery management practices; influence of market forces on the fishery; economic feasibility and potential of oyster aquaculture; dollar value of nutrient removal by oysters; societal values associated with oysters; and cultural changes that might result from various oyster management decisions. Oyster biologists and private industry are providing biological and economic information on various methods of oyster aquaculture, for example, caged versus on-bottom cultivation, use of diploid versus triploid oysters, and the potential for these practices to produce oysters with suitable characteristics and prices for the half-shell or shucking markets.

Don Webster (UMD)

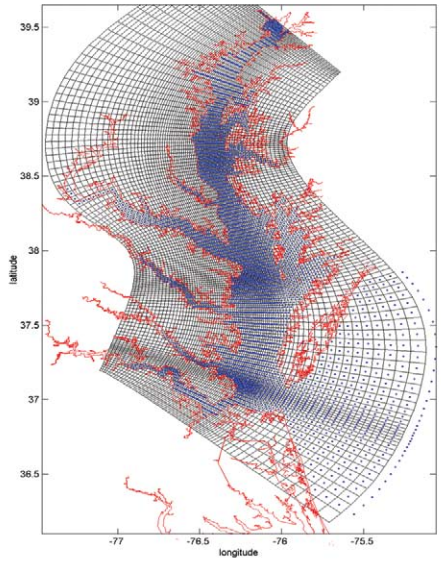
In total, this information will enable decision makers to better weigh the economic and cultural costs and benefits of introducing Asian oysters against other management options.

MODELING TO INTEGRATE DATA

We cannot safely test diploid (reproductively capable) Asian oysters in the field in advance of an actual introduction, but we can use models and the results of carefully controlled field and laboratory studies to predict likely outcomes of the proposed introduction and alternatives. An oyster population model and larval transport model have been developed to integrate information from the many field and laboratory studies yielding relevant data.

The larval transport model combines hydrodynamic simulations of Chesapeake Bay with data from larval behavior studies to provide insight on how native and Asian oyster larvae are likely to disperse. The demographic model tracks simulated oyster populations on more than 2,000 oyster bars in the Bay and incorporates output from the larval transport model to predict population growth, decline, and geographic distribution in subsequent generations.

Many risks associated with an Asian oyster introduction cannot be modeled, however, and must be considered as part of the broader assessment in the Environmental Impact Statement.



Ming Li/Liejun Zhong (UMCES)

For more information:
NOAA: Non-native Oyster Research *http://chesapeakebay.noaa.gov/nonnativeoysters.aspx*
Maryland Department of Natural Resources: In Focus – Oysters *http://www.dnr.state.md.us/dnrnews/infocus/oysters.asp*
Larval transport model for the EIS: *http://northweb.hpl.umces.edu/research/Oyster_larvae_DNR.htm*
NOAA Chesapeake Bay Oyster Larvae Tracker (CBOLT) *http://www.csc.noaa.gov/cbolt/*

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ASIAN OYSTERS:
INTERACTIONS WITH NATIVE OYSTERS

The proposed introduction of the Asian "Suminoe" oyster, Crassostrea ariakensis**, raises many questions about how this species might interact with the native Eastern oyster,* C. virginica*. Despite considerable declines in population, the Eastern oyster persists in many areas and numerous recovery efforts are underway; thus, the extent to which Asian oysters would compete with native oysters is of particular interest. Other factors, such as predation if one species is favored as a prey item, may influence the result of competitive interactions between the two species. Field and laboratory studies are providing valuable insight on these potential interactions (Figure 1), although the long-term outcome remains uncertain.*

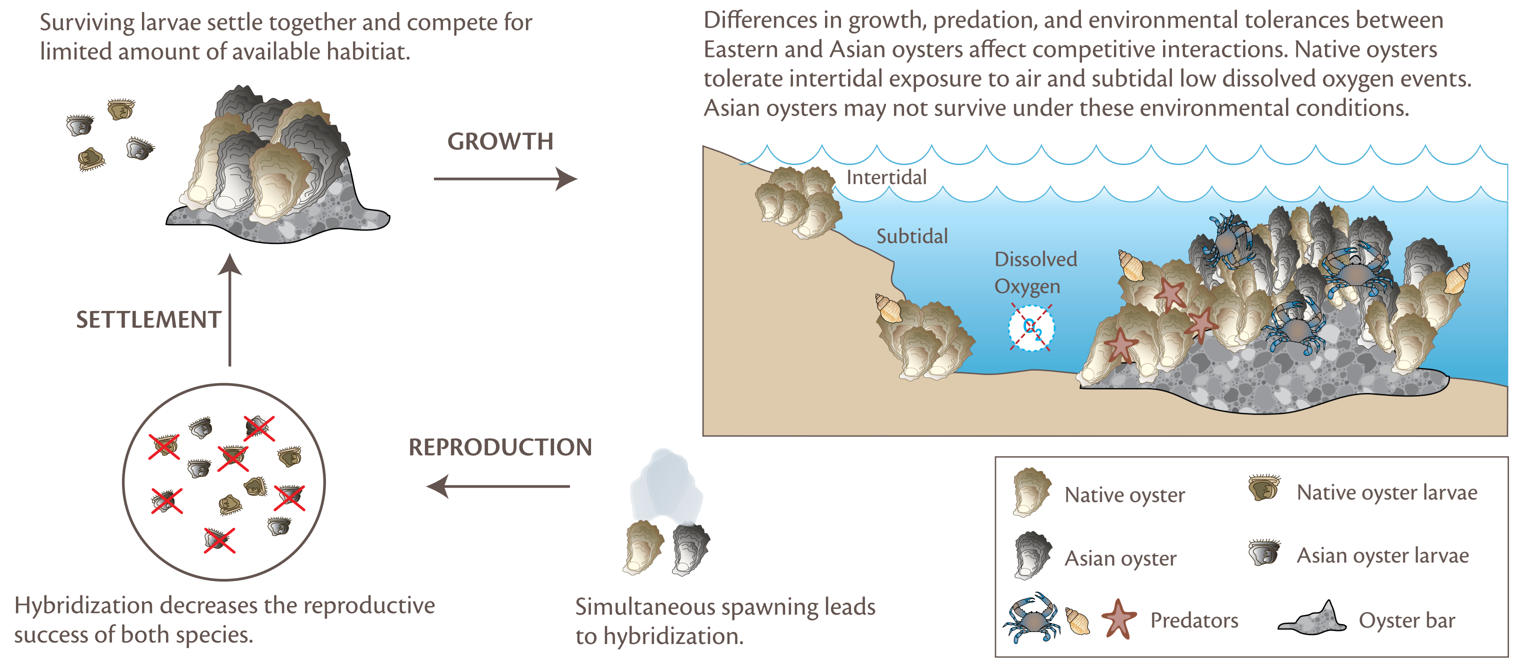

Figure 1. Several potential mechanisms for direct and indirect interactions between native and Asian oysters.

SETTLEMENT – COMPETITION FOR LIMITED HABITAT

Chemical cues from adult *Crassostrea* oysters increase settlement of both native and Asian oyster larvae. Aggregations of native or Asian oysters will provide concentrated sources of these cues and attract settling larvae of both species. Larvae of both species prefer to settle on sediment-free surfaces, and favor natural substrates such as shell or granite over fiberglass, PVC, or steel; however, the Asian oyster has a slightly greater tendency to settle on these artificial surfaces (Figure 2).

Similarities in larval settlement cues and substrate preferences suggest that Asian and native oysters would settle together, resulting in competition for limited habitat and the potential for a variety of interactions between the two species. The possibility also exists that Asian oysters might eventually increase the amount of habitat for native oysters. Eastern oyster larvae have been observed to set on Asian oyster shell in both field and laboratory studies. If Asian oysters successfully establish populations, they could provide valuable habitat for Eastern oysters and other species.

** referred to as the Asian oyster throughout this newsletter*

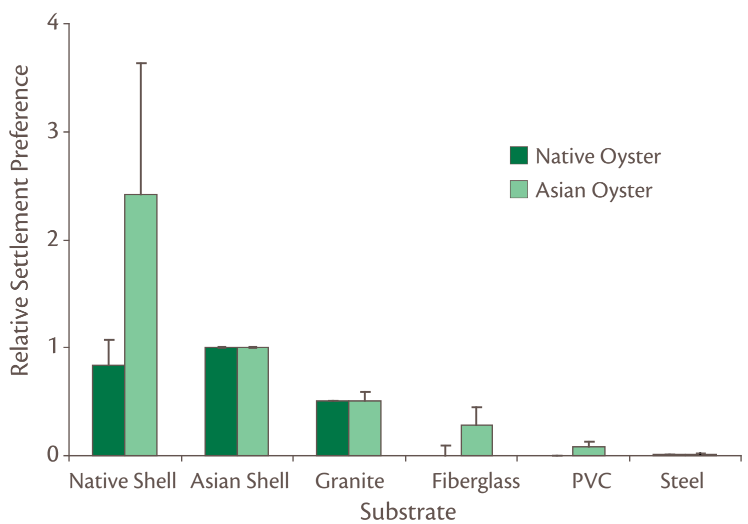

Figure 2. Mean relative settlement preference of native oysters and Asian oysters (Oregon strain) on various natural and artificial substrates.
Data: Tamburri et al., in press.

DIRECT CONTACT – SLOWER GROWTH IN BOTH SPECIES

Soon after larvae settle, competition for space intensifies as the young oysters grow. Early post-settlement crowding slows oyster growth, and both species grow even more slowly in mixed versus single species assemblages.

In single species assemblages, Eastern oysters grow vertically when they encounter another oyster, whereas Asian oysters tend to grow horizontally away from other oysters. In mixed assemblages, both species respond with increased vertical growth; however, the Asian oyster's response is much less pronounced (Figure 3).

This information indicates that co-occurrence of the two species may increase the impact of crowding on both species. Greater propensity for vertical growth suggests native oysters are better adapted to space-limited conditions.

Peter Kingsley-Smith (VIMS)

Figure 3: Differences in growth form in response to direct competition for space: (a) Eastern oysters, (b) Asian oysters, (c) Eastern and Asian oysters in a mixed assemblage. Both species exhibit a broad range of growth forms; (a) and (b) are extreme cases chosen to highlight differences typically observed in laboratory studies.

HYBRIDIZATION – REDUCED REPRODUCTIVE SUCCESS

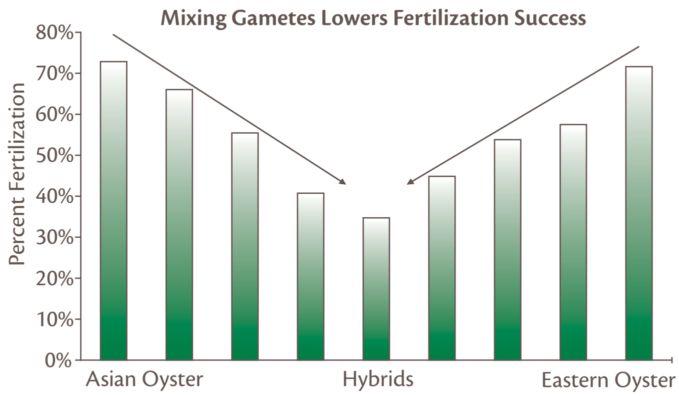

Figure 4. Fertilization rates for the Asian oyster alone, the Eastern oyster alone, and combined (hybrids). Data: Bushek et al, in press.

Crossing Eastern and Asian oysters produces hybrid larvae that die after several days. This creates a "gamete sink" — the loss of gametes that could otherwise produce viable offspring. Reproductive interference occurs when gametes of the two species are mixed, reducing the percentage of eggs that become fertilized. This may represent a significant threat to the reproductive success of both Eastern and Asian oysters if the two species co-occur and spawn simultaneously. The two species have overlapping reproductive seasons and similar salinity and temperature triggers for spawning, suggesting the potential for synchronous spawning. Fertilization rates for both species decline by as much as 50% as conspecific gametes are replaced by gametes from the other species (Figure 4).

LONG-TERM OUTCOME OF COMPETITION – UNCERTAIN

The long-term outcome of competitive interactions will also depend on differences in growth rates, mortality due to predation or disease*, and environmental tolerances of the two species. In general, Asian oysters grow faster than native oysters and this difference is most pronounced at higher salinities. Asian oysters also continue to grow during the winter when native oyster growth has ceased. Faster growth rates and a near year-round growing season may give Asian oysters a long-term advantage over the native oyster in terms of biomass accumulation.

Greater susceptibility to predation may negate some of the Asian oyster's growth advantage in parts of the Bay, depending upon the suite of predators present and their preference for one oyster species over the other. For example, flatworm predation, a major problem for newly set oysters, is similar for both species. However, five common Chesapeake Bay crabs prey significantly more on Asian oysters than native oysters, which have stronger shells. Oyster drills (whelks) and seastars — which are associated with higher salinity environments — prefer native oysters.

While the Eastern oyster uses intertidal areas as a refuge from predators, the Asian oyster is less tolerant of exposure to the air and may not be able to utilize intertidal habitats. The native oyster is also more tolerant of low dissolved oxygen (DO) and may have an advantage in subtidal areas subject to periodic low DO, a common problem in many parts of the Bay. These differences in environmental tolerance suggest the possibility of habitat partitioning, which might allow regional coexistence of both species in the long term. The ultimate outcome of all these interactions remains uncertain.

*see newsletter titled, Asian oysters: Implications for oyster disease

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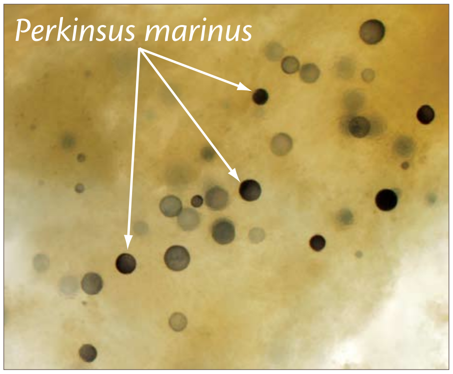
ASIAN OYSTERS:
IMPLICATIONS FOR OYSTER DISEASE

The proposed introduction of the Asian "Suminoe" oyster, Crassostrea ariakensis***, into Chesapeake Bay has been met with concern partly because of its potential implications for oyster disease. Diseases are major causes of mortality for the native Eastern oyster (*Crassostrea virginica*), a reality that underpins arguments for introducing a more disease-resistant oyster species. The Asian oyster is being investigated for its susceptibility to and potential to serve as a transmission vector for a range of oyster diseases. This will help determine whether the Asian oyster might worsen problems of established diseases or serve as an inroad for new ones (Table 1).*

ASIAN OYSTER SUSCEPTIBLE TO KNOWN PATHOGENS

EXISTING DISEASES

The disease commonly know as Dermo is currently the most destructive of all the diseases affecting the Eastern oyster in the mid-Atlantic region. Research has shown that the Asian oyster is relatively resistant to infection from the parasite (*Perkinsus marinus*) that causes Dermo (Figure 1), but heavy infections have been observed in laboratory settings. In its native environment, the Asian oyster has been shown to be susceptible to other *Perkinsus* species, however the effects are not well understood.



Infection of oyster muscle tissue with Dermo disease.

The potential for accidental introduction of a new *Perkinsus* species with the Asian oyster is a concern, but is controlled by international quarantine protocol.

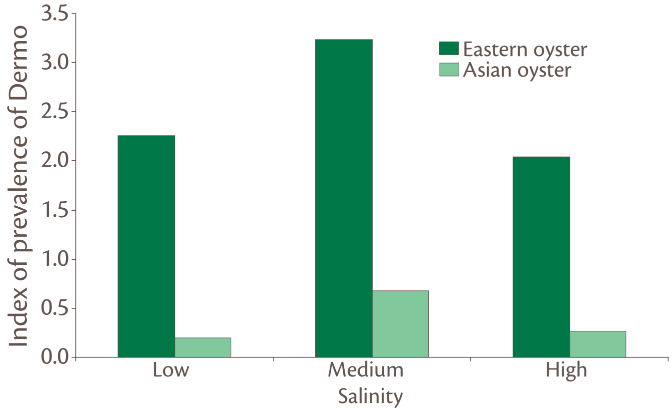


Figure 1: Prevalence of Dermo, caused by Perkinsus marinus*, in Eastern and Asian oysters in three salinity regimes. Data: Calvo et al, 2001.*

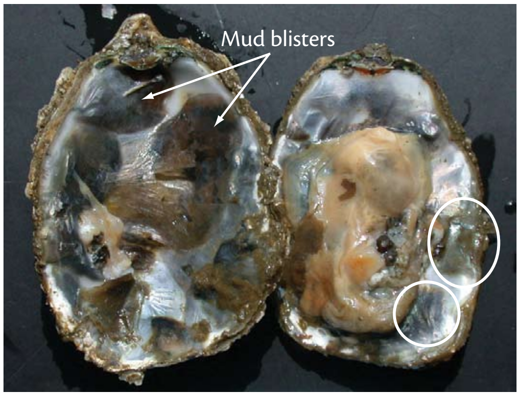
Eastern oysters are also susceptible to the disease known as MSX, which is caused by a protistan parasite called *Haplosporidium nelsoni*. In recent years, Eastern oyster populations have started developing a resistance to this disease. The Asian oyster is relatively resistant to MSX as well.

Infestation by common shell-boring polychaete worms (*Polydora* sp.) is a problem in Asian oysters. These pests have been found to easily penetrate the interior of thin Asian oyster shells.

Table 1: Comparison of diseases that affect Eastern and Asian oysters.

Disease/condition	Pathogen	Point of interest
Dermo	*P. marinus*	Asian oyster relatively resistant
MSX	*H. nelsoni*	Asian oyster resistant Eastern oyster somewhat resistant
Bonamiasis	*Bonamia* sp.	High mortality in Asian oyster
Virus infection	Herpesvirus	Risk of introduction
Polychaete infestation	*Polydora* sp.	Shell fragility, reduced marketability in Asian oyster

The "mud blisters" produced by the oyster in response reduce half-shell marketability and can impact oyster condition and defense against predators (Figure 2). Compromised shells could exacerbate an already heightened Asian oyster susceptibility to predators.



The shell on the left is almost completely covered in blisters of varying age. Note the calcareous nodules indicating the presence of worms (circles).

Figure 2: Photo of an Asian oyster heavily infested with Polydora *worms. Oysters lay down shell material to contain the worms, thus producing mud blisters.*

POTENTIAL NEW DISEASES

Surveys of Asian oyster populations in their native range have revealed another pathogen: a herpesvirus originating from Korea and Japan. This molluscan herpesvirus is similar to those that have caused high mortality of larval and juvenile shellfish in hatcheries in other countries. If this herpesvirus can be transmitted vertically from parents to offspring through oyster gametes, a possibility not yet disproven, a genuine risk of accidental introduction may exist. The potential effects of herpesvirus infection on mid-Atlantic species remains a key question.

** referred to as the Asian oyster throughout this newsletter*

EMERGING NEW DISEASE AFFECTS ASIAN OYSTER

In 2003, Asian oysters in controlled field trials in Bogue Sound, North Carolina, were found to be infected with a *Bonamia* species, a parasite of oyster blood cells, causing very high oyster mortality rates. The disease caused by this parasite, bonamiasis, primarily affects Asian oysters under 50 mm in size, though serious infections can still be observed in larger oysters (Figure 3). It is a disease of warmer summer months, when water temperatures are greater than 20–25° C, and of coastal waters with salinities above 25. The Eastern oyster is not known to be susceptible to *Bonamia*, but the crested oyster, *Ostrea equestris*, which is native to the South Atlantic, Gulf of Mexico, and West Indies is susceptible to *Bonamia*.

This disease has decimated oyster populations in Australia, New Zealand, and Europe, but was unknown in the mid-Atlantic and southeastern United States until recently. This *Bonamia* species now ranges from Cape Hatteras, North Carolina, to southern Florida. A northward expansion of the parasite's range with warming ocean temperatures must be addressed. *Bonamia* may eventually limit Asian oyster survival and culture in waters from the mid-Atlantic to southern Florida.

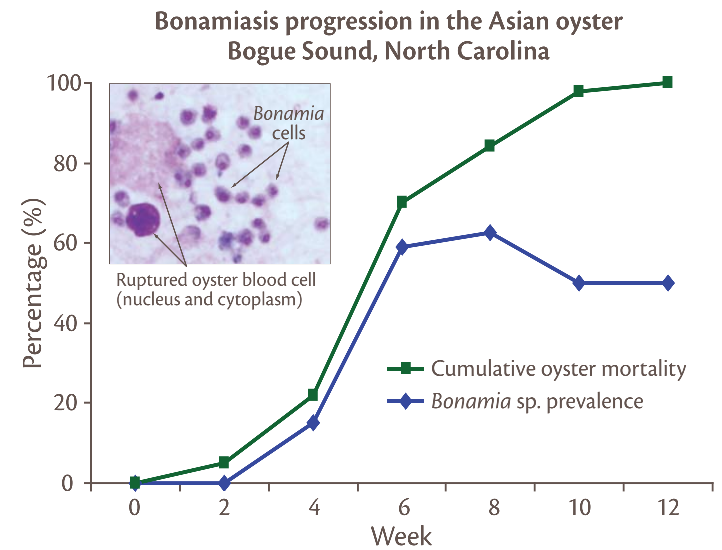


Figure 3: Oyster mortality and Bonamia *prevalence (i.e. the percentage of oysters with* Bonamia *cells) over time, July–October 2005. Data: Carnegie et al., submitted.*

COULD THE ASIAN OYSTER INCREASE DISEASE LEVELS?

> "A non-native species could potentially influence ... disease in native species by acting as a source and increasing transmission of pathogens, or by acting as a sink and decreasing pathogen supply and transmission. It is possible for a species to act as a source or sink if it becomes infected, whether or not that species suffers significant mortality from the pathogens..." (Chesapeake Bay Program's Scientific and Technical Advisory Committee, 2004)

Concern remains that the Asian oyster may be a reservoir for an exotic pathogen that otherwise would not gain a local foothold. Questions also remain regarding the function of the Asian oyster — pathogen source or sink — with respect to local pathogens (Figure 4). The Asian oyster may be irrelevant to MSX disease transmission, and while it acquires Dermo disease, there is little suggestion that Asian oysters will be significant sources of Dermo, particularly when measured against the vast numbers of more susceptible Eastern oysters. Virulence of *P. marinus* in Asian oysters may change over time, however, so the nature of future interactions of *P. marinus* with Asian oysters is impossible to predict. Any expectation that the Asian oyster will serve as a significant sink for *P. marinus* cells is probably unrealistic. The Asian oyster is more likely to act as a source for *Bonamia*, given the vast number of parasite cells that are generated by dying Asian oysters, and the susceptibility of at least one oyster species, *O. equestris*, to this parasite.

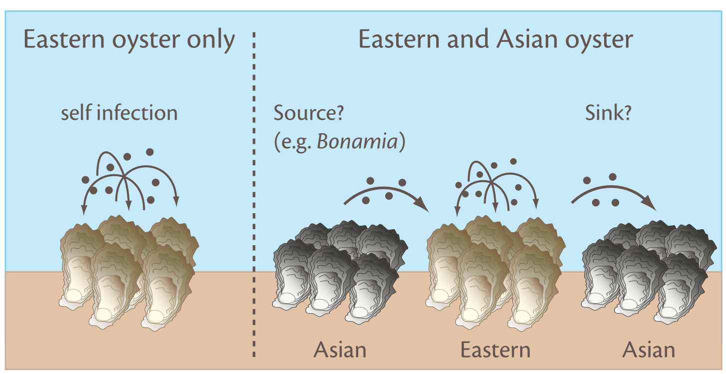


Figure 4: Questions still remain about the potential of the Asian oyster to act as a source or a sink for Dermo, bonamiasis and unknown or new diseases.

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