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September 10, 2003

Mr. Neil Anthony Sims
Vice-President/Research Director
Kona Blue Water Farms
P.O. Box 525 Holualoa, HI 96725

Re: seacage aquaculture

Dear Mr. Sims:

Thank you for your letter of May 29, 2003 regarding Kona Blue Water Farms proposed seacage grow-out facility for kahala (amberjack or almaco jack, *Seriola rivoliana*) and mahimahi (dorado or dolphinfish, *Coryphaena hippurus*) near Unualoha Point on the Big Island of Hawaii. According to the postmark on its envelope your letter was mailed in July, at which time I was out of the country; otherwise I would have replied much sooner. In any case, I will try here to address the questions raised in your letter.

Before beginning, I want to emphasize that my concern is with *seacage* aquaculture of *carnivorous* finfish. The term seacage (a.k.a. netcage, open netcage, netpen, marine netpen, open-netpen) means that farm fish are confined within a mesh through which ocean water passes freely. An alternative to seacage aquaculture is *contained* aquaculture (whether on land or in the water) in which sea water can be treated before it is returned to the ocean. By carnivorous fish, I mean fish whose natural diet includes other, smaller fish.

Let me also emphasize that I am very much in favour of many kinds of aquaculture. For example, aquaculture of herbivorous finfish (i.e., fish that eat mostly plants) in closed-loop terrestrial systems has been done successfully for thousands of years, and it's a great way to convert plant protein into animal protein. I also favour ocean ranching by creating more habitat for marine fishes, and giving those who created the habitat the rights to harvest the fish.

As our correspondence is also for the benefit of other interested parties, including DLNR, I'll quote your letter extensively, in italics, and respond to each quote.

> *"There may indeed be valid concerns about [disease transfer] between wild and farm salmon. However, much of the information that is available on the web, from such organizations as the David Suzuki Foundation, or the "Farmed and Dangerous" campaign, is not supported by scientific studies."*

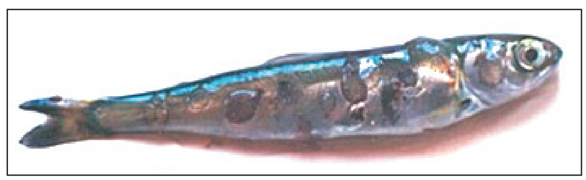
My concerns are not based on material take from the web. They come from on-site interviews with hundreds of residents of coastal British Columbia (BC), nearly all of whom welcomed salmon farming when it began, together with my reading of the scientific literature.

Since you mention the David Suzuki Foundation, I should tell you that I have great respect for that organization. Dr. David Suzuki is a scientist of unquestioned scientific integrity with an admirable record of research achievements in genetics. Although I have never spoken with him, I imagine that we would agree on most points concerning seacages.

Here it is necessary to note that the Federal Government of Canada and the Provincial Government of BC have strongly promoted salmon farming for political reasons (see Appendix A) and have therefore been reluctant to fund the straightforward experiments that would have addressed the question of disease transfer from farm fish to wild fish. Being a fisheries scientist yourself, you are aware that most fisheries scientists work for governments, either directly, or indirectly through funding of their research, and that government scientists are understandably reluctant to risk their jobs by contradicting powerful legislators. Accordingly, in the case of seacage salmon farming the basic environmental science is being funded by nongovernmental organizations (NGO's) such as the David Suzuki Foundation. For example, the David Suzuki Foundation recently funded a study comparing background levels of sea lice on juvenile wild salmon in areas with and without salmon farms (Rolston and Proctor 2003). This is the type of obvious science that should have been carried out by Canada's Department of Fisheries and Oceans (CFO) fifteen years ago. If CFO really wanted to examine the disease transfer question they would also have carried out experiments using "sentinel fish," near netcages containing diseased farm fish, but they have not done those experiments either.

> "*To our knowledge, there has never been a demonstrated case of a farmed fish transferring diseases to wild stocks — it is always vice-versa.*"

Here are a few examples of disease transfer from seacage fish to wild stocks: the epidemic of *Gyrodactylus salaris* on wild Norwegian salmon after introduction of the parasite via farm salmon from Sweden (e.g., Mo 1994); sea lice infestations on wild sea trout in western Ireland near salmon farms (e.g., Tully et al. 1999); sea lice infestations of wild sea trout in Scotland near salmon farms (e.g., Owen, 2002); and the loss of juvenile, wild, pink salmon in British Columbia near salmon farms (PFRCC, 2002).



A pink salmon smolt mortally infested with parasites after migration past a seacage in Tribune Channel, BC. Outmigrating juvenile salmon wait out tidal flood currents by sheltering in bays now occupied by sea cages. Photo courtesy Alexandra Morton, Raincoast Research.

When fish in seacages become diseased it is always with some natural parasite or pathogen of wild fish. These natural pathogens and parasites of wild fish readily transfer from seacage fish back to their natural hosts. In the wild, infected fish are removed by predators at the first sign of weakness. In a seacage, infected fish are protected from predators, so diseased fish in a netcage live longer than they would in the wild, shedding greater volumes of pathogen into the water. The pathogen is said to be biomagnified. Juvenile wild fish are most vulnerable.

The best documented cases of disease transmission from farm to wild are for sea lice because sea lice are ectoparasites whose pre-adult and adult stages are relatively large and visible. Epidemics of sea lice are therefore more obvious to the public than epidemics of other diseases associated with seacages and are therefore more difficult for authorities to ignore. As you know, ectoparasites are not just a problem in salmon culture. The kahala you propose to culture off Unualoha Point are troubled by gill parasites and skin parasites (Kearn et al. 1992, Whittington et al. 2002).

> *"Certainly, fish held in high densities in shallow water areas with poor circulation are more susceptible to disease. This is precisely the rationale for moving out into open ocean fish farming, where the fish are held at lower stocking densities, well clear of the substrate, in good current flow of clean water."*

The salmon farms in BC with disease problems such as kudoa, infectious hematopoietic necrosis (IHN) and sea lice, are not located in shallow areas with poor circulation. They are mostly located in water that is deep, relative to cage depth, and well flushed by tidal flows.

No matter where your farm is located, if wild fish are attracted to it—and they will be attracted, by your feed—those wild fish will give your farm fish parasites and pathogens. There are no predators in your cage to cull your infected fish, and no way for your healthy fish to physically separate themselves from your infected fish. In your seacage the selection pressure for low pathogen virulence is removed, and common pathogens that give you little trouble in the beginning will become more virulent with time. For many pathogens, by the time the infection manifests itself as disease the majority of fish have become infected. You will either have to let your fish die or treat them with chemicals. Your netcage will have become a pathogen culture facility. Effluent from your cage will carry elevated levels of pathogen to wild fish. Juvenile wild fish with low body weight and naive immune systems will be especially vulnerable.

I am not saying that your seacage will turn into a pathogen culture facility immediately. I am saying that it will happen eventually. If you adhere to low stocking densities and fallow your site at regular intervals, keeping it empty as often as it is stocked, your chances of avoiding disease are much better. In other words, you really need two sites, so that one is in production while the other is fallow. Economic pressures make it unlikely that you will be able to operate in this way. What is more likely is that, within a year or two, you will request another site in order to expand your business. You will claim that "economies of scale" are necessary to be competitive with similar seacage operations elsewhere. Moreover, you will soon find yourself competing with other, local seacage operators who will maximize short-term profits by overstocking and not fallowing. In order to compete with them on price, you won't fallow either.

When your fish become ill, you'll call your veterinarian and ask him to prescribe the latest antibiotic or chemical therapeutant. You'll invoke "vet-client privilege" so that the public doesn't know you are medicating your fish. Unfortunately vet-client privilege also prevents you from finding out whether your neighbour is medicating his fish. When your neighbour's fish become ill, the disease will sooner or later spread to your fish. If your neighbour is unscrupulous, and his diseased fish are insured, you may find that his fish escape "by accident," bringing the infection your way before you have time to harvest.

My point is that every seacage operator is at the mercy of his neighbours. Poor husbandry by his competitors can bankrupt him. With land-based aquaculture, or contained systems, the competition is fairer because bad practices by one operator do not necessarily result in dangerous enviromental variables for other operators.

> *"In the case of kahala, the prime species that we intend to culture, these fish are usually not eaten when captured in the wild in Hawaii because of two disease problems:*

> *parasitic worms and ciguatera. According to researchers from the Oceanic Institute, the parasitic worms that permeate the flesh of wild kahala are ingested by the fish when they are larve. The fish are not vulnerable to these parasites when they are older. As we will be rearing all of our farm stock in the hatchery, we will be able to avoid this infestation.*
>
> *Furthermore, wild kahala in Hawaii are known to present a high risk of ciguatera poisoning. The ciguatera toxins are produced by an epiphytic dinoflagellate, and become concentrated up the food chain. When kahala prey on smaller fish or crustaceans carrying these toxins, they retain the toxins in their flesh. Again, farmed kahala will be able to avoid accumulating ciguatera, as they will be separated from the coral reef-associated food chain. So our farmed fish will be healthier than those in the ocean."*

Your strategies for ciguatera and parasitic worms may work, but if you imagine that parasitic worms and ciguatera are the only diseases of kahala, then nature has many surprises in store for you. The one great lesson we are learning from seacage farming is that governments and industry will run out of research money (attempting to find treatments for diseases) long before nature runs out of diseases. For example, there are 225 known diseases of Atlantic salmon (Bakke and Harris 1998). Most of these are seldom pathogenic under natural conditions, and have come to the attention of science only because of the difficulties they have caused for seacage operators. Diseases seldom seen in nature turn into expensive problems for seacages (e.g., Kent 2000).

> *"You state in your letter that "Scientists who have studied the question believe that land based aquaculture ... is the only answer." ... We certainly do not agree with these academic assertions. ... unable to make it work with the high costs involved in land-based production."*

The start-up costs associated with land-based production are higher, but the production costs are lower, and eventually the start-up costs are amortized. (Agrimarine salmon farm near Cedar, BC, is a good example.) However, I understand what you mean. Higher start-up costs mean larger capital requirements. Larger capital requirements make it difficult to compete on price with lower cost operations. The way to address this problem is to differentiate your product by what the marketing people refer to as "branding." Agrimarine markets its fish as "eco-salmon," and they are hugely popular in BC stores because purchasers know that the product has not been medicated and that it has not impacted wild fish. If you think branding doesn't work consider the example of cigarettes: if branding can be used to convince people to poison themselves, it can certainly be used to market a healthy fish. If branding won't work on your product then your product is a commodity—there are many producers of amberjack—and you are eventually going to be put out of business by lower cost producers anyway.

Another, lower-cost alternative to seacage aquaculture is the floating, contained system. It's like a seacage, except that seawater can be filtered before being put back into the ocean. Being located at sea level reduces the energy required to pump water, and the wastes recovered can be recycled as fertilizer. The pathogens and parasites of wild fish can be filtered from the water as it enters the facility. You know that this is the direction your industry is moving, in reaction to disease and other environmental problems. Why inflict archaic technology on Hawaii?

> *"However, experience has shown that small-scale land-based facilities can only be economical for high-priced niche-market species and will go no way toward solving the world's food fish supply problems."*

Oh, my! That's quite a whopper. Asian farmers have been culturing fish in their backyards for several thousand years, and they have not been raising high-priced, niche-market species. The most disingenuous part of the whopper is your reference to world food fish supply problems. Culturing one pound of carnivorous fish, such as kahala requires about three pounds of wet fish to make the feed, even when your feed is 50% slaughterhouse offal and vegetable oil. The small fishes used to make fish feed (sardines, capelin, herring, anchoveta) are purchased cheaply in places like Peru, but the net effect has been to price those fish out of range of their former human consumers. Moreover, it would be better for us humans if we ate those little fish rather than converting them to big fish by culturing carnivores. As you noted in reference to ciguatera, toxins concentrate on their way up the food chain. Your farmed kahala will contain higher levels of persistent organic pollutants than the little fish that are used to make their feed.

> *"We have recently modified our proposal to accommodate some of the concerns that have been shared with us over the course of our draft EA review process. One of the most significant changes we are proposing is to make all of our six main cages of the submersible design rather than a mixed array of surface and submersible cages. These cages will be completely enclosed in mesh; we will not have the large seacages that seem to dismay you. The cages will be submerged beneath the surface most of the time and will only be raised ... near the surface for fish transfers or cage cleaning. This will hopefully alleviate your concerns—and nullify your assertion— that inevitably 'storms will tear (our) cages loose.'"*

As I noted above, the term "seacage" refers to any cage that allows free flow of water between the farmed fish and the surrounding ocean. Submerged cages are even more open than floating cages, since the surface area available for water transfers is larger. Submerged cages will still attract wild fish. They will still become pathogen culture facilities.

> *"...monitoring that has taken place at the existing fish farm site off Ewa Beach in Oahu...showed lack of any significant environmental impact from these cages. Another commercial project in Puerto Rico...shows no significant impact."*

If you put your farm in a location with a "good flush" then indeed your effluent will be dispersed over a very wide area. This looks good when you monitor, but it has nothing to do with my concerns regarding disease transfer. A good flush will transfer pathogens from wild fish farther away, and it will disperse the pathogens cultured by your farm over a much larger area. Wild fish, as you know, prefer not to fight a current, and when fish rest they generally do so in the lee of bottom prominences, which are exactly the places where your effluent will also settle.

"Your prediction for the future of open ocean fish farming in Hawaii is bleak, but is based on the presumption that large multi-national corporations will take control of the industry. Your demand for an EIS may accomplish this faster than any natural attrition of local companies."

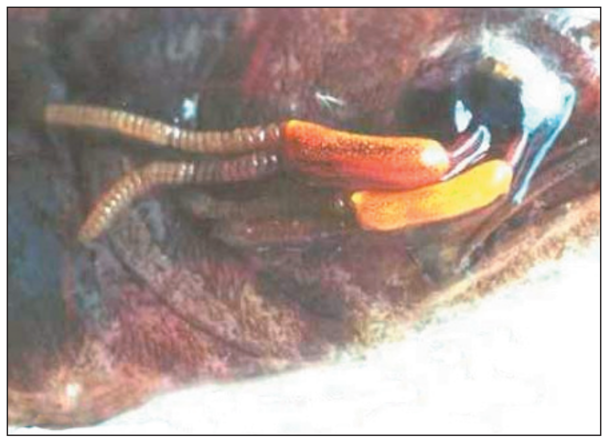
I'm sympathetic to this reasoning, and if you are willing to forgo vet-client privilege (see above) in Hawaii aquaculture then I'll be even more sympathetic. However, the cost of preparing an EIS is miniscule compared to the cost of a feed cycle, and in the course of preparing the EIS you are likely to learn things that will save you money. For example, I'd like very much to know your contingency plan for dealing with infestations of the monogenean parasites known to trouble cultured kahala. Will you bathe your fish in praziquantel, or sodium peroxocarbonate or formalin or malachite green? Will you release those last two toxins to the environment when you are finished treating?

> "*It is only in British Columbia and Alaska that there is any real opposition to fish farming*."

Oh, my! Another whopper. I can put you in touch with many people in Norway, Scotland, Ireland, New Brunswick and Chile who would be very glad to show you some "real opposition." This is the basis for my earlier suggestion that the state of Hawaii send a few legislators on a world tour to meet knowledgeable people who actually *live* near seacage aquaculture operations, instead of getting all its information from the aquaculture industry.

> "*Most of this opposition is fueled by local salmon fishermen who have found that they cannot compete with the greater efficiencies of fish farms*."

The truth is considerably more interesting. Most British Columbia (BC) fishermen initially welcomed salmon farms hoping they would provide off-season work. Even now, the greatest opposition to salmon farms in BC comes not from fishermen, but from long-time local residents who have seen the changes in local marine ecosystems that followed the opening of salmon farms. BC's tourist and sport-fishing industries have been especially hard hit. If you are a sport fishing guide, like my friend Chris Bennett, and your client pulls in a fish with a copepodid sticking out of its eyeball or a cancerous growth on its head, your tolerance for seacage farming goes into decline rather quickly.



Arrowtooth sole, with the eye parasite *Phrixocephalus cincinnatus*. Since seacages came to the Broughton Archipelago, once-rare copepodid infestations on wild fish are now routinely noted by sportfishing guides and commercial fishermen. Can this kind of thing be good for Hawaii's tourist industry? Photo courtesy Alexandra Morton, Raincoast Research.

What really triggered the opposition of BC commercial fishermen was the sea lice epidemic in the Broughton Archipelago that caused pink salmon spawners to drop from 3.6 million to 150 thousand in 2001. An estimated ten million pounds of expected wild salmon were lost because of parasites from seacages. An investigation by the Pacific Fisheries Resource Conservation Commission (PFRCC 2002) showed that sea lice from seacages were almost certainly the cause of the decline, yet Broughton seacage operators left pens stocked along the pink salmon migration routes in spring 2002. In consequence the Broughton odd-year, pink salmon runs show no sign of rebuilding in 2003 even as pink salmon runs appear to have maintained or increased on the rest of the coast. Expect more rage from BC fishermen.

Alaskan fishermen are upset by salmon farming in BC because they keep finding escaped Atlantic salmon (*Salmo salaris* from BC farms) in Alaskan streams, and they understand that, because Atlantic salmon have a different immune system profile from Pacific salmon, it is possible for Atlantic salmon to spread diseases that are potentially devastating to Pacific stocks. You'll recall how *Gyrodactylus* was spread to wild Atlantic salmon in Norway by escaped Atlantic farm salmon that had been imported from the Baltic. This phenomenon isn't uncommon in nature: the West Nile virus now devastating certain North American birds appears to be carried by song sparrows; the sparrows carry the disease, but their European heritage—they were introduced many years ago—makes them immune to it.

> *"Furthermore, communities don't just gain jobs from fish farms, they gain a sustainable industry with he standard, many-fold multiplier for the local economy."*

A recent report from BC (Marshall 2003) suggests that more jobs have been lost in tourism, sport and commercial fishing than have been gained from salmon farming, with or without the standard many-fold multipliers. His report is consistent with my personal observations in the small coastal communities of BC. As you know, seacage aquaculture of carnivorous finfish is one of the most capital intensive industries in existence, mainly because of the long "feed cycle" during which fish must be fed before they are brought to market. It's an industry that provides jobs for a very few highly educated people like you and me, and a few jobs on a "slime line" for locals. Farmed finfish production doubled in Norway from 1994 to 2000 while employment in the industry declined by 4 per cent (Norway Directorate of Fisheries 2001).

> *"By adopting fish farming Hawaii would accept some responsibility for what we consume, rather than constantly relying on foodfish imports that are usually based on unsustainable wild stock fisheries."*

Sadly, the kahala you propose to culture are carnivorous, so your proposed activity will consume about three times as much fish, by weight, as it produces. (According to Nutreco Aquaculture, one of the largest aquaculture companies in the world, between 4 and 5 pounds of fish are required to make one pound of fishmeal. The food you will need to feed your fish will be at least 30% fishmeal, and more like 65% fishmeal if you want a quality product. Assuming 50% fishmeal in your feed, and an optimistic feed conversion ratio of 1.3, you will consume 4.5 x 0.5 x 1.3 = 2.9 pounds of fish for every pound of fish you produce.) To regard such an activity as responsible requires considerable imagination. Shameful would be a more accurate description.

I am aware that websites promoting seacage aquaculture often state that the small fishes used to produce fish meal are unsuitable for human consumption. In the case of Pacific herring, I can assure you from personal experience that such statements are nonsense. Pacific herring have a much better flavor than the cultured salmon to which they are fed.

Mr. Sims, I'm a sincere supporter of aquaculture and I'm very pro-business. As you know, aquaculture is like agriculture in that it includes many kinds of activities, some of which are good and some of which are questionable at best. Culturing carnivorous fish like salmon or kahala is as senseless as culturing tigers; it's not an efficient way to produce the animal protein needed by humans. It's also energy intensive because of the costs of catching small fish to make fishmeal, as well as the costs of producing and transporting the fish food you will need to feed your kahala (Tyedmers 2000). The seacage industry is highly vulnerable to price shocks in petroleum.

Culturing carnivorous fish would be less absurd if you didn't need to feed them at least some fish-meal made from smaller fish, but so far nobody has found a way to do that, and if they did, the resulting product would no longer have the same health benefits of real fish. Farmed salmon, for example, is much oilier than wild salmon, and it has a less desirable ratio of omega-3 to omega-6 fatty acids because salmon feed is laced with vegetable oils. The threadfin produced by Hawaii Offshore Aquaculture Research Project had problematic lipid levels for similar reasons (Ostrowski et al. 2001), and laboratory analyses would probably show that the omega-3 to omega-6 ratios of farmed threadfin are inferior to those of wild threadfin.

My main objection to your proposal is that the nature of host-predator-parasite relations turns any seacage into a pathogen culture facility. Everywhere that seacage aquaculture is practised, pathogen levels rise and new pathogens emerge. Norway, Scotland, West Ireland, New Brunswick, Maine and BC have all had similar experiences. Seacage culture of warm water fish has exactly the same problems (Seng and Corni 2002) for the fundamental reasons outlined above and in Appendix B. The aquaculture industry has been in denial about the effects of seacages for two decades, and sympathetic governments have coddled it by directing their research funding at finding treatments for disease, never pausing to consider that the disease problem of seacages may be fundamentally unsolvable. Their strategy hasn't worked because of the long time lag between detection of a commercially important disease and the discovery of a treatment. The price of this poor strategy in BC is now being paid with seacages full of fish rotten with kudoa and IHN, and in ongoing employee layoffs.

Intensive terrestrial culture of animals such as chickens and cattle has been profitable because farmers are able to physically separate their cultured animals from wild stocks thus limiting transmission of parasites and pathogens. The proper marine analog of terrestrial animal culture is the closed containment system, not the seacage.

Hawaii is not obligated to take up a fundamentally unsound idea like seacages just because other countries have done so. If we focus our energy on contained systems, and on ocean ranching by creation of new habitat, we will lead the aquaculture industry into the future rather than the past.

I would appreciate it if you would post this letter and its appendices on your website together with the other comments on your proposal.

Sincerely,

Neil Frazer
Professor

Cc: DLNR, Public

Attachments:

References
A. Understanding the diversity of opinion on seacages
B. Toward a theory of seacage disease.

References

Kearn, G.C., Ogawa, K. and Maeno, Y., 1992. Hatching patterns of the monogenean parasites *Benedenia seriolae* and *Heteraxine heterocera* from the skin and gills, respectively, of the same host fish, *Seriola quinqueradiata*, *Zoological Science*, **9**, 451-455.

Kent, M.L., 2000. Marine netpen farming leads to infections with some unusual parasites, *Int. J. Parasitology*, **30**, 321–326.

Norway Directorate of Fisheries, 2001. *Key Figures from Norwegian Aquaculture Industry: 2000.*

Ostrowski, A.C., Bailey-Brock, J. and Leung, P.S., 2001. *Hawaii Offshore Research Project (HOARP) - Phase II Final Report*, Sea Grant Program, University of Hawaii at Manoa, Honolulu, HI 96822

Owen, J. 2002. Sea trout loss linked to salmon farm parasite, *National Geographic News*.

Marshall, D., 2003. *Fishy Business: The Economics of Salmon Farming in BC*, Canadian Centre for Policy Alternatives, Vancouver and Ottawa, Canada.

Mo, T.A. 1994. Status of Gyrodactylus salaris problems and research in Norway. Pp. 43-58 in: *Parasitic Diseases of Fish* (eds. A.W. Pike and J.W. Lewis), Samara Publishing Ltd., Dyfed, Great Britain. ISBN 18-736-9202.

PFRCC (Pacific Fisheries Resource Conservation Council), 2002. *Protection of Broughton Archipelago Pink salmon stocks, Report to the Minister of Fisheries and Oceans, Report to the BC Minister of Agriculture, Food and Fisheries.*

Rolston, D., Proctor, B., 2003. Salmon Farms and Sea Lice: A baseline report of the incidence of sea lice on juvenile salmonids on British Columbia's north Coast, David Suzuki Foundation, Vancouver, BC, Canada.

Seng, L.T., and Corni, A., 2002. Infectious diseases of warm water fish in marine and brackish waters. In: *Diseases and Disorders of Finfish in Cage Culture*. Edited by P.T.K. Woo, D.W. Bruno and L.H.S. Lim, CAB International, Oxon, England.

Tully, O., Gargan, P., Poole, W.R., and Whelan, K.F., 1999. Spatial and temporal variation in the infestation of sea trout (*Salmo trutta* L.) by the caligid copepod *Lepeophtheirus salmonis* (Kroyer) in relation to sources of infection in Ireland, *Parasitology*, **119**, 41-51.

Tyedmers, P., 2000. *Salmon and Sustainability: The Biophysical Cost of Producing Salmon Through the Commercial Salmon Fishery and the Intensive Salmon Culture Industry*, PhD dissertation. University of British Columbia: Vancouver, BC.

Whittington, E.I., Corneille, S. and Talbot, C. 2002. Monogenean parasites in sea-cage aquaculture, *Austasia Aquaculture*, **16**, 46-48.

Appendix A. Understanding the Diversity of Opinion on Seacages

A reader may well wonder how it is that two scientists at the same university can have such radically different opinions about a concept as simple as the seacage, especially when those two scientists have had substantially the same scientific training. For example, my friend and colleague emeritus, Dr. Charles Helsley is much in favour of seacages, and he believes that the environmental problems of seacages are solvable. It would be unfair to suggest that he feels that way because, as Director of UH Sea Grant he is tasked with bringing new technologies to Hawai`i, and seacages are a very fashionable idea. I'll suggest it anyway, and explain why below, after introducing the concepts of political capture and scientific capture.

My own opinions regarding seacages are based on my travels on the coasts of BC, southeast Alaska and Washington over the past dozen years. My intention was to write a series of books on the northwest coast of North America. I had no grant for this activity, but it seemed to me that the rapid changes on that coast might have lessons in them for Hawai`i. I travelled by small boat, often alone, to the remotest areas of the coast. Seacages were not my main interest, but I interviewed independent seacage operators, such as Rob Smeale at Doctor Bay and Gus Angus at Jervis Inlet. (This wasn't as much fun as it sounds—I once spent most of an afternoon getting covered with fish slime while helping a seacage manager replace a net.)

Seacage issues became increasingly difficult for me to ignore because, wherever seacages were present, long-time local residents were deeply concerned about the subsequent changes to traditional food sources such as wild salmon and clams. Most of these people admitted to having been enthusiastic supporters of seacages when they began. The only residents who did not complain about seacages were the small percentage of residents actually employed by

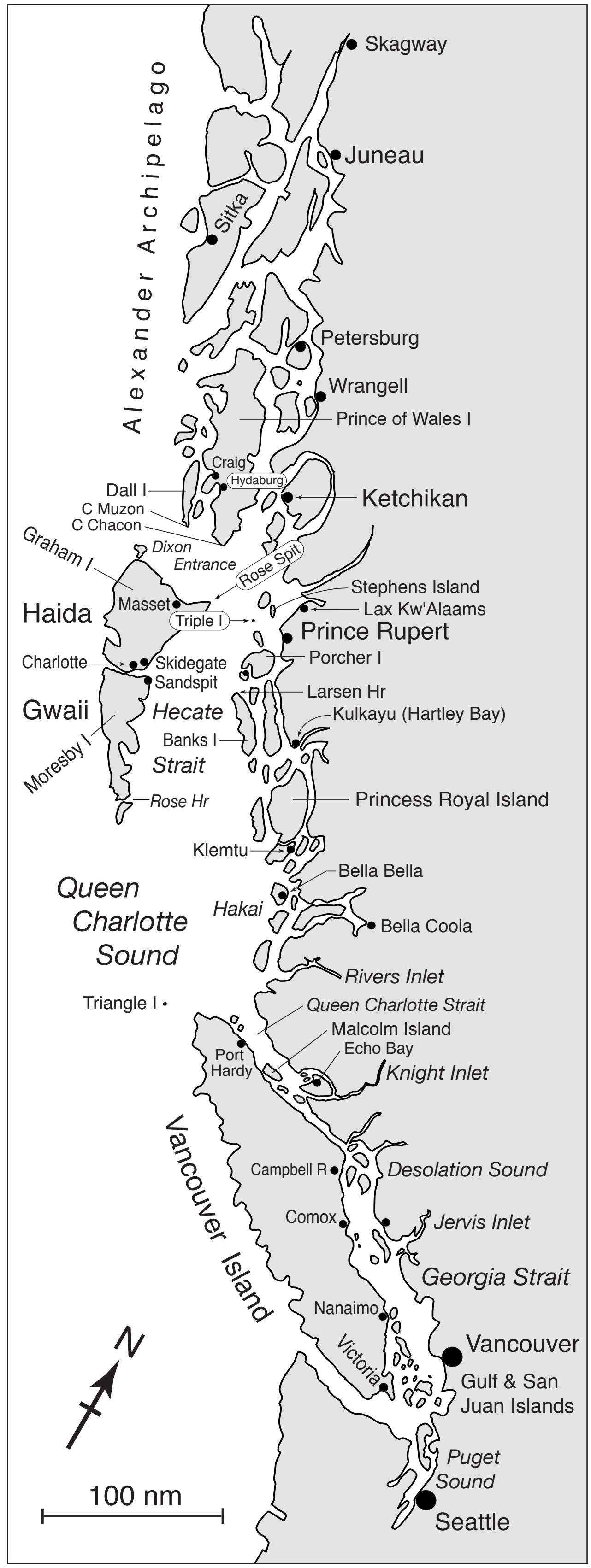


Figure A1. Coastline personally surveyed by the author since 1990. (Lynn Canal, Portland Canal, and Gardner Canal were not surveyed.)

the seacage companies. Some of the residents who spoke to me were people such as Billy Proctor of Echo Bay whose remarkable knowledge and powers of observation I was able to verify by discussions of science and by comparing his descriptions of obscure places on the coast with my own direct observations of those same places. I made a habit of visiting Billy every year on my way through his area, just for the pleasure of talking science with him.

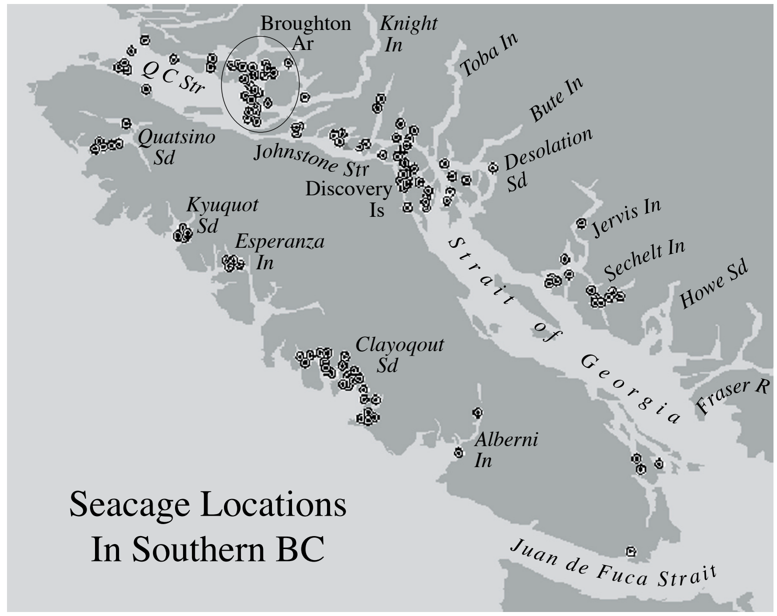


Figure A2. Most seacages are located on the south coast of BC, for proximity to transportation centers, but none are located near large population centers. Environmental concerns resulted in a moratorium on seacage expansion in 1995, Lifting of the moratorium in 2002 was protested by every concerned NGO.

Some of the residents I met seemed to me to be genuinely heroic people: Alexandra Morton, a resident whale biologist, was threatened physically by seacage operators when she began to note the effects of seacages on marine wildlife, and she was threatened with prosecution by federal authorities when she began studying sea lice on juvenile salmon. Examining Ms. Morton's samples, reading her papers in draft, I could find no fault with her sampling techniques or her analysis, and her observations of infested juvenile salmon were consistent with the observations of sportfish guides and commercial fishermen.

In trying to make sense of the seacage debate I did what scientists usually do when they are new to a field: they bury themselves in its scientific literature. I found that about 90% the scientific literature of seacages is concerned with finding chemical treatments or vaccinations for the diseases of seacage fish. Not surprisingly, since water flows freely through netcages, virtually all of the diseases of seacage fish are the natural diseases of wild fish. It was immediately obvious that farm fish were getting disease from passing wild fish. The really striking thing was that so little research had been done on the transmission of disease *from seacage fish back to wild fish*. By far the largest number of references to this obvious topic were regular denials from paid, seacage industry representatives and from government officials with an administrative loyalty to aquaculture. "There is no evidence of transmission of disease from farm fish to wild fish," they would inevitably say.

All scientists are familiar with the principle that absence of evidence is not evidence of absence. It seemed to me that the game being played was the same game that tobacco companies played for fifty years: if you don't look for a connection between tobacco use and lung cancer, you are not going to find one. Similarly, if you don't give researchers the money to study disease transmission from seacage fish to wild fish, you are not going to find any evidence for that, either. There was absolutely no government research money flowing to anyone wanting to investigate the topic.

If seacage industry officials had genuinely wanted to give their industry a clean bill of health, the science needed to do so was obvious. For example, if you want to investigate transmission of, say, sea lice, from farm fish to wild fish, all you need to do is to put small, uninfected fish in very small floating cages at various distances from the seacage in question. If the subsequent pattern of sea lice infestation in your "sentinel fish" shows no spatial or temporal gradient of infestation away from the farm then you can plausibly argue that "there is no evidence of transmission from farm to wild." Such experiments are not difficult to perform, and relatively inexpensive, as science goes, but they were never funded.

Other odd things happened in BC: The director of Pacific Biological Station, who (not coincidentally) was also the Head of the Aquaculture Division, interfered with the research of a graduate student investigating the behavior of escaped farm fish.* A cabinet minister illegally interfered with an investigation of environmental violations by a seacage company. During an epidemic of sea lice on juvenile wild salmon (something that had never been observed prior to seacages) the same director of Pacific Biological Station, a large federal laboratory, lied to the public about background levels of sea lice in the area of the epidemic—internal memos obtained under Canada's Access to Information Statute (ATIP) by Sierra Legal Defence subsequently revealed the lie.

In order to understand the situation in BC it is helpful to generalize a concept the economists refer to as "regulatory capture." What they mean by this phrase is that a government bureau created to regulate a particular industry for the benefit of the public eventually becomes so heavily influenced by that same industry that the agency's regulatory function is lost. Capture is then said to have occurred. It's easy to see how this happens: regulatory personnel either get to like the people they spend most of their time with, or they change jobs. Regulatory capture is more often the rule than the exception. For example, agencies tasked with oversight of the securities industry seldom do so with any great enthusiasm except during the brief period following a crash in the stock market.

To introduce the concept of political capture consider the map of BC shown in Fig. A3. Comparison with Fig. A2 shows that of BC's 79 electoral districts, only three (districts 3, 5 and 46) contain significant numbers of seacages, and these districts are relatively sparsely populated. Most BC residents therefore had to rely on information provided by the seacage industry or their government. Each electoral district has a Member of the Legislative Assembly (MLA), but even with the best of luck there are not likely to be more than 4 MLAs with any deep understanding of wild fish. When the seacage industry came calling and said that it would create a new cash source for BC by raising fish in cages just like cows or chickens, you can't blame most MLAs for wanting to jump on the wagon and join the parade. How different can salmon farming be from, say, cattle ranching, they must have thought.

I don't mean to imply that politicians are more obtuse than the rest of us. However, they differ from the rest of us in one important respect: if they admit they are wrong about something, they are likely to lose their jobs. The seacage industry convinced BC politicians that seacages were the wave of the future, and after the politicians had committed political capital to it, by promising economic benefits from a new export industry, they were trapped. Political capture had occurred.

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* John Volpe, the graduate student, successfully resisted the interference. Volpe's dissertation research showed that, contrary to government and industry statements, farmed Atlantic salmon were happy to breed in a stream environment. In subsequent research, as a junior professor at the University of Alberta, Volpe decapitated other industry myths by showing that escaped Atlantics had successfully bred in BC streams and produced viable progeny. In public appearances Volpe has been courageously forthright about his findings and their implications, and he is rightly regarded as a scientific hero.

In Canada, political capture also occurred at the federal level, which is at first surprising, since responsibility for wild salmon in Canada rests with the federal government. To understand how this happened so easily it is helpful to introduce the concept of "captive science." In the 1960s and 1970s Canada's federal politicians became increasingly annoyed with fisheries scientists who (while funded by a more or less independent body called the Fisheries Research Board) occasionally noted that certain fish stocks were being overfished. Accordingly, in 1979, the federal government rolled all fisheries science up with the Coast Guard and the Hydrographic Service into a bureaucracy they could control. They called it Canada Fisheries and Oceans (CFO). Since then, if you were a fisheries scientist working for CFO (which is where most fisheries scientists worked after 1979 except for a few professors), and the Minister of Fisheries and Oceans didn't like your stock estimate, he sent you back to the lab to work up other estimates until you gave him one he liked. This was a good system for getting politicians reelected but it had predictably disastrous results for fish such as the northern cod which were harvested to commercial extinction over the decade following creation of CFO.

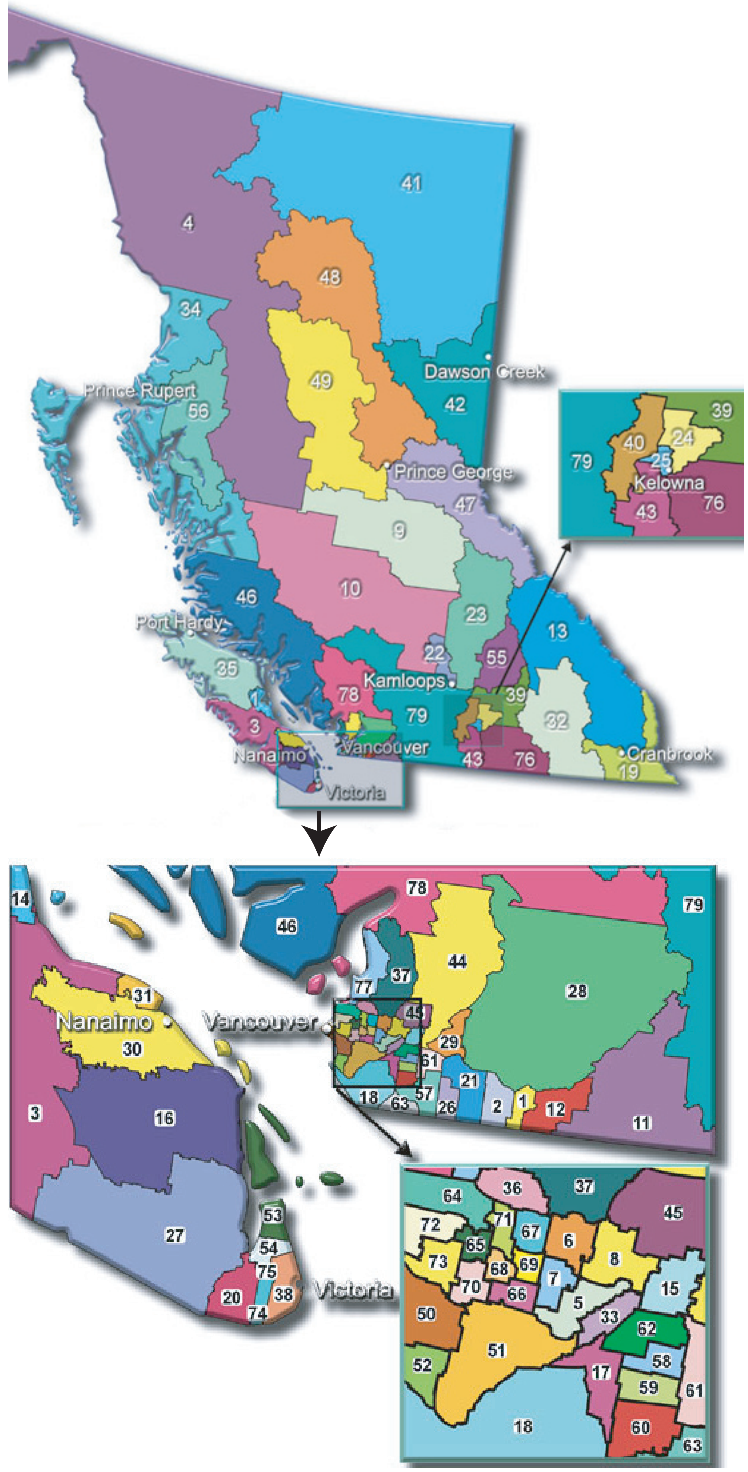

Figure A3. BC electoral districts show the distribution of population and capital. Location of seacages far from urban centers (cf. Fig. A2) means that relatively few BC residents directly experience the effects of seacages on wild finfish and shellfish, creating a public relations opportunity for the seacage industry and its government supporters. NGO opposition to seacages is driven by testimony from residents of sparsely populated coastal districts 3, 5 and 46 who have personally witnessed the effects of seacages on local ecosystems and fisheries.

Creation of CFO made Canada's federal goverment an easy sell for the seacage industry, because it meant that the industry no longer had to convince scientists; all it had to do was convince politicians. Very few members of Parliament (MPs) knew anything about salmon, and many of them, if asked, were apt to confuse

Pacific salmon with Atlantic salmon, which were never as numerous as Pacific salmon and had been fished to commercial extinction long before the creation of CFO. However, every MP was well aware of Canada's enormous coastline, and a few were easily persuaded that Canada should have a seacage industry like Norway's. Some of the persuaders were Norwegian salmon farmers fleeing increasingly restrictive regulations in Norway following the *Gyrodactylus* disaster there.

At CFO-Pacific the now-captive scientists quickly had healthy sockeye salmon growing in closed tanks, but when they tried to grow out the sockeye in seacages, the fish soon sickened and died. Sadly, by the time CFO scientists suspected that disease would be an insoluble problem for seacages it was too late to turn back; federal politicians had made the same promises that had been made in BC, and they could not admit they were wrong. When CFO scientists dragged their feet in promoting seacage aquaculture, the politicians created a special office within CFO called the "Commissioner for Aquaculture Development." CFO scientists hunkered down in their labs to study fish diseases, consoling themselves with the knowledge that they would never run out of work.

The above is the story of seacages in BC, as briefly as I can tell it, based on my own study and observations. The salient point is that BC's seacage industry and the CFO bureaucracy now find themselves in the absurd position of having to pretend that wild fish cannot be infected by the natural diseases of wild fish when those diseases come from fish in a netcage. They are afraid to fund or carry out the rather simple experiments that would address the question, because they understand enough biology to know what the results will be. Premature promises by politicians resulted in their capture by the seacage industry, and government fisheries scientists have been captives of the politicians since 1979. They all swim in circles, like fish in a cage.

The BC history is relevant because something similar is now taking place in the U.S. The National Marine Fisheries Service (NMFS) was captured by fishermen long ago, with the consequence that there are now far fewer wild fish left to catch. NMFS is part of the National Oceanographic and Atmospheric Administration (NOAA), a large, technologically-oriented bureaucracy for which seacages have an obvious appeal.

Now back to Dr. Charles "Chuck" Helsley and myself. Both of us are geophysicists, not biologists. Being Director of Sea Grant, Chuck is naturally interested in funding high-technology projects because we are technologists and that is what we are good at. He probably reads the aquaculture journals and the aquaculture magazines which are (to a much greater extent than in earth science) repositories of professional optimism. Chuck could also fairly be regarded as a captive of the NOAA money he is required to spend. Hawai`i has not yet had any negative experience with seacages, and Chuck's duties as Director of Sea Grant do not include touring the cold, rainy coast of BC (or Norway, or Scotland, or Western Ireland, or Chile) asking people who actually live near seacages what the local experience has been.

Like Chuck, I'm a geophysicist, but my investigation of seacages and their effects in BC convinces me that the disease problem of seacages is fundamental and cannot be solved other than by contained systems. I want to emphasize that the disease problem is a problem for the farm fish as well as the wild fish. One can reasonably accuse BC salmon farmers of secrecy and, in some cases, even mendacity, but it is unreasonable to imagine that they have not done everything they can think of to control diseases that cost them huge amounts of money, resulting in closure of farms and layoffs of employees.

Exactly the same thing can be said of seacage operators in Norway, Scotland, West Ireland and Chile. Even with the benefit of large subsidies from governments in the form of research, their disease problems grow worse every year. In Scotland, seacage operators now spend 30 million pounds (48 million dollars) a year just to control sea lice, with no hope of eradication. Something fundamental is going on here.

I'm forced to the conclusion that the ancient Hawaiians got it right, and that controlling disease with predators is, in the long run, commercially less expensive than controlling it with medication. (For example, the fishponds constructed by our Hawaiian predecessors contained hundreds of species of fish—when one species became ill, another species ate it, and the owner of the fishpond later ate the second species.) In scientific jargon, my conclusion is that complex, multi-species "sea farms" with multiple trophic levels are more robust and less expensive than single-species, seacage systems. I don't mean to suggest that these are startling insights, but perhaps it is significant that a technologist like myself should be driven to them by data. (For the beginnings of a theory, see Appendix B.)

If I'm correct, the easiest, cheapest and safest way to get more fish is to begin by taking better care of the fish habitat we now have. By "safe" I mean a method that won't fall apart if the price of petroleum doubles, or if the price of fishmeal shoots up because feed fish in the waters off Peru have suddenly vanished like the northern cod.

Another relatively safe way to get more fish is to create more habitat and then to harvest whatever fish show up in the habitat. For example, the kahala you propose to culture are broadcast spawners with a pelagic larval phase that transforms to a fish when it encounters a substrate. If you hang enough hardware in the ocean and let seaweed grow on it—notice we are letting the sun supply the energy—you will soon have an ecosystem that is certain to include many edible fishes* although the mixture of species may change from year to year. In any habitat creation scheme ownership issues will arise, but these issues are solvable, and they will lead to ownership solutions for wild fish that are necessary anyway if wild fish are ever to be harvested in a sustainable manner.

While we experiment with creating more habitat we should also experiment with contained systems for which we can control the environmental variables and not spread disease to wild fish.

* It is interesting that the metal cage used by the Hawaii Offshore Aquaculture Project to culture moi was used as an attachment by rapidly growing seaweeds which then attracted a variety of herbivorous fishes together with their associated predators (Helsley 2000).

Appendix B. Toward a Theory of Seacage Disease.

In science, experimentalists always say that one should not believe any theory unless it is supported by good observations, and theoreticians say that one should never believe observations unless they are consistent with a good theory. Here I use principles well known in epidemiology and marine zoology, to outline a theory for disease in seacages. As the observations consist partly of the differences between wild fish and seacage fish, any theory must also take account of fish in the wild. Any such theory must explain the following observations:

O1. Outbreaks of disease in wild fish are most frequently observed when wild fish aggregate for an extended period, as for migration or spawning.

O2. Seacage fish at high stocking densities are more likely to become ill than seacage fish at low stocking densities.

O3. Seacage fish are more likely to become ill when wild fish of the same or similar species are present near the seacage.

O4. Seacage fish are more likely to become ill if other seacages are located nearby.

O5. Often when seacages are first introduced to an area, disease outbreaks are infrequent, but become increasingly more frequent with time.

O6. Diseases which are infrequently observed in wild fish can be epidemic for seacage fish.

O7. Diseases which are not notably virulent in wild fish often become more virulent in seacage fish.

O8. Declines of wild fish are more pronounced in areas where juvenile wild fish encounter mature seacage fish.

O9. Some species of wild fish decline or disappear in areas with seacages, but others don't.

Here are the theoretical principles that explain the above observations. To understand most of the principles it is sufficient to have in mind a single *parasite* (or pathogen) species, a single *host* species, and a single *predator* species.

P1. Other things being equal, the chance of a healthy fish becoming infected increases with the number density of parasites in the water. Thus, other things being equal the chance of a healthy fish becoming infected increases with the number density of infected fish.

P2. A predator is more likely to eat an infected fish than a healthy fish because infected fish are slower and less alert.

P3. (a) In the wild, natural selection favours parasites that debilitate the host slowly, giving the host time to contact other potential hosts (low virulence). (b) In a seacage, natural selection favours parasites that consume their host quickly, and replicate (high virulence). Changes in virulence take time.

P4. When the system is perturbed by, say, a sudden increase in the number of hosts, the buildup of parasites takes time.

P5. Juvenile fish are more susceptible to disease than adult fish because of their low body weight and naive immune systems.

P6. Some species of parasites and pathogens specialize in fish of a particular species or (more usually) genus.

Now let's see how the observations O1–O9 follow from principles P1–P6.

O1. *Outbreaks of disease in wild fish are most frequently observed when wild fish aggregate for an extended period, as for migration or spawning*. You can see how this follows right away from P1 because aggregated fish are closer together than non-aggregated fish.

O2. *Seacage fish at high stocking densities are more likely to become ill than seacage fish at low stocking densities*. This follows from P1 because high stocking densities means that fish are closer together than they might prefer to be.

O3. *Seacage fish are more likely to become ill when wild fish of the same, or similar, species are present near the seacage*. This follows from P1 because most adult, wild fish carry low levels of parasites. When the wild fish swim near a seacage the parasites are able to spread to the seacage fish.

O4. *Seacage fish are more likely to become ill if other seacages are located nearby.* This follows from P1 because a nearby seacage represents a dense, fixed aggregation of fish. Any illness in the nearby seacage results in large amounts of pathogen being shed into the water.

O5. *Often, when seacages are first introduced to an area, disease outbreaks are infrequent but become increasingly more frequent with time*. This is a consequence of P3 and P4. The sudden introduction of caged fish is a large perturbation in the number of available hosts. Parasite levels take time to adjust. As the new fish are confined and protected from predators, parasite populations evolve toward increased virulence as they increase in number. The end effect is a larger background density of parasites outside the seacages. Under these conditions, new outbreaks of disease occur more frequently than they did when seacages were new to the area.

O6. *Diseases which are infrequently observed in wild fish can be epidemic for seacage fish*. This follows from P1 because seacage fish are often confined at number densities greater than those at which wild fish would choose to aggregate, hence parasites can spread faster.

O7. *Diseases which are not notably virulent in wild fish often become more virulent in seacage fish.* This follows from P3: as parasites evolved on wild hosts, they were selected for not killing their hosts too quickly, but this selection pressure is absent for parasites replicating on farm hosts.

O8. *Declines of wild fish are more pronounced in areas where juvenile wild fish encounter mature seacage fish*. This follows from P5. Juvenile, wild fish of carnivorous species do not normally encounter wild adults of the same species (else they would be eaten), hence they do not invest metabolic energy in the immune systems necessary to defend themselves from the parasites carried by wild adults.

O9. *Some species of wild fish decline or disappear in areas with seacages, but others don't*. This follows from P6. Wild hosts susceptible to the species of parasite carried by the seacage fish will decline. Wild hosts with no susceptibility will be unaffected.

Results from computer modeling

Figure B1 shows the results from a computer model that I recently wrote to investigate the behavior of farm fish and wild fish with a common parasite. It's a Lotka-Volterra model that explicitly incorporates principles P1, P2 and P4. Initial conditions (t=0) have a population of wild fish (solid line, left scale) in equilibrium with a population of parasites (dotted line, right scale), and there are no farm fish in the system. At t=10 farm fish (dashed line, left scale) are added to the seacages, increasing to 50% of the equilibrium wild fish level by t=20. Addition of farm fish causes parasite levels to increase, and wild fish to decline. Total fish, i.e., the sum of farm fish and wild fish, (dash-dot line, left scale) initially increase, but then decline. Wild fish slowly oscillate about a new equilibrium value about 35% of their no-farm level. Total fish converge to about 85% of the original number of fish.

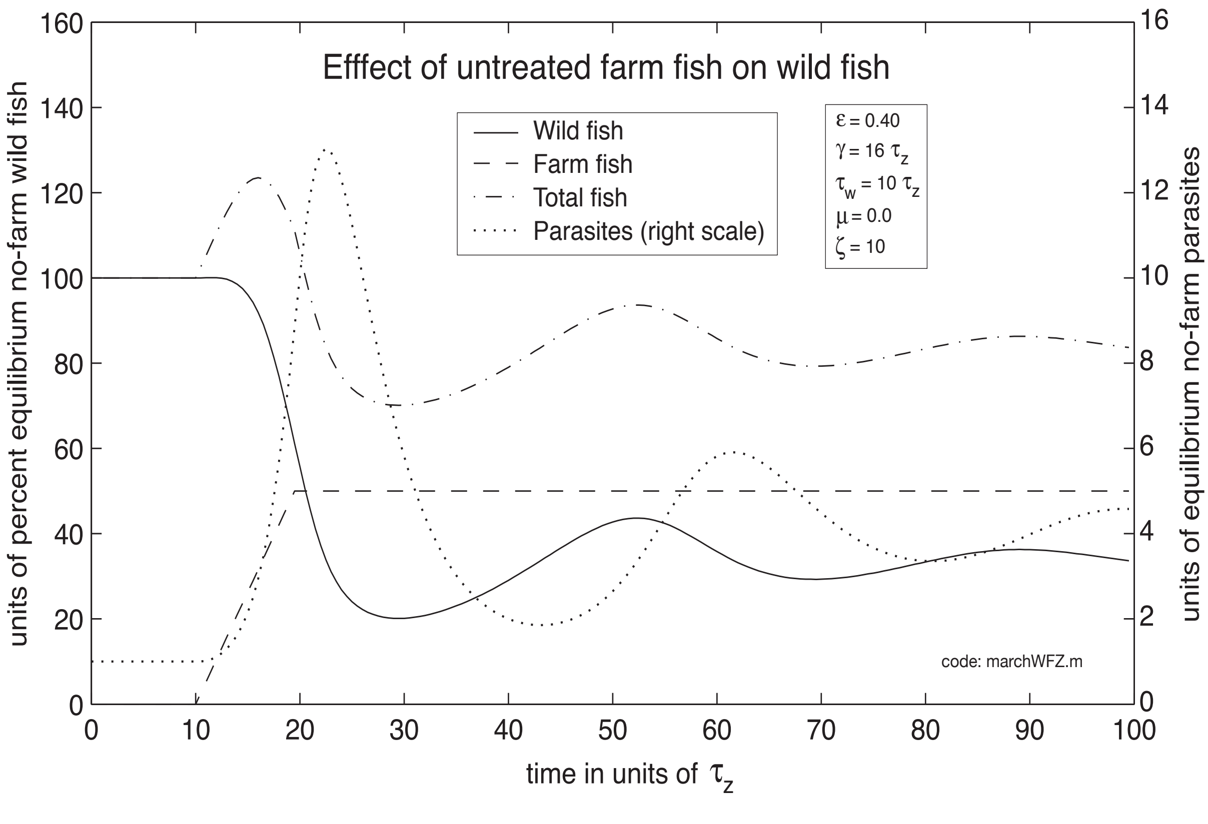

Figure B1. Natural system consisting of wild fish and seacage fish with a common parasite. Predators external to the seacage are assumed to feed on a variety of species so that declines in wild fish do not significantly affect predation pressure. Parasites in a seacage are assumed to reproduce 40% faster than parasites in the wild because of the higher spatial density of seacage fish. Parasites from wild fish can infect farm fish and vice-versa. Time is measured in units of τ_z, the time constant for parasite (propagule) decline in the absence of fish. Farm fish are not chemically treated for parasite removal, but they are harvested and replaced at the rate of 100% replacement per 16 time units, removing their parasites from the system.

Using the same computer model I generated Figure B2 which shows equilibrium levels of wild fish for various levels of farm fish in seacages. The line ε=0 represents the most optimistic scenario in which parasites reproduce no faster in seacages than in the wild. In the most optimistic (ε=0) scenario total fish rise slightly, but wild fish decline significantly. Even for (ε=0), wild fish can be driven to extinction if farm levels are raised too high.

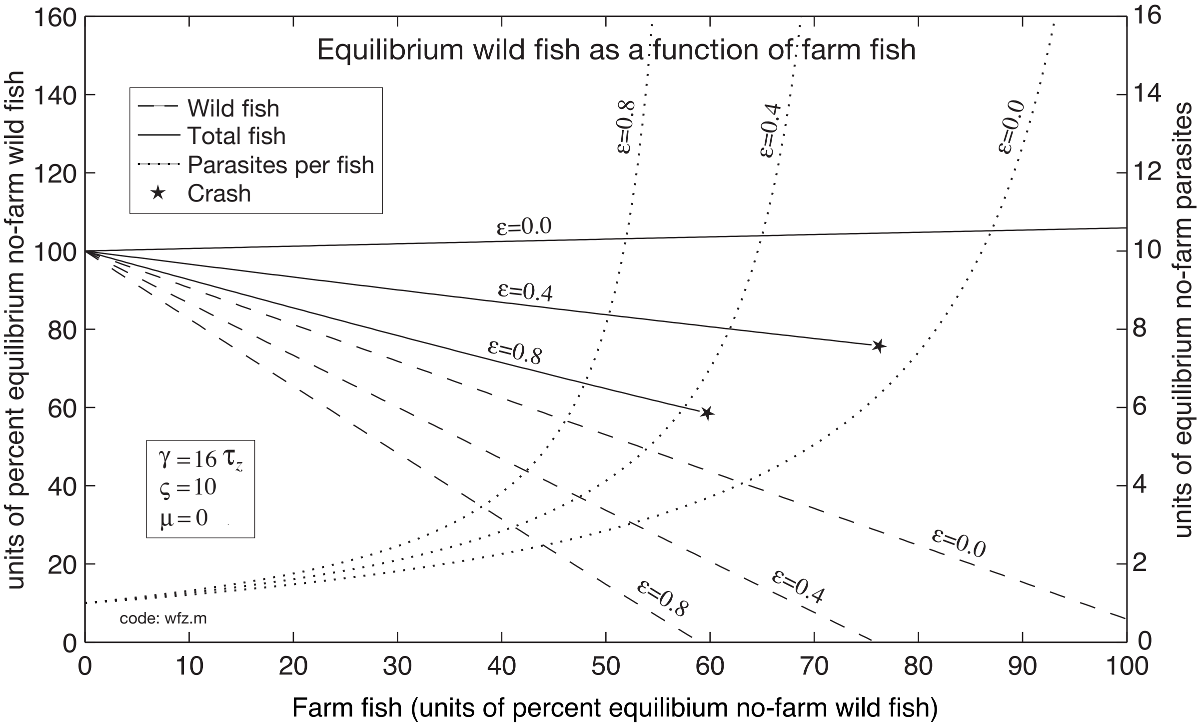

Figure B2. Equilibrium levels of the wild fish–parasite system for various levels of farm fish in seacages. Parasites are assumed to reproduce ε times faster in seacages than in the wild, and farm fish remain in seacages for 16 parasite time constants prior to harvest.

One of the uses of Fig. B2 is that it explains why all seacage operators eventually find it necessary to chemically treat their fish on a regular basis (lowering the parasite harvest interval γ). Without those chemical treatments parasite loads rise to levels at which farm fish stop growing and their appearance makes them unsaleable. As the chemicals used for parasite treatment are toxic to humans, farm fish cannot legally be treated for a time interval prior to harvest, and during this time parasites rapidly multiply and spread to wild fish. When a novel infection takes hold in a seacage it is not possible to treat the fish, because there is no treatment, and the seacage operator cannot compensate for an ε>0. Terrestrial animal culture is not subject to these problems because it is able to physically separate domestic animals from wild animals, thereby blocking parasite interchange. The proper marine analog of the domestic feedlot is a contained system, not a seacage.

In case you are interested, here are the equations for the system consisting of wild fish and parasites with no farm fish present:

$$\frac{\tau_z\, dw}{w\, dt} = \frac{\tau_z}{2\tau_w}\left(2 - w - \frac{z}{\varsigma}\right) \qquad \text{(B1a)}$$

$$\frac{\tau_z\, dz}{z\, dt} = -1 + w \qquad \text{(B1b)}$$

and here are the equations for the the system consisting of wild fish, parasites and farm fish:

$$\frac{\tau_z\, dw}{w\, dt} = \frac{\tau_z}{2\tau_w}\left(2 - w - \frac{z}{\varsigma}\frac{w}{(w+f)} - \mu\frac{\tau_z}{\gamma}\right) \qquad \text{(B2a)}$$

$$\frac{\tau_z\, dz}{z\, dt} = -1 + w + (1+\varepsilon)f - \frac{\tau_z}{\gamma}\frac{f}{(w+f)} \qquad \text{(B2b)}$$

In these equations *w* is the number of wild fish divided by the no-farm, equilibrium number of wild fish; *z* is the number of parasites divided by the no-farm, equilibrium level of wild fish; *f* is the number of farm fish, divided by the no-farm, equilibrium number of wild fish; ζ is the equilibrium ratio of parasites to wild fish in the no-farm case; τ_Z and τ_W are the characteristic response times of parasites and fish, respectively; ε is the relative increase in the speed of parasite production in the farm compared to the wild; γ is the grow-out time of farm fish (or the time between parasite treatments); and μ is the toxicity to wild fish of the chemical used to treat farm fish. In the calculations for the figures above, τ_W was 10 times τ_Z, γ was 16 times τ_Z, and μ was always taken to be zero.