CHAPTER 14

Net-Pen salmon farming: Failing on two fronts (and why this is just the latest stage in humanity's terminal ravaging of the seas)

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Introduction and Purpose

Although I am not a fisheries biologist, much of my work bears both directly and indirectly on the issues at hand. The direct part is reflected in the title of this chapter which suggests that my primary focus will be on the net-pen salmon farming industry.

The main purpose of this paper is actually to highlight the forcing mechanism behind the apparent collapse of global fish stocks. I am in good company in taking this tack. Much of Robert Lackey's contribution to this volume also focuses on what he refers to as the "drivers" damaging salmon stocks in the Pacific Northwest—habitat destruction, overfishing, climate change, etc. (see Chapter 15 Lackey). "Forcing mechanism" (a term I borrow from climate change science) implies much the same thing, but I am exploring the concept on a more general level than is Lackey. While Lackey describes the proximal factors driving the decline of salmon I am concerned with the distal cause. This paper makes the case that collapsing fisheries are merely symptomatic of a much deeper problem that we moderns find difficult to acknowledge: that marine fish are just the latest casualties of what might be termed *gross human ecological dysfunction*, a malaise that emerges, ironically, from our species' remarkable evolutionary success.

Recognizing *Homo sapiens* as an ecological entity

To understand this thesis fully we have to accept the simple fact that once we clear away the fog of technological and cultural sophistication, human beings remain biological entities—i.e., 'animals'—to the core. And what a wondrous beast we are! Modern *Homo sapiens* has evolved to become the most astonishingly successful predatory mammal ever to stalk the lands and waters of Earth. And the story doesn't end there. Not only do humans take top prize among carnivores, but we also dominate the competition among terrestrial herbivores. In fact, any human ecologist (that is, an ecologist who studied humans as s/he might study any other lifeform)[1] would discover that this same ecological reality prevails on every continent. With the continuous expansion of the human enterprise, powered by extra-somatic energy and continuous technological advances, *H. sapiens* has long been the dominant macro-consumer in all of the major eco-system types on Earth. In this light, an alternative title for my paper might have been: "**Dominant terrestrial predator makes successful transition to marine habitat."**

Why is this a critically novel insight? Because not only are we moderns generally ignorant of the astonishing breadth of our *de facto* ecological niche, but techno-industrial society actually promotes the belief that the human enterprise is all but independent of nature. Economists, for example, observing that an increasing proportion of our incomes and GDP are derived from the so-called knowledge-based sectors, argue that the economy is "decoupling" from nature, that it is "de-materializing." Although quite untrue, this is the kind of cultural myth that shapes the policy decisions that help to propel the continuous expansion of the human enterprise.

It is worth reflecting a little more on our economic models because they illustrate as well as anything else modern humans' psychological estrangement from nature. Keep in mind that economic models, like all conceptual models, are what psychologists would refer to as "social constructs." That is, they are products of the collective human mind and, as such, they reflect prevailing cultural perceptions and understandings at least as much as they reflect reality.

The particular model that I have in mind is commonly found in text-book chapters on environmental or resource economics. It shows the economic and "the environment" as separate systems linked only by a counter-current flow of resources from the environment to the economy and of wastes from the economy to the environment. To many readers this example of "Cartesian dualism" will all seem very natural. But again, this model, this way of thinking, is merely an expression of mind—the western mind. It reveals how techno-industrial society tends to conceive of the economy as essentially separate from "the environment" (and it is just a short step from there to believing the "decoupling" myth that technology can make us independent of it too). [2]

The important thing to realize is that there are still cultures today with whom we could not have a conversation about "the environment" as a discrete entity *out there* separate from the human enterprise *over here*. Other peoples see themselves not in isolation but rather as an integral part of "nature" and, if we think about it for a moment, this is actually a more physically (and therefore scientifically) valid way of perceiving reality. The fact is that, despite our technological hubris, humans are functionally very much a part of nature. What we call "the economy" is merely our description of how we organize socially to interact with the rest of the material world. From this perspective, the economy can be conceived as a fully contained, totally dependent, open, growing sub-system of a materially closed, non-growing ecosphere (Daly 1990, Rees 1995). Our relationship with nature is as an embedded dependent sub-system, not as an independent entity existing in splendid isolation from everything else. Recall my argument above that people have become the dominant macro-consumer in all the major ecosystems on earth. It should now be clear that, within the confines of the non-growing ecosphere, the continuous growth of *H. sapiens*

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[1] Regrettably, there are very few human ecologists. Academic ecology, betraying its Cartesian roots (and modern humans' reluctance to acknowledge their biological selves) focuses almost exclusively on non-human species.

[2] As Canadian ecologist Stan Rowe once observed, in our ecologically estranged culture the very word "environment" becomes its own pejorative, meekly setting itself apart from something else more important.

and his economic infrastructure can proceed only at the expense of many other species, including fish, with which we share the planet.

To appreciate humans fully as biological beings requires an introduction to some basic facts of human nature, those inherited qualities that help determine both individual and social human behaviour. Like all other species, humans evolved in response to the pressures of natural selection and we have accumulated certain qualities over time that account for our spectacular evolutionary success. It is true, of course, that human evolution differs from that of non-human species—human evolution has long been governed as much by cultural as it has by purely biological factors. Nevertheless, humanity's biological heritage continues to exert powerful influences. Most importantly (and, again, like all other species) *H. sapiens* has a hard-wired genetic predisposition to expand into all of the "niche" space available to it. (This was Reverend Malthus' famous insight.) Arguably, culture has actually had its most dramatic effect working in tandem with this expansionary predisposition. Human inventiveness and cultural adaptations have worked steadily for thousands of years to mitigate the effects of negative feedback – disease, resource shortages, extreme weather events – that would normally inhibit the growth of human populations beyond the capacity of local ecosystems to sustain them. In fact, technology and trade (including its most recent morph, "globalization") have enabled many human populations to expand to the point where they can completely degrade their local habitats and still survive – indeed, grow and prosper – because they can import the material requirements (and luxuries) for life from elsewhere.

This pattern of local 'patch disturbance' and increasing reliance on imports may come back to haunt us (Rees 2000). However, most economists and politicians do not seem much concerned and, since a particularly persuasive form of technological optimism prevails in the world today, society generally does not display any sense of urgency to the inexorable sprawl of cities over prime farmland or to the latest example of a fisheries collapse. (Basically, we would rather have the money.) Humans may have evolved to expand to their ecological limits but they have neither evolved nor acquired any general inhibition against them destroying their own habitats.

The 2nd law of thermodynamics as the first law of resource dissipation

We are getting close to being able to show why the collapse of fish stocks is virtually inevitable but first we need to bring a little more science into the picture. The science I am referring to is modern interpretations of the 2nd law of thermodynamics, particularly as they apply to "far-from-equilibrium" self-organizing systems (see Prigogine and Stengers 1997). We have come to realize that all living systems, from cellular organelles to the ecosphere itself, share certain common properties as complex, open, self-producing, far-from-equilibrium dissipative structures. That is a fancy way of saying all that living systems, including our own bodies, can organize, maintain themselves and grow only by importing useful resources from their environments and by "dissipating" their wastes back into their environments (Schneider and Kay 1994).

We also recognize that each of these systems exist as a subsystem (or quasi-independent "holon") within a loosely overlapping hierarchy (or holarchy) of such systems, the highest level of which is the ecosphere (Kay and Regier 2000). This means that the "immediate environment" for any holon is actually the next level up in the holarchy. We can now restate the fundamental relationship between adjacent subsystems levels in thermodynamic terms: subsystems grow by importing available energy and matter (essergy) from their host systems and by exporting degraded energy and material wastes (entropy) back into their hosts. (In effect, each holon is a potential thermodynamic parasite on the next level up in the holarchy.)

In an ecosystemic steady-state, the rates of resource consumption and waste discharge by any sub-system (e.g., a species population) are maintained by negative feedback within a range that is compatible with the rates of production and assimilation by its host system. The total holarchy therefore retains its long-term functional integrity. However, as noted, the hierarchical relationship between sub-systems and their hosts contains the seeds of potential pathology. If a sub-system (e.g., the human enterprise) demands more than its host system can produce, or discharges more waste than its host can assimilate, then the development and growth of that sub-system will *necessarily* result in the destructive dissipation of the higher level in the holarchy (Rees 2003).

Let us bring this to ground. The ecosphere (i.e., the aggregate of all ecosystems) is a thermodynamic sub-system of the solar system. It evolves and maintains itself by dissipating exogenous solar energy. In short, the ecosphere feeds on an extra-terrestrial external source of essergy. By contrast, the human enterprise – the economy – is an embedded sub-system of the ecosphere. It grows and maintains itself and by dissipating available energy/matter exogenous to itself but endogenous to the ecosphere. In short, the human enterprise is thermodynamically positioned to consume the ecosphere from the inside out (Rees 1999). Fish stocks are just the most recent casualties of this inevitable process.

Unsustainability is an old—and continuing—problem

This conceptualization of human-environment interaction provides a novel framework within which to reinterpret both our species' ecological history and present reality. There is, of course, increasing recognition that modern society is trending steadily downward ecologically. However, the evidence is that this is by no means a unique situation for human societies. Indeed, given that complex human societies in all their guises have always been dependent on supportive ecosystems that the human enterprise is everywhere predisposed to expand and that this tendency is reinforced by technology, it would be surprising if history were not filled with examples of at least regional ecological crises. In fact, unsustainability *is* an old problem for humans and if my thesis that the primary drivers are in our genes is correct, then things are not likely to change any time soon. This may be a pessimistic assertion, but if we are ever to create the circumstances that would justify optimism for modern society, we must come to understand the forces driving human history.

And our history is a rich source of instruction indeed. One of the more relevant lessons – one that even makes it to the popular press from time to time – is the story of Easter Island. Easter Island is little more than an isolated rock scarcely 165 square kilometres (65 square miles) in area stuck in the middle of the South Pacific Ocean 2,250 kilometres (1,400 miles) from the nearest land mass, another smallish rock, called Pitcairn Island. Virtually denuded today, Easter was once a verdant subtropical paradise, heavily forested with at least two very important tree species and many plant and animal species useful to humans. It was first inhabited by a canoe-load or two of wandering Polynesians only around the year 450 or 500 A.D. The new colony took hold and flourished to become a complex culture in microcosm. As written in its genes, the human population of Easter Island expanded to perhaps 10,000 people by A.D. 1400-1500. Over those 10 centuries, the Easter Islanders developed class structure, division of labour, religion, agriculture, science and art, including some of the finest stonework – both fitted stones for buildings and platforms and carvings – known to preindustrial times. In short, Easter Island culture evolved most of the basic manifestations and characteristics of the much grander and earlier human societies of Europe, Africa, Asia and even the Americas (Incas and Aztecs), with which most people are more familiar.

Then, at the very height of their cultural evolution, the Easter Islanders did something that seems truly bizzare. They cut down the last palm tree growing on their isolated rock. Now, this was a society dependent on trees for many things, including the dugout canoes by which they obtained most of their animal protein – Easter Islanders ate porpoises and fish that could be obtained only by active pursuit in boats. How could these people have possibly reached the stage where there was nothing for it but to cut their last trees and, with the trees, any hope of cultural survival? When the Dutch explorer Roggeveen "discovered" Easter Island in A.D. 1722, there were only about 2,000 survivors, most living in rude reed huts and caves. These sorry remnants of the Easter Island culture that had been thriving just 200 years earlier now lived in part by making cannibalistic raids on each others' encampments. Having failed to develop suitable cultural constraints on their economic growth, the Easter Islanders had predictably consumed their island ecosystem "from the inside out."

Many articles have been written about Easter Island. The authors often wonder at the socio-cultural dynamic at work in a society numerically no larger that a minor town, where everyone was aware of their total dependence on the limited local resources of their tiny island, and yet where apparently nothing was done to prevent their self-destruction. Historian Clive Ponting (1990) was mystified that the Easter Islanders seemed "…unable to devise a system that would allow them to find the right balance with their environment." Considering that modern humans also inhabit a tiny island isolated in space with no hope of finding alternative supplies and that almost everyone is aware that we are facing an ecological crisis, anthropologist Jared Diamond's (1995) asks a chilling question: "Are we about to follow [Easter Island's] lead?"

Does Easter Island represent the cultural norm?

It might be easy for technological man to dismiss this question as absurd if Easter Island were a singular case. After all our technological prowess and mastery over nature distinguishes us from more primitive cultures. Ominously, however, Easter Island is by no means exceptional. As Joseph Tainter observes: "what is perhaps most intriguing in the evolution of human societies is the regularity with which the pattern of increasing complexity is interrupted by collapse…" (Tainter 1995). It seems that ignominious collapse may well be the norm for complex human societies.

Tainter argued that societies evolve and "complexify" as a problem-solving strategy in response to various problems (e.g., irrigation is invented to overcome the impediment to food production represented by seasonal rainfall). Eventually, however, as expansion continues, societies reach the point where they can no longer cope effectively with mounting pressures. Such cultures suffer from diminishing returns to investment in complexity (lower payoffs despite increasing commitments of resources). In these circumstances, a society becomes increasingly brittle and unstable—socially, politically or ecologically—and therefore more vulnerable to collapse in the face of the next major challenge (Tainter 1988).

In light of Tainter's findings, the modern record of resource exploitation is hardly encouraging. A decade ago, Ludwig, Hilborn and Walters (1993) reported that while there is a considerable variation in detail, there is remarkable consistency in the history of resource exploitation: "Resources are, inevitably, over-exploited often to the point of collapse or extinction." Despite this dismal history, grossly diminishing returns to fishing effort, and the unambiguous warnings of fisheries scientists, there is no evidence that the pattern of exploitation is changing. Recently, Christensen et al. (2003) and Myers and Worm (2003) report that after only fifty years of industrial fishing the large predatory fish biomass of the world's oceans is only about 10% of pre-industrial levels. (Humans, as top carnivores in the sea, are shredding the marine foodweb from the inside-out.) Do people today even begin to understand the potential consequences of global resource depletion? Are we incapable of taking a lesson from the repeated collapses of previous complex societies? Is it conceivable after all that we are on a tack that might lead to global crisis and collapse?

Hypothesis: *Homo sapiens* is inherently unsustainable

Tainter has provided a satisfactory answer to the question: "What is the socio-cultural dynamic that leads to collapse in the face of crisis?" However, the question I want to address here is - "What is the bio-cultural dynamic that drives human societies to expand to the point of crisis?" Contemplating this question has previously led me to the following general hypothesis: Humans, particularly techno-industrial humans are inherently unsustainable. That is, the modern form of unsustainability is an inevitable emergent property of the interaction between techno-industrial society, as presently conceived, and the ecosphere (Rees 2002).

A bio-evolutionary factor—the maximum power principle

We can assess this hypothesis by examining two critical mechanisms that underlie humanity's predisposition for continuous growth. The first is purely biological and can be summarized in terms of the so-called "Maximum Power Principle" (see Odum 1983, Ch. 1 and 7). Ludwig Boltzman, one of the fathers of thermodynamic theory, was familiar with Darwinian natural selection and recognized in the early 20th century that the struggle for existence is really a struggle for free energy available to do useful work. From this perspective, all species are competing for energy (you can see it in plants as they lean towards the sun) – food getting among animals is a struggle to obtain the low-entropy energy and matter they need to grow and reproduce. Alfred Lotka, one of the great ecologists of the 20th century, reformulated this idea into the *maximum power principle* (Lotka 1922): Systems that prevail (i.e., successful systems) are those systems (individuals, species, ecosystems) that evolve or develop in ways that maximize the flow of useful energy available to them.

What has this to do with the human condition? Almost everything. To begin, *H. sapiens* has long had a significant leg-up in the competition for free energy. No other large mammal comes close to matching the human capacity to appropriate useful energy/matter from our host, the ecosphere, for use in the expansion of our own population and the accumulation of manufactured capital, the vital infrastructure of the human economy.

Humans have at least four qualities that confer this competitive advantage (Rees 2002). First, humans have a very catholic diet. We can eat many kinds of plant and animal matter and if we can't eat something then we feed it to some other animal and then eat that animal or its products. In this way, humans have access to more food energy than any other large vertebrate macro-consumer. Second, we are uniquely adaptable, being able to live in virtually any habitat on the planet. This gave even pre-agricultural humans unparalleled geographic access to all potential wild food sources on Earth. Third, and perhaps most important, humans have complex language, particularly written language. This is "most important" because the written word leads to humanity's fourth critical quality—cumulative knowledge and continuous technological development. Human beings are unique among species in that language and culture enable us to get continuously better at appropriating bio-energy, other forms of energy and, consequently, all the other resources needed by society, from the ecosphere.

(N.B. If there was more time, I would elaborate on the importance of fossil energy in this game because for the last 150 years techno-industrial society has become increasingly dependent on non-renewable forms of fossil energy to sustain itself and fuel growth. Without fossil fuel, it is unlikely we could have depleted the seas, deforested so much of the planet, and so significantly increased agricultural production. Modern techno-industrial society would simply not be possible. On the one hand, then, we have used fossil fuel to grow ourselves and "dissipate" many other resources at the expense of the ecosphere. On the other, global society itself may now be at risk partly because accessible reserves of cheap petroleum and natural gas are being depleted and there are no ready substitutes for many uses of these premium fuels.)

The biodiversity costs of human expansion

It should not be a surprise that on a finite planet, humanity's expansive evolutionary success imposes huge costs on non-human species. First, the demand for food-energy needed to grow the human population necessarily indirectly displaces competing species from their ecological niches. Where, for example, are the 50 million bison, the millions of pronghorns, the grizzlies, and so on that used to inhabit the Great Plains of North America? Well, at least their energetic equivalent is sitting in your seats. The native grassland that used to support that great abundance of non-human biomass has been replaced by introduced wheat, oats, barley etc., that mainly feed humans and their domestic stock. In this light, anyone who tells you there is no inherent conflict between the continuing growth of the material economy and the conservation of nature, does not know about the second law of thermodynamics. Human appropriations of the free energy flows through ecosystems are irreversibly unavailable to other species.

Humans also directly eliminate remaining competitors. We cull seals and sea lions that threaten wild fish and fish-farms; we shoot wolves that prey upon wild ungulates or domestic stock that we would prefer to eat ourselves; and we even poison our own food to eliminate insect pests that would otherwise ravage our cereal and other crops.

Finally, the human enterprise also grows by depleting both self-producing and non-renewable natural capital stocks—which brings us back to far-from-equilibrium thermodynamics. As emphasized earlier, the human enterprise is a self-producing dissipative structure that, beyond a certain point, can maintain its own growth only by consuming its environment.

The human ecological footprint and competitive exclusion

We can further illustrate human domination of the ecosphere using ecological footprint analysis (EFA). EFA is a quantitative tool that estimates the total area of ecosystems appropriated by any designated human population to produce the resources that it consumes and to assimilate the wastes that it produces. The Worldwide Fund for Nature (now known as the World Wildlife Fund, WWF) has recently applied the method to trace the growth of aggregate human ecosystem demand since 1960. Most significantly, the WWF study reveals that the steady increase in the human "ecological footprint" over the last 40 years has been accompanied by a corresponding decline in the WWF's own "Living Planet Index," an indicator of non-human species diversity/biomass (WWF 2002).[3] This relationship holds for both terrestrial and in aquatic ecosystems. In effect, the WWF study illustrates what ecologists call "the competitive exclusion principle"—the displacement of one species from part of its range by a superior competitor—when it is observed between two competing non-human species. In this case, however, we are observing the displacement of just about all other macro-consumers by the growth of the human sub-system. To repeat, it is not possible for one sub-system in a finite global systems holarchy to expand indefinitely except by appropriating increasing quantities of energy/matter that would otherwise be available to support other sub-systems.

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[3] According to the WWF, the human ecological footprint now exceeds the long-term human carrying capacity of the earth by about 20%. The empirical evidence is declining resource stocks and rising pollution levels.

It is worth noting that modern human-induced biodiversity loss is actually a hyper-extension of an ancient legacy. The recent paleo-ecological, anthropological, and archeological literature tells a convincing story that the initial settlement of a new habitat by human beings was generally accompanied by the extinction of previously dominant large mammals and (particularly flightless) birds. "For every area of the world that paleontologists have studied and that humans first reached within the last fifty thousand years, human arrival approximately coincided with massive prehistoric extinctions" (Diamond 1992). It seems that even early humans, with their relatively primitive weapons and tools, were able to alter significantly the species composition of the ecosystems that sustained them.

The socio-cultural factor: myth-making and the human capacity for self-delusion

Mythmaking is a universal property of all human societies, including our own (See Grant 1998). Obviously, the natural propensity for human societies to expand is a powerful force, but the story does not end there. The cultural norms of industrial society reinforce the biological drive to fill all available ecological space. Our prevailing mythology is heavily biased toward unlimited economic growth *in spite of the evidence that we may have already exceeded safe limits*. Indeed, it is probably fair to say that most of the modern world subscribes to a common myth of perpetual material economic growth fueled by open markets and expanding trade. "Globalization" is the prevailing watchword and anyone who objects on the face of the evidence is swept aside as naïve, stupid or merely quaintly reactionary. The irony here is that we profess to be a knowledge-based culture—modern society claims to have abandoned myth for the safety of solid science. This itself may well be our greatest cultural myth.

The propensity to create grand overarching myths is only one dimension of a general human capacity for self-delusion. Humans generally prefer illusion to reality if the latter is likely to inconvenience them. As Gustave Le Bon wrote in the 19th century: "The masses have never thirsted after truth. They turn aside from evidence that is not to their taste, preferring to deify error, if error seduce[s] them. Whoever can supply them with illusions is easily their master; whoever attempts to destroy their illusions is always their victim." (Le Bon 1960 [orig. 1896]). Today, we are seduced by our big houses, our SUVs, our VCRs, our computers and all the other material trappings of modern society. Advertising continuously reinforces our illusions and the socially constructed consumer mentality serves as armour against the cascade of evidence that the price of our material bounty may be the destruction of the very systems that sustain us. Derrick Jensen put it this way: "For us to maintain our way of living, we must… tell lies to each other, and especially to ourselves… [the lies] are necessary because without them many deplorable acts would become impossibilities" (Jensen 2000).

Unfortunately, globalization and trade do indeed obscure the truth and prolong the reign of the dominant myth. Ecological footprint analysis shows that much of the consumption enjoyed by inhabitants of wealthy countries is derived from distant ecosystems often in other countries half a world away. Indeed, rich countries live, ecologically, on an area several times the size of their domestic territories, on land and waters that they effectively appropriate through trade and natural material cycles. The overharvesting of British Columbia's forests and the collapse of Canada's northern cod stocks are not the result of domestic consumption, but rather of economic exploitation to satisfy export markets. The associated forest and marine ecosystems have been incorporated into the ecological footprints of the importing countries.

There are two problems here. First, trade removes negative feedback that would otherwise mitigate unsustainable growth by blinding wealthy importers to the fact they have exceeded their domestic carrying capacities. Second, the material lifestyles of the rich can simply not be extended to the entire human family. It is physically impossible for every country to be a net importer of biophysical goods and services. Again, the growth myth has placed the global economy on a collision course with ecological reality (Rees 2002).

There is yet another mythic construct that undermines efforts toward ecological sustainability. Recognizing that some resources may actually become depleted, economists have fostered belief in what has become known as the principle of near perfect substitution. This principle was stated in a rather mild form by Nobel Laureate economist Robert Solow as follows: "If it is easy to substitute other factors for natural resources, then the world can, in effect, get along without natural resources so exhaustion is merely an event, not a catastrophe" (Solow 1974). I have a number of quotes like this from economists and other technological optimists arguing that if we simply allow markets to work, human ingenuity will find a substitute for any scarce product of nature, including salmon. Here is a statement by Mark MacDonald writing in a recent issue of "*The Business Examiner"* (June 2003): "Wild stocks, which are a major source of food for people throughout the world, are diminishing. Production of farmed fish, an obvious replacement for wild, could be stepped up significantly." In other words, humans can substitute for nature; with existing technology we can do a better job at raising salmon.

The case of net-pen salmon farms

The substitution principle thus provides a cue for us to return to fish and develop the final focus of this paper. The question is, does the substitution of salmon farms for wild stocks really do a better job? In addressing this question I want to acknowledge the doctoral work of my former student, Dr. Peter Tyedmers now at Dalhousie University. Tyedmers (2000) undertook a massively detailed comparative analysis of the energy and material flows, and the ecological footprints, associated with the wild salmon fishery and the net-pen salmon farming industries in British Columbia. To develop my argument, I need refer to only a few highlights of Dr. Tyedmers' study.

To begin, a key requirement of the salmon farming industry is feed pellets. Several points stand out from Tyedmers' analysis:

- At the time of the study, feed pellets for farmed salmon were typically 56% rendered fish by weight (e.g., Peruvian anchovy, South Pacific sardine, Araucarian herring, Inca scad, chub mackerel).
- Approximately 1,800 kg of whole fish were required for fishmeal and 3,000 kg of whole fish for fish oil per tonne of salmon pellets (1997 data).
- Only one kg of farmed salmon is produced for every four to five kg of other fish (wet weight) incorporated in feed.

In short, the feed industry represents a significant diversion of high-quality animal protein, much of which might otherwise be available for direct human consumption. Today a full 12% of the total global wild fish catch is sold to produce feed for farmed carnivorous fish. Most importantly, the 20% trophic level transfer efficiency associated with the conversion of feed-stock fish to salmon shows that salmon farming actually reduces the total amount of food available to humans. (Political and consumer pressure has therefore forced several major feed producers to pledge to replace 50% of the fish-meal in their feeds with alternative protein sources by 2010: Powell 2003.)

Energy dissipation

Turning to the energy costs of raising of farmed salmon, it takes 48,000 megajoules of energy (the equivalent of 1,300 litres of diesel fuel and 3.3 tons of carbon dioxide emissions) to produce a tonne of salmon feed. The approximate industrial energy investment for cultured Atlantic salmon is 94,000 megajoules per tonne of fish and for chinook salmon, 117,000 megajoules per ton. In both cases, 90% of this energy is associated with the production of the feed alone. A single kilogram of farmed chinook salmon fillet ready for the plate has an embodied industrial energy content equivalent to 5 litres of diesel fuel.

Figure 14.1 compares the industrial energetics of farmed Atlantic and wild Pacific chinook salmon with the energetics of the capture fishery for chinook, coho, sockeye, chum and pink salmon. Note that the wild salmon fisheries are several times less energy intensive than is salmon farming and even the wild fishery is more energy intensive than it needs to be. (Salmon, after all, could be caught with little energy expenditure if we employed river-mouth trap fisheries as First Nations fishers once did.) The data below the graph show the protein Energy Return on Investment (EROI) for each salmon production method. None of these methods returns more that 11% of the energy consumed in the production process. However, the 6% to 11% EROIs associated with the various capture fisheries are all vastly superior to the 2.0% to 2.5% EROIs of farmed Atlantic salmon and farmed chinook salmon respectively. Indeed, salmon farming positions the production of salmon at the same level as intensive factory farming of chicken and beef, which are among the most energy-intensive forms of livestock-rearing.

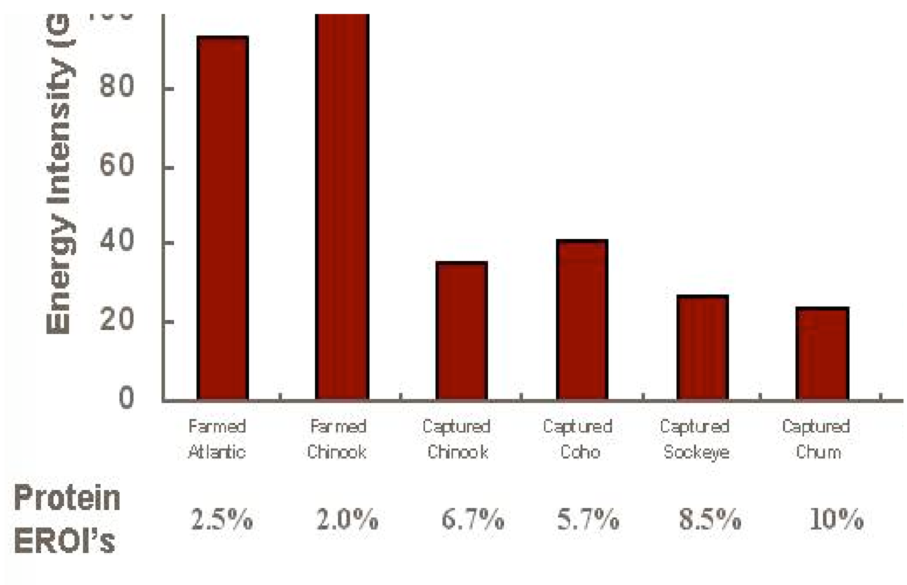

Figure 14.1. Energy inputs to BC salmon and protein Energy Return on Investment (EROI) for BC Salmon.

Industrial ecological footprints

Ecological footprints are usually calculated for defined human populations but it is also possible to estimate the total ecosystem area "appropriated" to sustain consumption/production by a specified industry or economic sector. Figure 14.2 compares Tyedmers' estimates of the total ecosystem demand by farmed Atlantic and chinook salmon with those of each of the five major wild salmonid species caught by the BC salmon fishing fleet. Clearly, the ecological footprints per tonne of product produced by salmon farms are larger than those of the fleet fishery, regardless of species. It takes between 12 and 16 hectares of land and aquatic ecosystems, in photosynthetic production and assimilative capacity, to produce a ton of farmed salmon per year. The fleet fishery is more generally efficient by a factor of two to three. These data hint at the fundamental unsustainability of salmon farming—the global ecological impact of this technology is significantly greater than that of commercial fishing, three-fold greater in the case of farmed chinook compared to captured pink salmon. This analysis again suggests that food production for humans, as exemplified by salmon farming, is moving in the direction of greater energy intensity per unit product (i.e., diminishing returns).

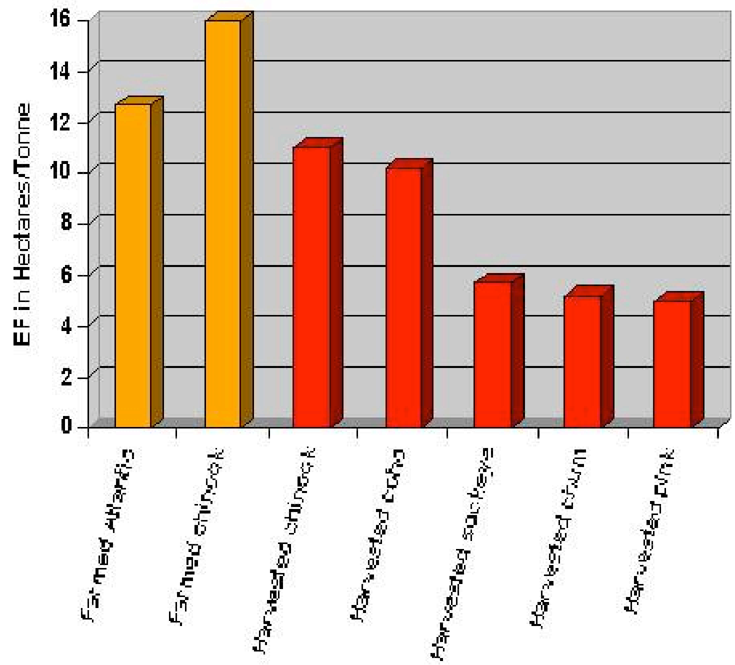

Figure 14.2. Ecological footprints (EF) of farmed and harvested (captured) salmon.

The socio-economic dimension

We have already noted that salmon farming actually reduces global food supplies. Much of the southern hemisphere fish-catch destined for fish meal could be consumed directly by the poor in the exporting countries rather than be used to produce a smaller quantity of salmon for rich consumers in the North. I recall at least one study showing that, in the 1990s, as more and more caught fish were being diverted to the animal feed industry (currently about 38% of the global total catch), the quantity of fish in the diets of the average Peruvian declined by 50%. Poor people were simply being priced out of the marketplace. Moreover, high global prices and export demand for South Pacific catches, has apparently closed dozens of small domestic fish packing plants in both Chile and Peru. In BC, while we welcome the salmon farming industry as an economic shot in the arm, it is effectively helping to shut down the packing industry in Chile and Peru. In 2002 a survey 102 of these plants in Peru showed that only 24 were operating because of a shortage of feedstock. The Peruvian government was forced to declare that certain species, such as Jack Mackerel and Pacific Club Mackerel, be reserved exclusively for domestic human consumption in order to keep these plants open.

More generally, what these data show is that as northern countries deplete their own fish stocks, they simply extend their marine ecological footprints ever further into the world's oceans to maintain domestic levels of consumption. (Another example: eastern Canadian fish processors now use catches from Asia and the South Pacific.) This illustrates a grotesque social dimension of globalization—under prevailing terms of trade, we now achieve through commerce what used to require territorial occupation. It is time to ask ourselves whether it is morally acceptable for the wealthy—that 25% of the human population who consume 86% of global economic output—to use their economic power in ways that effectively deprive poorer people of the basic requirements for life.

Micro Conclusions: Net pen salmon farming and the fallacy of near-perfect substitution
The forgoing data show that in 2000, net pen salmon farming was failing on both biophysical and social grounds. Salmon farms are a costly and inefficient technological substitute for a superior service of nature. That is, the salmon farming industry expends large quantities of costly and increasingly scarce fossil fuel to do several jobs that wild salmon do for free, particularly foraging at sea to catch their own food. This represents a waste of scarce financial and energy resources that could be used for other socially productive purposes. Salmon farming also generates considerable carbon dioxide emissions and therefore contributes to potential climate change and simultaneously depriving poorer people of food.

The data also serve to illustrate the fallacy of the principle of near-perfect substitution. They are compatible with economist Robert Kaufman's observation that substituting manufactured capital for depleted natural capital requires investment that could otherwise be used to build additional (not replacement) productive capital or for consumption. Kaufman showed that, because of the hidden costs of shifting from consumption to investment, "it is not possible to substitute capital for environmental life support and maintain material well-being" (Kaufman 1995). In other words, substituting technology for nature is ultimately a losing proposition.

Macro Conclusions: Humankind is inherently biased against sustainability
I started out by arguing that the collapse of ocean fish stocks is merely the more recent marine equivalent of humanity's historic usurping of terrestrial ecosystems. It has taken humans a little longer to dominate the marine ecosystem, but it has finally been made possible by technological advances and cheap plentiful fossil fuel. Even the motivation is similar. Most people are under the illusion that agriculture was a great invention, one that was readily adopted by people everywhere. However, there is much evidence to the contrary—agriculture may well have been forced upon us by necessity. With the shift from stone to metal tools and weapons, human hunter-gatherers apparently became so effective that they frequently depleted game populations and otherwise overharvested their habitats. This forced them to start growing food to feed their expanding populations. However, this, in turn, made more food available, enabled the development of complex societies and allowed populations to expand even further. Are we not repeating some of this process in the sea? Is it not the overharvesting of wild fish that has forced us to turn to industrial-scale mariculture and is not this "advance" actually accelerating the exploitation of marine ecosystems? (I suspect that if we still had our original stocks of salmon and cod, we would not dream of fish-farming.)

The history of marine fisheries also tends to support my assertion that when it comes to human expansionary behaviour we are not a science- or knowledge-based culture. The global community has the data to show that the world's oceans are being emptied, but like the Easter Islanders, people today seem "…unable to devise a system that would allow [us] them to find the right balance with [our] environment."

Why does the torrent of scientific data showing the fundamental unsustainability of the human growth dynamic receive so little attention? What does it tell us about ourselves when reports that we have mined 90% of the fish biomass from the sea barely make the news and even then promptly drop from public consciousness? Why are our fisheries ministers not organizing urgent international meetings to deal with this crisis? As noted, humans have evolved no inhibitions to destroying their own ecosystems, terrestrial or marine. And this evolutionary blind spot is expanded even further by the promise of "near perfect substitution" and perhaps even more by the big money to be made in industrial aquaculture. (At least one Canadian fisheries official actually remarked that the persistence of capture fisheries is a threat to the development of aquaculture.)

Finally, the history of fisheries and aquaculture supports the conclusion that at least some of the behavioural tendencies that conferred competitive superiority upon "the naked ape" in the relatively empty world of 50,000 years ago, have become maladaptive in today's ecologically full world. The inclination of humans to expand to the capacity of their environments and to accumulate possessions (the qualities that move economists to refer to people as "self-interested utility maximisers with insatiable material demands") presumably helped to ensure survival in technologically limited times but are depleting the planet today. Arguably, there is no solution to the (un)sustainability conundrum until we acknowledge and counter these root causes of contemporary human ecological dysfunction.

We hear a great deal about climate change, water scarcity, overfishing, and other so-called "environmental problems" but these are mere symptoms of the greater malaise. If we do not come to see unsustainability as *an emergent property of humans in nature* and to assert social control over the causal predispositions, we are destined to deplete our entire habitat and repeat the cycle of societal collapse on a global scale. And a global collapse would be very different in consequence from a regional one. Global failure has the potential to bring misery to billions of people and may even preclude the emergence of future civilizations. In the sobering words of Sir Fred Hoyle (1964): "It has often been said that, if the human species fails to make a go of it here on Earth, some other species will take over the running. …this is not correct. We have, or soon will have, exhausted the necessary physical prerequisites so far as this planet is concerned. With coal gone, oil gone, high-grade metallic ores gone, no species however competent can make the long climb from primitive conditions to high-level technology. This is a one-shot affair. If we fail, this planetary system fails so far as intelligence is concerned."

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