A brochure explaining to the general public why animal research is important is described. Salmon farming is said to use less of "nature's subsidies" than the raising of chicken or pigs. A letter writer is concerned that, "[b]ecause of the capitalization costs and other financial and political constraints, the wealth flowing from pond-harvested shrimp is concentrated away from the lower economic classes." And a correction of a 1997 report reveals that an unknown serum factor may have been responsible for the suppression of mutations in a human tumor cell line.

Animal Rights Brochure

R. Michael Conn and James Parker make an important point in their editorial "Animal rights: Reaching the public" (20 Nov., p. 1417): The scientific community can and must do more to tell the public why animal research is important.

The American Physiological Society (APS) has taken a step in this direction by publishing an eight-page color brochure containing a series of essays on this subject. The brochure, *Questions People Ask About Animals in Research.... With Answers From the American Physiological Society*, is intended to provide the public with informative and readable responses to their legitimate concerns about why we need to use animals in research. The brochure may be viewed at www.faseb.oriz/gps/pubaff/animals/index.html. Single copies are available at no charge from the APS Public Affairs Office at the address below.

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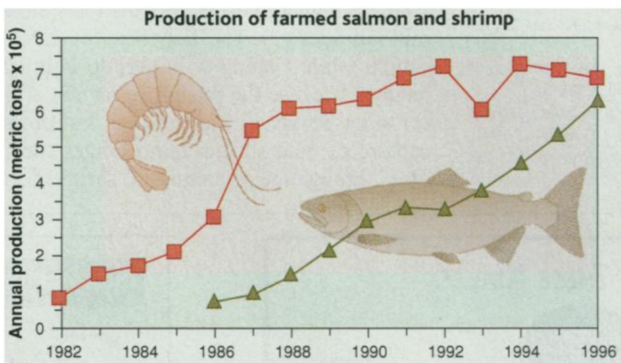
Shrimp and Salmon Farming

May I respond to the Policy Forum "Nature's subsidies to shrimp and salmon farming" by Rosamond L. Naylor *et al.* (30 Oct., *Science*'s Compass, p. 883)? Like many new endeavors, this industry is undergoing rapid change, but the authors focus only on its present performance in forming their conclusions and, by doing so, condemn it prematurely. Specifically, they challenge the farming of carnivores, like salmon, and the use of fish meal in salmon foods, but do not address the implications of research showing that almost all fish meal in these feeds can be replaced with other ingredients, including meals of plant origin (*1*). In other words, the dietary preference of salmon in nature does not mandate that they are fed with animal proteins in captivity.

It may be several years before this research can be commercially applied but, when it is, farmed salmon will be fed some of the same raw materials as those now fed to chickens and pigs, albeit they *will* be processed differently. Chickens and pigs are fed huge amounts of food grains and protein concentrates that could otherwise be used directly in the human diet. By comparison, salmon has important advantages and its farming should be considered in this wider context. Salmon do not use energy to keep warm or to support their weight. Because they are highly fecund, little food is used for maintenance of breeding stock. The edible meat yield of salmon, at over 80%, is significantly higher than for chickens and pigs, and the meat is more healthful. With such attributes, salmon may actually use fewer of "nature's subsidies," when it is farmed, than its terrestrial competitors.



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References and Notes

1. For example, D. A. Higgs *et al.*, Eds., *Nutrition and Utilization Technology in Aquaculture* (AOCS Press, Champaign, IL, 1995), pp. 130–156; R. R. Stickney *et al.*, *J. World Aquacult. Soc.* **27**, 57 (1996).

Response

Forster is correct that a growing body of research suggests that it may be technically possible to replace much of the fish meal used in feeds for farmed salmon with oilseed proteins (*1*). While we expect that salmon feeds will become more plant-based, there remain impediments to achieving this goal, and wild fish may continue to be a dominant ingredient in salmon feed for some time to come. Salmon dietary requirements for essential amino acids such as cysteine and methionine cannot easily be met by plant proteins (*2*) and will continue to be derived from other sources, such as fish meal. Only briefly mentioned in our paper, salmon feeds contain high concentrations of fish oils as well as fish meal. Fish oils are added to feed primarily as an energy source, because salmon are poor at using carbohydrates for energy. Although considerable substitution of vegetable oils for fish oils may be possible, salmon diets will continue to require n-6 highly unsaturated fatty acids, which at present can only be derived in commercial quantities from fish oils (*3*).

Economic considerations will likely be the biggest factor in whether salmon are eventually fed largely plant-based diets, especially given salmon farming's increasingly narrow profit margins. Depending on source and inclusion rate, oilseed meals can compromise feed palatability and fish growth (*1*)—and therefore profitability. Moreover, reduced palatability or diet digestibility can aggravate waste loading to the environment. Industry experts forecast that aquaculture's demand for fish meal and fish oil will continue to rise (*4*)—meaning that aquaculture will continue to place pressure on the finite stocks of wild fish from which fish meal and fish oils are derived.

As Forster points out, farming cold-blooded fish may be, at least in principle, more energetically efficient than raising some warm-blooded livestock, such as pigs and poultry, that are opportunistic omnivores. We agree that the demands on environmental goods and services of different types of intensive food production merit detailed consideration. However, comparing the feed conversion efficiencies of different types of animals can be misleading unless the sources of feed ingredients, especially relative shares of wild fish versus crop plants, are also taken into account.

The long-term sustainability of aquaculture will depend on which species are farmed and the methods by which they are produced. We strongly support farming of largely herbivorous fish, omnivores that are flexible in their dietary requirements, and filter-feeding bivalves. Many of the most important farmed carp and tilapia species, for example, are herbivores or omnivores, and they account for a significant share of protein consumed in the developing world (*5*). The best aquaculture production methods, in our view, include polyculture systems that make efficient use of inputs and generate little waste. We agree that continued examination of the scientific progress of the salmon (and shrimp) industry is desirable. However, sustainability will not be achieved until the industry as a whole internalizes the environmental costs of production.

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Naylor *et al.* correctly point out some of the environmental impacts occurring during operation and after the collapse of coastal shrimp aquacultural systems. There are at least two other rather insidious long-term consequences not mentioned, but which society, especially the local fishing community, absorbs. Shrimp ponds are usually built within the intertidal habitat, especially in mangrove ecosystems. The size of the natural shrimp harvests, and the harvest of other coastal fisheries, is limited by the area of intertidal lands (*1*). The potential wild harvest will thus decline in proportion to the loss of the mangrove zone. The yield per hectare is 10 times higher in the tropics than it is in the mid-latitudes (*2*). The fisheries "by-catch" caught while fishing wild shrimp is much reduced because the mangrove habitat critical to the survival of juveniles is lost or the capture of wild shrimp is no longer subsidized through the economics of shrimp fishing (the ratio of shrimp to by-catch may be as high as 1 to 20). Ironically, extensive conversion of mangroves to shrimp ponds may also threaten the supply of wild post-larvae shrimp used to stock ponds. Because of the capitalization costs and other financial and political constraints, the wealth flowing from pond-harvested shrimp is concentrated away from the lower economic classes. A few may therefore gain economically at the expense of the artisanal fishing community and others who would otherwise consume inexpensive and high-protein food. A lower overall social benefit seems to be the inevitable consequence of widespread shrimp pond aquaculture in mangroves.

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Response

We fully agree with Turner's comments. Space limitations prevented us from fully addressing points related to wild fisheries harvests, wild post-larvae supplies, by-catch, and socioeconomic impacts of shrimp farming. Instead, we opted to focus on a number of direct environmental impacts of shrimp and salmon farming.

The decline in potential wild fisheries harvests was mentioned briefly. In our statement on nursery areas destroyed by aquaculture, we referred primarily to mangroves, but also to freshwater wetlands, seagrass beds, and coral reefs. Mangrove forests protect coral reefs by absorbing pollutants (*1*) and retaining silt and clay sediments from rivers and coastal waters (*2*) that interfere with reef productivity.

The destruction of nursery habitats caused by mangrove conversion has a direct impact on commercial species, species in the food chain that support commercial and subsistence-based fisheries, and wild post-larvae supplies (*3*). In addition, it reduces the supply of wild spawners and broodstock on which shrimp hatcheries in Asia and parts of Latin America depend.

Moreover, as Turner points out, mangrove conversion lowers the volume of by-catch, which is an important source of nutrition for some coastal communities (*1*). Perhaps more worrisome, shrimp farming has caused food insecurity, marginalization, unemployment, and other socio-economic disruptions among poor, rural communities through land privatization and expropriation, salinization of soil and water, and loss of mangrove goods and services (*4*). The latter includes erosion and flood control, water purification, fuelwood supplies, and a variety of food sources that are essential for the livelihood of subsistence communities (*5*).

Jurgenne Primavera, Jason Clay, Nils Kautsky, Rosamond Naylor, Carl Folke, Malcolm Beveridge, Rebecca Goldburg, Jane Lubchenco, Harold Mooney, Meryl Williams

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The Conditional Mutator Phenotype in Human Tumor Cells: Correction

In a previous report, "Conditional mutator phenotypes in hMSH2-deficient tumor cell lines" (5 Sept. 1997, p. 1523) (*1*), some of us (B.R. and M.M.) demonstrated that two hMSH2-deficient tumor cell lines exhibited a conditional mutator phenotype. When the cells were kept in a growing state, mutation rates were low. However, when the cells were allowed to come to confluence and stand in high-density, suboptimal growth conditions, the mutant frequency increased as much as 7900-fold. We suggested that this increase might have been the result of an accumulation of mutations occurring while the cells were maintained in suboptimal culture conditions.

An alternative explanation for the differences in mutant frequencies is suggested by more recent experiments. When these tumor cell lines were grown in medium supplemented with a new serum batch, both log-growing and high-density cultures displayed a high mutant frequency. To confirm that the serum was the component of the medium that led to the changes in mutant frequency, we grew cells from the same inoculum side by side in medium supplemented with our original serum or in medium supplemented with the new batch. Cells grown in our original serum showed a low mutant frequency, while those grown in the new batch had a substantially (>2000-fold) elevated frequency. When cells were grown in mixtures of the two kinds of serum, mutant frequency was again low. These data argue that the conditional mutator phenotype is the result of suppression of mutation in log-growing cells by factors in the original serum. Since high-density cultures accumulate mutations, we suggest that high-density cultures may not respond to this suppressive mechanism or that the factor responsible for suppression may become exhausted in the medium. Nevertheless these data demonstrate that serum factors may play an important role in governing mutation rate in some tumor cells.

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CORRECTIONS AND CLARIFICATIONS

The units of measurement in the graph accompanying the Policy Forum "Nature's subsidies to shrimp and salmon farming" by Rosamond L. Naylor *et al.* (*Science*'s Compass, 30 Oct., p. 883) were incorrect. They should have been "metric tons x 10^5." The correct graph appears in this issue on page 639.