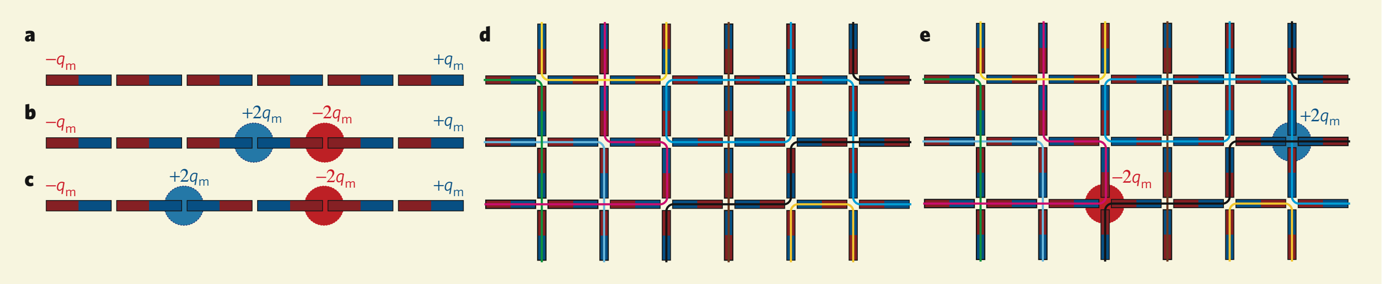

**Figure 1 | Making monopoles. a**, In the lowest-energy state, all the elements in a chain of magnetic dipoles point in the same direction: the north pole (magnetic charge $+q_m$) of one magnet touches the south pole (magnetic charge $-q_m$) of the next. The charges cancel out all the way along the string, except at the ends. **b**, Flipping one of the dipoles in the middle excites the chain out of its ground state, creating two magnetic charges $+2q_m$ and $-2q_m$. **c**, Each of these charges can be moved independently of the other by flipping a dipole next to it — they are free monopoles. **d**, Castelnovo *et al.*[1] study spin orientations in spin ice. Shown here is square spin ice, a two-dimensional variant that has been produced in an artificial form, as an array of nanoscale magnets[10]. Four magnetic poles meet at each point on the square lattice, and the energy is lowest when two are north poles and two are south poles. Spin ice in the ground state can be construed as a series of strings of magnetic dipoles embedded in a higher-dimensional lattice. **e**, Flipping dipoles on a single string (the black one) creates a pair of well-separated magnetic poles just as in one dimension.

carry a quantized amount of energy, momentum, electric charge and spin. In their theoretical study, Castelnovo *et al.* find the first instance of such an excitation with a non-zero magnetic charge. Under certain conditions, these magnets behave as a gas of independent magnetic poles. There is even a phase transition at which a thin vapour of these monopoles condenses into a dense liquid.

How a monopole can be created in a world of magnetic dipoles can be understood by considering a one-dimensional string made by laying tiny dipoles end to end. In this case, a single misaligned dipole gives rise to two independent magnetic charges that can be moved far apart, for the price of putting some energy into the system (Fig. 1a–c). The monopoles that arise are boundaries separating regions with perfectly aligned dipoles. These topological defects, known as domain walls, or 'kinks', have recently been studied in magnetic nanowires[3].

The emergence of free magnetic monopoles is an example of the phenomenon known as 'fractionalization': that the collective behaviour of many particles in a condensed-matter system is most effectively described in terms of fractions of the original particles. Fractionalization is often tied to topological defects[4] and is common in one-dimensional systems, such as the string already mentioned. The only confirmed case in two dimensions is the fractional quantum Hall effect, which occurs in a cold gas of electrons placed in a strong magnetic field[5]. Measurements of conductance[6] and electrical noise[7] in this system indicate the involvement of 'quasiparticles' with one-third of an electron's charge.

Castelnovo and colleagues provide the first example of fractionalization in a three-dimensional system. But how does the physics of free monopoles on a string survive in a higher-dimensional setting? The answer lies in the special nature of the ground states of the authors' chosen system, spin ice, which allows one-dimensional ideas to be transferred to two and three dimensions (Fig. 1d,e).

The monopoles in spin ice are magnetic analogues of electrically charged defects $H_3O^+$ and $OH^-$ in water ice. The movement of these defects through water ice causes it to conduct electricity when an electric field (potential difference) is applied across it. Might it be possible to create a steady magnetic current in spin ice by placing it in a magnetic field? Unfortunately not. The motion of a kink alters the state of a string, making it impassable to the next magnetic charge. In water ice, a kink of a different flavour, known as a Bjerrum defect[8], repairs the damage done by the original defect. Because there is no analogue of Bjerrum defects in spin ice, magnetic monopoles are somewhat limited in their motion, and cannot sustain a direct magnetic current.

That still leaves the possibility of generating an alternating magnetic current, which would be interesting in its own right. In any case, learning how to move magnetic monopoles around would be a step towards technologies such as magnetic analogues of electric circuits and magnetic memories[9] operating on the atomic scale. ■

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AQUACULTURE

# The price of lice

Andrew A. Rosenberg

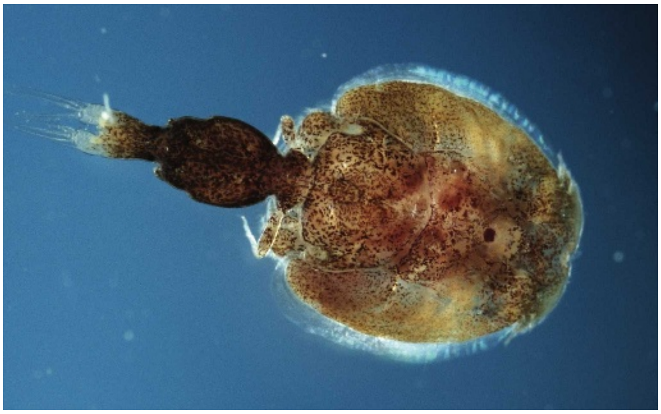
**Wild salmon stocks in Canadian coastal waters are being severely affected by parasites from fish farms. So intense are these infestations that some populations of salmon are at risk of extinction.**

The global demand for fish is on the rise, and farmed sources are taking much of the strain — the catch of wild fish has levelled off, and may well be declining[1], but aquaculture production is expanding rapidly[2]. The ecological costs of that expansion can be heavy, however, as Krkošek *et al.* show in *Science*[3]. The message of their paper is that there are some serious issues that cannot be ignored if the expansion of aquaculture is to be productive rather than destructive.

Consumers can readily see the shift towards aquaculture, particularly for products such as farmed salmon, which has become a staple of supermarkets and restaurants in Europe and North America. Those buying fish will be aware of press reports of overfishing and resource depletion. Some may even look for eco-labels or carry a little card to guide them towards the purchase of sustainable products. As my colleague Carl Safina has said, "Give a man a fish and you have fed him for a day. Give a man a seafood choice card and you have made him impossible to dine with."

But aquaculture products tend to be subject to less public attention, even as issues ranging from habitat destruction to the effects of using wild fish to feed farmed stocks[4] become of greater concern. The emphasis of aquaculture development has, not surprisingly, been on increasing production, lowering costs and improving products. These needs of the industry have been well served by the science of fish farming. Unfortunately, however, research pointing out the environmental costs of production has been viewed as an attack on the industry, rather than as a challenge to be tackled and overcome.

Krkošek *et al.*[3] have provided new, empirical evidence of the environmental costs of the nearshore, net-pen aquaculture of salmon — the pending extinction of several populations of wild pink salmon, *Oncorhynchus gorbuscha*, on the coast of British Columbia. Until now, most research on the effects of net-pen aquaculture has revealed instances of certain consequences, such as the competition of wild fish with escaped farm stocks for spawning habitat, but not of effects at the population level. Krkošek and colleagues' analysis of 142 populations of pink salmon shows that wild stocks adjacent to fish farms have suffered dramatic increases in mortality of juvenile fish owing to infestation by sea lice, *Lepeophtheirus salmonis* (Fig. 1), and that most of the exposed populations are at risk of extinction within four salmon generations. It is the location of the salmon farms, compounded with the tendency of sea lice to proliferate near intensive farm facilities, that are cause for concern. Although farmed salmon can be treated to reduce sea-lice infestation, wild stocks have no such protection. As juvenile wild salmon emerge from rivers, their migration route runs a gauntlet of salmon aquaculture pens and, therefore, high levels of salmon lice.



BLICKWINKEL/HARTL

**Figure 1 | Salmon louse.** This marine organism belongs to a group of crustaceans known as copepods. It feeds on the external surfaces of fish, and can eventually kill them.

The lesson of this analysis[3] is that neither fisheries science nor the aquaculture industry can be driven solely by the desire to increase production. Many aquaculture facilities are set in complex ecosystems, and influence the structure and function of those ecosystems. Policy-makers must ensure that the environmental costs are evaluated and monitored, and are factored into decisions about farm location and expansion. The argument that costs will be unfairly passed on to consumers rings hollow, because if such costs are not controlled, we the public eventually bear them in their entirety. In such a circumstance, there is little incentive for producers to reduce environmental impacts. The results of Krkošek and colleagues' study, and their warning that the terrible cost of extinction of wild-salmon stocks is not far off, highlights that point.

Net-pen aquaculture is not just about salmon. As the industry expands into other species, such as cod, halibut and sablefish, the same concerns over the location of farms, disease and parasite transmission, and other impacts will certainly apply to these species too. It is vital to assess the potential environmental costs and to reduce them before the advent of large-scale farming of these species.

Can we design aquaculture systems that reduce ecosystem impacts, or eliminate some of them entirely? I think that we can, but not with a confrontational mentality. Overfishing of wild stocks is not a contrived problem, nor is it unsolvable: good management practices are often contentious and difficult to implement, but ultimately they can work. Similarly, the problems facing the aquaculture industry are not unsolvable, but denial that those problems exist will not provide answers. In the case of salmon lice, solutions include adhering to strict guidelines on the introduction and transfer of non-native fish, and siting of net pens away from areas where wild stock is vulnerable. Overall, the priority in aquaculture should be to anticipate any adverse environmental consequences and to tackle them at that stage, rather than struggle to recover after those consequences are already apparent. ■

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NEUROSCIENCE

# Love hangover

Leslie C. Griffith

**In many species, males have developed strategies to safeguard their genetic material from dilution by that of competing males. Fruitflies achieve this by altering the behaviour of their partners.**

Sex can be transformative. Humans often romanticize the after-effects of copulation, but for most organisms there are real biological consequences to mating that go beyond the transfer of sperm. Most species have strategies for protecting their genetic investment that can involve alterations in both the biology and behaviour of the mating partners. For example, in the fruitfly *Drosophila melanogaster* a component of seminal fluid, known as sex peptide, leads to increased egg-laying by the mated female and behavioural changes that reduce the likelihood of her re-mating. How sex peptide triggers such a complex array of effects was unknown. On page 33 of this issue, Yapici *et al.*[1] identify the receptor for sex peptide and show that it is expressed in the reproductive tract and in a subset of female neurons believed to be involved in sexual behaviour.

Enhancing the survival of potential progeny is a common goal of males in many species. In mammals, intercourse changes the immunological environment of the female reproductive tract, increasing the probability of successful fertilization and implantation[2]. This type of post-copulatory effect benefits both the male and female partner. For many species there are also other mating-associated events that apparently maximize the reproductive success of just one of the involved parties, often at the expense of the other. An obvious example of this is mate guarding. Males of many avian, reptile, rodent, primate and insect species remain close to a recent conquest to lower the probability of her re-mating with a more desirable male and so diluting or displacing their own sperm. The female may benefit in terms of decreased predation, but she loses any opportunity to better the genetic lot of her offspring. The success of this strategy for the male depends on his vigilance, and potentially decreases his chances of mating with other females, so is not without cost.

Nature has also come up with more subtle forms of mate guarding. In snakes[3] and various insect species[4–6], mating can lead to changes