AQUATIC ECOSYSTEMS

Pesticide impacts through aquatic food webs

Effects of neonicotinoid insecticides ricochet all the way to fisheries yields

By **Olaf P. Jensen**

Testing chemicals for toxicity is straightforward, but detecting their effects at the population, community, or ecosystem level is exceedingly difficult. As one moves to higher levels of ecological organization, the number of confounding factors and compensatory mechanisms increases (*1*). Standardized, laboratory studies of pesticides, required by regulatory agencies, typically focus on the short-term effects of acute exposure to individual model organisms with the results scaled up mathematically to estimate long-term and indirect effects. However, long-term and ecosystem-scale ecological studies frequently show surprises and emergent phenomena that couldn't be predicted by extrapolating from results at smaller temporal, spatial, and organizational scales (*2*). To understand the long-term ecosystem impacts of contaminants, one must study entire ecosystems for a long time. On page 620 of this issue, Yamamuro *et al.* (*3*) have done just this, demonstrating that neonicotinoid pesticides can affect entire food webs.

Much of what we know about indirect food web impacts of contaminants comes from studies of oil spills. However, even oil spills that release millions of barrels of crude oil can have weak or undetectable effects at the population or community level. The Deepwater Horizon spill—the largest in United States history—is a good example. Extensive studies of nearshore fish populations following the spill have found little evidence of declines (*1*, *4*), despite known toxicity and exposure (*5*). Pesticides present a challenge similar to that of oil spills, but a different kind of exposure: a continued "press" disturbance as they are

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repeatedly added to the environment rather than the discrete "pulse" disturbance of a major oil spill.

Using more than 20 years of data on the chemistry, biology, and fishery harvests of Lake Shinji, Japan, Yamamuro *et al.* track the impacts of pesticides up the food chain from arthropods such as aquatic insect larvae and crustacean zooplankton to the commercial harvest of smelt and eel. Neonicotinoid pesticides were first used in the rice paddies surrounding Lake Shinji in 1993. Arthropod populations in the lake collapsed that same year, followed shortly thereafter by a complete collapse of the fisheries for fish species that feed on these arthropods. Changes in fish catch are not a perfect reflection of changes in the fish populations themselves—fishers often give up when fish become rare, causing catch to decline more rapidly than abundance—but this is a large and astoundingly fast response to a food web perturbation.

Department of Marine and Coastal Sciences,
Rutgers University, New Brunswick, NJ 08901, USA.
Email: ojensen@rutgers.edu

Insecticides from rice paddies may make their way to lakes and alter aquatic food webs. Rice paddies in Unnan, Japan are located near Lake Shinji.

This study by Yamamuro *et al.*, although observational, presents compelling evidence from more than a decade of data both before and after neonicotinoid insecticides were introduced to this region. In courtroom dramas, a conviction requires evidence of means, opportunity, and motive. A convincing case for impacts at the ecosystem scale likewise requires a means (plausible pathway for impacts to occur), an opportunity (toxic concentrations measured in the relevant environment), and if not a motive, then the elimination of other plausible suspects. In this case, the means are clear: Arthropods, including midges and, to a lesser extent, crustacean zooplankton, are exceptionally sensitive to neonicotinoids (*6*). This is no surprise—killing insects is what insecticides are designed to do. The means for such impacts on arthropods to then propagate to other species in the food web are also evident. Although the specific trophic pathways fueling aquatic food webs depend heavily on the size of the lake or river (*7*), most links between primary production and fish are through arthropods. Neonicotinoid concentrations in Lake Shinji suggest plenty of opportunity. Observations immediately following the first use of these insecticides in the region are missing, but measurements in 2018 show concentrations well above the lethal amounts for many arthropods. Several alternative explanations for the collapse in aquatic arthropods and fisheries were evaluated and rejected: Invasive species, hypoxia, or changes in fish stocking cannot plausibly explain the observations. Further implicating the collapse of arthropods in the decline of fisheries, the commercial harvest of a third fish species, less reliant on arthropod prey, did not decline.

If neonicotinoids are toxic enough to have caused the rapid decline of arthropod and fish populations in Lake Shinji, then why aren't there reports of widespread effects on aquatic ecosystems? After all, neonicotinoids are the most widely used insecticides in the world. One explanation is that the use of neonicotinoids on rice involves the direct application of insecticide or insecticide-treated seeds to an aquatic environment, the rice paddy. Although this may be a worst-case scenario, it is not an unusual one; rice is one of the three largest cereal crops in the world (*8*). Rice seeds coated with neonicotinoids are widely used, and more than 90% of this coating ends up in soil or water (*9*). Also, there is the issue of not seeing a problem if we don't look for it. Long-term monitoring of zooplankton is rare, geographically unrepresentative, and often confounded by impacts from multiple stressors (*10*). Freshwater fisheries and fish populations are also notoriously data deficient (*11*). Despite such data limitations, Yamamuro *et al.* are not alone in finding indirect food web effects of neonicotinoids. A study in the Netherlands (*12*) showed an association between neonicotinoid use and population declines in birds. The more we look for population- or ecosystem-level impacts of neonicotinoids, the more we are likely to find them.

Proponents of industrial agriculture and its heavy reliance on new chemicals argue that, although it would be ideal to reduce the use of pesticides, there are many mouths to feed. Yamamura *et al.* show that the trade-off is also between one type of food production (agriculture) and another (fisheries). A fishery that was sustainable for decades collapsed within a year after farmers began using neonicotinoids. This is hardly the only pronounced impact of agriculture on fisheries. Runoff from "America's breadbasket" creates a recurring dead zone in the Gulf of Mexico roughly the size of Israel (*13*) with serious economic losses for fishermen (*14*). A more comprehensive comparison of the environmental impacts of the world's food systems is urgently needed (*15*) and must include the indirect impacts that propagate through food webs. ■

REFERENCES AND NOTES

1. F. J. Fodrie *et al.*, *Bioscience* **64**, 778 (2014).
2. S. R. Carpenter, *Ecology* **77**, 677 (1996).
3. M. Yamamuro *et al.*, *Science* **366**, 620 (2019).
4. E. J. Ward *et al.*, *Environ. Monit. Assess.* **190**, 530 (2018).
5. A. Whitehead *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **109**, 20298 (2012).
6. C. A. Morrissey *et al.*, *Environ. Int.* **74**, 291 (2015).
7. Y. Vadeboncoeur, G. Peterson, M. J. Vander Zanden, J. Kalff, *Ecology* **89**, 2542 (2008).
8. U.N. Food and Agriculture Organization (2019), FAOSTAT 2019: FAO Statistical Databases; www.fao.org/faostat/en/#home, Rome.
9. R. Sur, A. Stork, *Bull. Insectol.* **56**, 35 (2003).
10. E. Jeppesen *et al.*, *Hydrobiologia* **676**, 279 (2011).
11. D. M. Bartley, G. J. De Graaf, J. Valbo-Jørgensen, G. Marmulla, *Fish. Manag. Ecol.* **22**, 71 (2015).
12. C. A. Hallmann, R. P. B. Foppen, C. A. M. van Turnhout, H. de Kroon, E. Jongejans, *Nature* **511**, 341 (2014).
13. N. N. Rabalais *et al.*, *Estuaries Coasts* **30**, 753 (2007).
14. M. D. Smith *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **114**, 1512 (2017).
15. B. S. Halpern *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **116**, 18152 (2019).

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