Vol. 241: 235–236, 2002 | MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser | Published October 4

THEME SECTION

Nearshore vertebrate predators: constraints to recovery from oil pollution

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Chronic impacts of oil pollution in the sea: risks to vertebrate predators

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Following the 1989 'Exxon Valdez' oil spill in Alaska, several studies of the biological consequences were conducted (e.g. Wells et al. 1995, Rice et al. 1996), targeting especially the vertebrates, whose high diversity, abundance, and importance helps distinguish the coastal ecosystem of the northern Gulf of Alaska. Virtually unique among field programs studying impacts of oil spills has been the availability of support for years after the 'Exxon Valdez' spill for assessment of some of the potential processes of long-term impacts of oil in the marine environment. This Theme Section synthesizes results of the Nearshore Vertebrate Predator project, which was initiated in 1995 to test several hypotheses to explain delays in recovery of some sentinel vertebrates in the coastal ecosystem. The project involved 4 species: 2 marine mammals and 2 marine birds, each of which had demonstrated acute impacts of the spill at the population level and also showed some evidence of delayed recovery (Rice et al. 1996). One bird (harlequin duck: *Histrionicus histrionicus*) and one mammal (sea otter: *Enhydra lutris*) feed largely on benthic invertebrates, plus another bird (pigeon guillemot: *Cepphus columba*) and mammal (river otter: *Lontra canadensis*) consume a diet dominated by fish. Parallel studies of each species were conducted to examine: (1) the status of population recovery 6 to 9 yr after the oil spill; (2) whether food availability constrained the recovery; (3) whether ongoing exposure to oil toxicity delayed recovery; and (4) whether demographic limitations intrinsic to the species and unrelated to food availability or chronic oil toxicity limited the rate of recovery.

The role of acute mortality to marine organisms from exposure to petroleum hydrocarbons can be inferred from well-designed observational sampling over short time intervals. Consequently, a substantial body of information on acute risk has been gathered in nature following oil spills and in the laboratory using protocols of acute toxicity testing (e.g. National Research Council [NRC] 1985). The role of longer-term mortality from oil exposure has proved a much more elusive research target for marine ecologists despite a long-standing recognition of its potential significance (Gray 1982, National Research Council [NRC] 1985, Boesch & Rabalais 1987). Such research is more costly to conduct because it involves time frames of years instead of days and requires simultaneous evaluation of multiple mechanisms of potential impact to biological systems. Unlike acute mortality, which mostly occurs as an immediate narcosis reaction to toxicity (Rice et al. 2001) or some other direct process like physical smothering of rocky-shore invertebrates, long-term consequences of exposure of marine ecosystems to petroleum hydrocarbons can occur via several direct and

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indirect processes mediated through the ecosystem and can be induced at lower pollutant concentrations (National Research Council [NRC] 2002). Among the most important of these potential mechanisms of long-term impacts of petroleum hydrocarbons (Peterson 2001) are: (1) delayed impacts due to impaired survival or reproduction from compromised health or suppressed growth after initially sublethal exposures; (2) impacts that cascade through the population via losses of key individuals important to critical social organization functions; (3) impacts of chronic persistence of toxic components of oil, biological exposures, and resultant population-level responses; and (4) delayed impacts of habitat degradation, prey decline, trophic cascades, and other indirect effects of ecosystem perturbation.

The Theme Section comprises 4 synthesis papers that describe the results of 5 years of research from 1995 to 1999 to follow recovery and test the multiple hypotheses that may help explain any documented delay in the recovery process. The only species for which no synthesis paper is included is the river otter (published elsewhere), which failed to exhibit compelling evidence of long-term impacts or substantially delayed recovery. By contrasting the responses of the 4 consumers, 2 of which feed on benthic invertebrate prey in shallow waters and 2 of which feed largely on fishes, the Nearshore Vertebrate Predator project produced important insight into the risk of long-term impacts of petroleum hydrocarbons to apex vertebrate consumers. When compared with piscivores, vertebrate consumers of benthic invertebrate prey possess a relatively high risk of chronic exposure to residual oil in bottom sediments, physiological responses to that exposure, and elevated mortality for periods of years after an oil spill (Peterson 2001). The inclusion of understanding of how chronic exposure to multi-ringed PAHs sequestered in low concentrations in ground waters of anadromous fish streams induced elevated mortalities of developing pink salmon embryos (Rice et al. 2001) helps reveal the general significance of studies of the 'Exxon Valdez' oil spill to enhancing appreciation of long-term, chronic, and delayed impacts of oil pollution in the marine environment. Chronic and indirect effects of exposure to petroleum hydrocarbons at low concentrations cannot be ignored in assessments of spill impacts (Wikelski et al. 2002) and in management of chronic sources such as storm water runoff from developed lands into rivers and estuaries (Rice et al. 2001, National Research Council [NRC] 2002). Risk assessment models based solely on acute toxicity underestimate impacts of oil pollution by overlooking the effects of chronic exposures, delayed impacts, and indirect effects driven by ecosystem processes (Kimball & Levin 1985).

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