# Oil spills and fish health: exposing the heart of the matter

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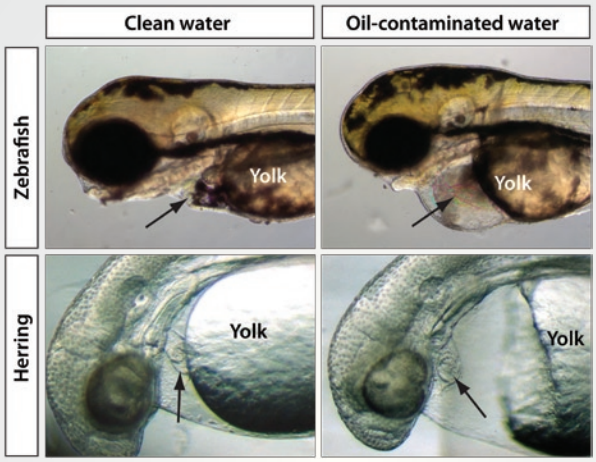
The chemical complexity of crude oil and its fuel products poses many important challenges for exposure science in marine ecosystems that support productive fisheries throughout the world. Meeting these challenges will enable better decisions on approaches to protecting and restoring these ecosystems.




As we learn more about exposure and effects of oil spills, many assumptions are being proven wrong and more unknowns are being identified. Beyond the widely documented physical effects of oil spills on seabirds and marine mammals, scientific studies are increasingly finding that the "invisible" components of oil are also toxic to the developing hearts of fish. The figure shows magnified views of the head region of hatching-stage fish embryos. The heart is indicated by arrows. Zebrafish (*Danio rerio*) are a small tropical fish used as a model system for laboratory studies, much like mice or rats. Pacific herring (*Clupea pallasi*), which are native to cold northern Pacific waters, are among the species affected by the *Exxon Valdez* oil spill. When zebrafish or Pacific herring are incubated in clean water, the heart fills a compact space. When the embryos of these species (and others) are incubated in water contaminated with low levels of polycyclic aromatic hydrocarbon (PAH) compounds from crude oil, the heart fails to pump properly and fluid accumulates in this space (a condition called edema), "inflating" the overlying skin and displacing the yolk mass.

## BACKGROUND

Major oil spills typically trigger heightened public concern for highly visible species such as birds and marine mammals. However, because these events do not occur every day and are difficult to study, we know much less about the unseen and more subtle effects of oil exposure in marine ecosystems. Consequently, academic and government scientists alike have had great difficulty predicting the impacts of an event like the blowout of the *Deepwater Horizon*–MC252 well in the Gulf of Mexico. Moreover, the lack of knowledge required to measure the impacts of large oil spills hinders our ability to determine whether multiple small oil spills, which occur almost daily, have effects on our coastal ecosystems. The chemicals in crude oil that we know are toxic to fish enter waterways not only via large oil spills but also every day in smaller quantities, as "fallout" from motor vehicle exhaust and through stormwater runoff from streets and parking lots. The frequency of such smaller events is likely to increase worldwide with rising automobile ownership and coastal population growth. The number of small spills of "bunker" fuel, which powers large ships, is also likely to increase with the expansion of container shipping in worldwide trade.

Exposure of marine organisms to oil-derived chemicals is usually assessed by two means. One approach uses analytical chemistry to detect oil compounds in tissues; the other uses biological markers to indicate oil exposure, i.e., measurable changes in a physiological or other biological parameter in response to oil. Both approaches have important limitations that stem from two major information gaps. The first is incomplete characterization of the thousands of chemicals that may be present in a particular oil. The second is a limited understanding of what biomarkers mean for the health of oil-exposed organisms. Moreover, neither approach is perfectly diagnostic for pinpointing oil exposure in habitats with overlapping sources of petroleum pollution, such as urban stormwater runoff. This is problematic for apportioning exposure sources along urbanized bays and coasts (e.g., San Francisco Bay and Puget Sound) and in regions such as the Gulf of Mexico that receive smaller, chronic inputs from oil exploration and extraction.

Key advances in understanding the effects of oil on fish followed the 1989 *Exxon Valdez* oil spill in Alaska's Prince William Sound—to date, the most intensively studied case of a large, one-time input of crude oil into a relatively pristine aquatic ecosystem. Intensive environmental monitoring and research following the spill engendered a new understanding of the near- and long-term impacts of oil spills on individual organisms, populations, and communities that extended well beyond the visible physical effects of oil-covered birds and sea otters (Peterson et al., 2003). In the 1990s, field and laboratory studies of fish such as Pacific herring and pink salmon that spawn (deposit eggs) near oiled shorelines discovered important toxic effects of "invisible" dissolved



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oil components on fish embryos and larvae. More recent studies have built on these findings, with the goal of further sorting out which specific chemicals in complex oil mixtures are causing this early-life-stage toxicity in fish (Incardona et al., 2004, 2005, 2009). This more refined understanding is needed to develop next-generation biomarkers for oil exposure and to more accurately estimate the potential decline and recovery of fish populations that spawn in future spill zones.

## IMPACT AND IMPLICATIONS FOR EXPOSURE SCIENCE

The studies following the *Exxon Valdez* spill narrowed the search for chemicals in oil that are toxic to fish to a family of compounds containing a few hundred chemicals. Some members of this family—polycyclic aromatic hydrocarbons (PAHs)—were known to be toxic, but published research revealed little about how they might cause developmental defects in fish. One reason for this is that more than 60% of the published papers on PAH toxicity are on a single carcinogenic compound (benzo[$\alpha$]pyrene) that typically makes up only 0.02% of the total PAH content of crude oil. Suspect PAHs that are more abundant in crude oil have received almost no attention from the scientific community because they are only weakly carcinogenic.

We recently found that these more abundant chemicals in crude oil target the heart and can cause heart failure in developing fish embryos (Incardona et al., 2004, 2005, 2009; see figure in box). This implies that most of the conventional tools for assessing oil exposure have limited usefulness for understanding effects on fish at vulnerable early life stages. New cardiac-specific biomarkers that are diagnostic of both oil exposure and cardiovascular injury are needed. In addition, we have begun to address the related issue of smaller but more frequent spills. Large oceangoing vessels are fueled by tens to hundreds of thousands of gallons of refined bunker oil. Although the volume of a spill of bunker oil would most likely be small as compared with that from a crude-oil tanker or a burst wellhead, bunker oil is the concentrated remains of the overall oil-refinement process. Thus, on a mass basis, residual fuel oils have higher concentrations of many uncharacterized chemicals, with novel and lethal forms of toxicity to fish embryos that we and others are only just beginning to study (Hatlen et al., 2010).

At the current pace of research, our ability to predict the effects of oil spills—large and small—on marine ecosystems will advance in only small steps, with punctuated bursts of progress in reaction to major spill events. Research focused on understanding the consequences of oil exposure in our oceans continues to be needed in order to support more scientifically robust decisions about preventing spills and how to assess their impacts when they occur.

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