Biological Effects Modeling

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Role of Models wrt Biological Effects

• Predict trajectory, form and concentration of oil
• Protect human health (public and responder safety; seafood safety)
• Protect organisms (deployment of response assets)
• Predict damages to natural and human use resources (compensatory restoration)
Effects of Oil on Organisms

• Mechanisms of Injury
  – Chemical toxicity
    • Impairment of cellular functions
  – Ecological changes
    • Loss of keystone species
      – Keystone species = plants/animals exert controlling influence on ecosystem (disproportionate to biomass)
        » Their removal leads to negative change in ecosystem
    • Take over of habitats by opportunistic species
  – Loss of habitat/shelter/protection
    • Elimination of ecologically important species
Cellular Level Effects

• Narcosis
• Metabolic disruption
• Genetic changes
Levels of Effects

- Individual
- Population Level
- Ecosystem Level
Potential Long Term Effects
Adapted from Boesch and Rabalais (1987) for spills only

• High Priority:
  – Chronic effects resulting from persistence of med and high Molecular weight aromatic etc cmpd and degradation products in sediments and cold environments
  – Damage to coastal wetlands, reefs and vegetation beds

• Intermediate Priority
  – Physical fouling of aggregations of birds, mammals and fish

• Lower Priority
  – Effects of response itself (e.g., physical disturbance)
  – Reduction of fishery stocks due to mortality of eggs and larvae
Toxicological Terms

• Exposure: contact by swallowing, breathing or direct through skin /eyes etc
  – Acute: intense, short time event (24, 48, 96 hr) result = death
  – Chronic: long time event (weeks, months, years)
  – Sublethal: below concentration that causes death
• Dose: amount of contaminant deposited in/on organism
• Response: biological effect on organism
• Exposure → Dose → Response

• Exposure = Intensity \times Frequency \times Duration
Exposure Mechanisms

• Smothering/Coating
  – Hypothermia
  – Impede movement
  – Clog gills etc
• Ingestion/uptake via gut
• Dermal absorption
• Inhalation (air breathers)
• Form of oil (e.g., droplets or dissolved)

important: Bioavailability
Toxicological Terms

• **LC\textsubscript{50}:** Concentration causing death in 50% population
  – Lower the LC\textsubscript{50} = greater toxicity of cmpd

• **EC\textsubscript{50}:** Conc causing 50% population to have some observable adverse effect

• **NOEC:** Highest conc causing no observable effect on organisms
Factors Affecting Acute ad Chronic Toxicity of Hydrocarbons (HC)

(Oil in the Sea III)

• Concentration of HC and length of exposure
• Persistence and bioavailability of specific HCs
• Ability of organisms to accumulate /metabolize HCs
• Fate of metabolized products
• Interference of specific HCs or metabolites with normal metabolic processes that alter survival and reproduction
• Specific narcotic effects of HCs on nerve transmission
What Affects LC$_{50}$?

• Type of oil component
  – Total petroleum hydrocarbons
  – Specific hydrocarbon (e.g., naphthalene)
  – Component groups (e.g., monoaromatics, polycyclic aromatics (2 ring, 3 ring))
    • SINTEF, SIMAP

• Species and........
  – Life stage: eggs, larvae, juvenile
  – Season: (e.g., metabolic rate)
Toxicity Tests

- Testing regime: static, flow-through, spiked
- Choice of organism and life stage
- Method of preparing test solution
  - Water Accommodated Fraction (WAF)
- Exposure conditions
- Response monitored
- Weathered vs. fresh oil
Toxicity Databases

• e.g., EPA, NOAA
• Issues with sources, validity of data included, comparability of data, translation to actual environmental exposures
• New databases are being created
• Cmpd specific, Components, Oil
Factors Influencing Effects

• Mobility of organism
  – Floater (plankton) (currents)
  – Swimmer (nektan)
    • Strong: avoidance, unless difficult (enclosed water body) (random)
    • Weak
  – Sessile (non-motile)
  – Aquaculture (captive)
Factors Influencing Effects

• UV light (photo-enhanced toxicity)
  – UV magnifies effects b/c transforms cmpd to more toxic form

• Type of hydrocarbon
  – e.g., low MW alkanes, 1 to 3 ring PAHs most acute toxicity..... solubility, toxicity, volatility characteristics
  – DiToro introduced concept of Toxicity Units (TU)
    • Additive toxicity when multiple cmpds present

• Lots of data is available now
  • Issues: length of exposure, mechanism, phase of oil, nominal vs. measured concentrations,
Biological Effects Population-Based Models

• Wildlife (fur and feathers)
  – Certain species have high probability of oiling
    • Behavior: birds to dwell on water surface, dabblers, adults bring oil back to nest (eggs, young)

• Fish

• Invertebrates: shrimp, shellfish

• Marine mammals and reptiles (turtles)
Biological Effects Habitat-Based Models

- **Habitat** | **Recovery Time**
- Saltmarsh | 3-5 years
- Mangroves | 10 years+
- Sandy beach | 1-2 years
- Plankton | Weeks to months
- Coral reefs | Years
- Seagrass beds | Years
Dispersants Add Another Layer of Complexity

- Dispersant
- Solvents
- Bioavailability of oil cmpds
- Dispersants.....Dispersed oil
Basic Biology

• Birth: eggs or live young
• Growth (larvae, juveniles)
• Reproduction (adult)
• Death (predation, injury, disease, age-related)
Biological Growth Models

(a) Exponential (un-restricted) growth
- The growth rate of the population accelerates.

(b) Logistic (restricted) growth
- Carrying capacity of environment
- The rate slows down
- Point of maximum growth
- The rate accelerates
Perturbation (e.g., oil spill)

Recovery

Normal Variability

Spill Impact

(Source: NAS, 2003)
Predator Prey Models
Predator Prey Models
Predator Prey Models

\[ p^0 : \frac{\partial^0 u_0}{\partial t^0} = 0 , \]

\[ p^1 : \frac{\partial^0 u_1}{\partial t^0} = \frac{\partial^2 u_0}{\partial x^2} + \frac{\partial^2 u_0}{\partial y^2} + au_0 - bu_0v_0 , \]

\[ p^2 : \frac{\partial^0 u_2}{\partial t^0} = \frac{\partial^2 u_1}{\partial x^2} + \frac{\partial^2 u_1}{\partial y^2} + au_1 - b(u_1v_0 + u_0v_1) , \]

\[ p^3 : \frac{\partial^0 u_3}{\partial t^0} = \frac{\partial^2 u_2}{\partial x^2} + \frac{\partial^2 u_2}{\partial y^2} + au_2 - b(u_2v_0 + u_1v_1 + u_0v_2) , \]

\[ p^4 : \frac{\partial^0 u_4}{\partial t^0} = \frac{\partial^2 u_3}{\partial x^2} + \frac{\partial^2 u_3}{\partial y^2} + au_3 - b(u_3v_0 + u_2v_1 + u_1v_2 + u_0v_3) , \]

\[ \vdots \]

\[ p^0 : \frac{\partial^0 v_0}{\partial t^0} = 0 , \]

\[ p^1 : \frac{\partial^0 v_1}{\partial t^0} = \frac{\partial^2 v_0}{\partial x^2} + \frac{\partial^2 v_0}{\partial y^2} + bu_0v_0 - cu_0 , \]

\[ p^2 : \frac{\partial^0 v_2}{\partial t^0} = \frac{\partial^2 v_1}{\partial x^2} + \frac{\partial^2 v_1}{\partial y^2} + b(u_1v_0 + u_0v_1) - cv_1 , \]

\[ p^3 : \frac{\partial^0 v_3}{\partial t^0} = \frac{\partial^2 v_2}{\partial x^2} + \frac{\partial^2 v_2}{\partial y^2} + b(u_2v_0 + u_1v_1 + u_0v_2) - cv_2 , \]

\[ p^4 : \frac{\partial^0 v_4}{\partial t^0} = \frac{\partial^2 v_3}{\partial x^2} + \frac{\partial^2 v_3}{\partial y^2} + b(u_3v_0 + u_2v_1 + u_1v_2 + u_0v_3) - cv_3 , \]

\[ \vdots \]
Marine Ecosystem Models
Marine food webs are complex, yet understanding trophic linkages is essential to successful management of fisheries. Our research tests the trophic position output from ecosystem-based models (panel 1) using compound-specific nitrogen isotope analysis of amino acids. The $\delta^{15}N$ values of “source” amino acids in consumers provide a measure of the isotopic composition of the base of the food web whereas “trophic” amino acids are enriched in $^{15}N$ relative to the source amino acids (panel 2). Fractional trophic position is calculated by comparing the isotopic compositions of these amino acids in the tissues of consumers (panel 3). Collection and analysis of samples to determine baseline $\delta^{15}N$ values are not needed.
ing short-term effects from high concentrations of petroleum. Chronic pollution, such as might occur from urban runoff into coastal embayments, may have continuous effects at low exposures. Not all oil pollution is clearly separable into these two categories. For example, exposure and effects are known to occur for long periods after some spills (Vandermeulen and Gordon, 1976; Sanders et al., 1980; Spies, 1987; Teal et al., 1992; Burns et al., 1993), and chronic exposures can be quite high, as is the case near petroleum seeps (Spies et al., 1980; Steurmer et al., 1982). The reader should bear this in mind during the ensuing discussion of the effects of acute and chronic exposure to oil. Additionally, this report generally focuses on the effects to benthic and wildlife populations, which were found to be most at risk from oil (Boesch et al., 1987).

It is within this complex multi-scale, spatial, and temporal environment that we are challenged to detect change and its effect on marine ecosystems. The difficulty is made more pronounced by the tendency of people to make assumptions about the variability in the ecosystem and that variability can obscure large and continuing impacts. Second, the actual impact of the oil may be more complex than we realize if it interacts with spatially or temporally constrained phenomena.

In the closing decades of the twentieth century it was commonly held that the “balance of nature” has been severely altered by human actions. Consequently, much of our public policy was directed toward maintaining the status quo or returning ecosystems to a more pristine condition. While there is little doubt that human activities have had considerable impact in oceanic ecosystems, there has not been an equally widespread appreciation of how ecosystems change without human interference. The occurrence of several well-developed El Niños in the 1980s and 1990s made strong impacts on the public consciousness about longer-term cycles in the oceans. In Alaska, which has a strong resource-based economy, interest in oil spills has waned in the face of other challenges.
Biological Effects Response Modeling
Example: Deborah French-McCay ASA CRRC Project

Guidance for Dispersant Decision Making: Potential for Impacts on Aquatic Biota

Project Objectives
Following any oil spill, there is a theoretical point at which continued response measures no longer benefit the environment or result in quicker recovery periods. The goal of this research is to identify the timing and nature of trade-off decision points in the context of response activities and expected level of resource injury. This project will provide responders with a quick guide allowing them to determine the likely water volume extensively affected by naturally or chemically dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil, with which they can evaluate trade-offs of dispersant use and plan monitoring activities, including natural resource damage assessment.

Research Progress
The direct measurement of water column effects from naturally and chemically dispersed oil is extremely difficult, if not impossible, because of the inherent patchiness of concentrations and water column organisms and the ephemeral nature of subsurface plumes. The spatial and temporal scales of patches with potentially toxic concentrations are typically on the order of meters to kilometers and hours to days. Thus, modeling is the most productive method for estimating water column acute toxic effects from dispersed oil. It also provides estimates of areas swept by floating oil and shoreline oiled, within which wildlife and shoreline habitat injuries would occur.

The Oil Spill Impact Guide (OSIG) will be based on a matrix of 240 model runs using Aplogit Science Associates Spill Impact Model Application Package (SIMP) physical fate, exposure, and toxicity models. Variables will include: oil type, weathering stage, oil volume, environmental conditions (e.g., wind speed, temperature), dispersant use, and toxicity to aquatic biota. The key model results from these runs will be the volume of water where acute toxic effects would occur and the area of water surface oiled (which would impact wildlife and socioeconomic uses). Model results from the matrix will be summarized in both tabular and chart formats so that users of the guide can look up the order of magnitude of likely impact and interpolate between results for intermediate conditions to those runs in the matrix of scenarios. The guide will be provided in three forms: a report describing the approach, assumptions, and results of the modeling and guidance development; a field guide in paper/PDF format; and a calculator in spreadsheet format that will facilitate interpolations.

Partners & Transferability
The research and lessons learned from this project will contribute to national efforts aimed at developing decision-making tools and supporting information related to spill response, and specifically with respect to dispersant use. Results will be presented and explained to the spill response community during a spill response related meeting or conference. The presentation will be part of a focused half-day workshop on dispersant decision-making, where discussion of the results and implications will be solicited. The seminar will include presentation of the Oil Spill Impact Guide and calculator. The OSIG will be freely available on the web. Potential end-users of the guide include NOAA’s Office of Response and Restoration, port authorities, US Department of Defense, US Coast Guard, state resource and response agencies, international trade partners, and private interest groups monitoring coastal environments.

Further Information
The Coastal Response Research Center is a partnership between the National Oceanic and Atmospheric Administration, through the Office of Response and Restoration, and the University of New Hampshire. The goal of the Center is to reduce the consequences of spills and other hazards that threaten coastal environments and communities by conducting research, developing new response and restoration methods, and transferring technology to practitioners. For more information about this, and other, Center-funded projects, see www.crrc.unh.edu/research.
What Don’t We Know

• Rates and uncertainties
• Chronic toxicity
• Genetic effects
• Relationships
• Toxicity Test Simplicity to Complex Environment with Multiple Impacts
  – Arctic changing baseline climate change
• CRRC R&D Needs Reports: Biological Effects