PROTOCOL FOR SEAFOOD RISK ASSESSMENT TO SUPPORT FISHERIES RE-OPENING DECISIONS FOR AQUATIC OIL SPILLS IN CALIFORNIA

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Office of Environmental Health Hazard Assessment

LIST OF CONTRIBUTORS

Authors
Susan A. Klasing, Ph.D.
Robert K. Brodberg, Ph.D.

Primary Reviewers
Margy Gassel, Ph.D.
Lori Lim, Ph.D.

Final Reviewers
Anna Fan, Ph.D.
Lauren Zeise, Ph.D.
Melanie Marty, Ph.D.
Allan Hirsch

Director
George V. Alexeeff, Ph.D.

For further information about this report, contact:

Pesticide and Environmental Toxicology Branch
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

1001 I Street, P.O. Box 4010
Sacramento, California 95812-4010
Telephone: (916) 327-7319

1515 Clay Street, 16th Floor
Oakland, California 94612
Telephone: (510) 622-3170

LIST OF ABBREVIATIONS

AT	averaging time
ASF	age sensitivity factor
BaP	benzo[a]pyrene
BaPE	benzo[a]pyrene equivalent
BTEX	benzene, toluene, ethylbenzene, xylene
CDFW	California Department of Fish and Wildlife (formerly California Department of Fish and Game)
CF	conversion factor
cPAH(s)	carcinogenic polycyclic aromatic hydrocarbon
CR	consumption rate
CSF	cancer slope factor
ED	exposure duration
HI	hazard index
LOC	level of concern
NAS	National Academy of Sciences
OEHHA	Office of Environmental Health Hazard Assessment
OSPR	Office of Spill Prevention and Response
PAH(s)	polycyclic aromatic hydrocarbon
PEF(s)	potency equivalency factor
ppb	parts per billion
RfD	reference dose
RL	risk level
SCAT	Shoreline Cleanup and Assessment Technique
SFEI	San Francisco Estuary Institute
U.S. EPA	U.S. Environmental Protection Agency

PREFACE

The Office of Environmental Health Hazard Assessment (OEHHA), a department within the California Environmental Protection Agency, is responsible for evaluating potential public health risks associated with seafood consumption following aquatic oil spills in California. This task includes making recommendations on fisheries closure and re-opening to the California Department of Fish and Wildlife. OEHHA's authorities to conduct these activities are based on a mandate in the:

- California Fish and Game Code
  - Section 5654 (see below)

This report presents human health toxicity values that OEHHA will use to support these recommendations.

This report was updated in March, 2015, to reflect changes in Fish and Game Code. Specifically, the definition of "oil spill" now includes inland as well as marine waters and is no longer limited to one barrel (42 gallons) of product or more.

5654. (a) (1) Notwithstanding Section 7715 and except as provided in paragraph (2), the director[1], within 24 hours of notification of a spill or discharge, as those terms are defined in subdivision (ad) of Section 8670.3 of the Government Code, where any fishing, including all commercial, recreational, and nonlicensed subsistence fishing, may take place, or where aquaculture operations are taking place, shall close to the take of all fish and shellfish all waters in the vicinity of the spill or discharge or where the spilled or discharged material has spread, or is likely to spread. In determining where a spill or discharge is likely to spread, the director shall consult with the Administrator of the Office of Spill Prevention and Response. At the time of closure, the department[2] shall make all reasonable efforts to notify the public of the closure, including notification to commercial and recreational fishing organizations, and posting of warnings on public piers and other locations where subsistence fishing is known to occur. The department shall coordinate, when possible, with local and regional agencies and organizations to expedite public notification.

(2) Closure pursuant to paragraph (1) is not required if, within 24 hours of notification of a spill or discharge, the Office of Environmental Health Hazard Assessment finds that a public health threat does not or is unlikely to exist.

(b) Within 48 hours of notification of a spill or discharge subject to subdivision (a), the director, in consultation with the Office of Environmental Health Hazard Assessment, shall make an assessment and determine all of the following:

(1) The danger posed to the public from fishing in the area where the spill or discharge occurred or spread, and the danger of consuming fish taken in the area where the spill or discharge occurred or spread.

(2) Whether the areas closed for the take of fish or shellfish should be expanded to prevent any potential take or consumption of any fish or shellfish that may have been contaminated by the spill or discharge.

(3) The likely period for maintaining a closure on the take of fish and shellfish in order to prevent any possible contaminated fish or shellfish from being taken or consumed or other threats to human health.

(c) Within 48 hours after receiving notification of a spill or discharge subject to subdivision (a), or as soon as is feasible, the director, in consultation with the Office of Environmental Health Hazard Assessment, shall assess and determine the potential danger from consuming fish that have been

[1] The Director of the California Department of Fish and Wildlife
[2] The California Department of Fish and Wildlife

contained in a recirculating seawater tank onboard a vessel that may become contaminated by the vessel's movement through an area where the spill or discharge occurred or spread.

(d) If the director finds in his or her assessment pursuant to subdivision (b) that there is no significant risk to the public or to the fisheries, the director may immediately reopen the closed area and waive the testing requirements of subdivisions (e) and (f).

(e) Except under the conditions specified in subdivision (d), after complying with subdivisions (a) and (b), the director, in consultation with the Office of Environmental Health Hazard Assessment, but in no event more than seven days from the notification of the spill or discharge, shall order expedited tests of fish and shellfish that would have been open for take for commercial, recreational, or subsistence purposes in the closed area if not for the closure, to determine the levels of contamination, if any, and whether the fish or shellfish is safe for human consumption.

(f) (1) Within 24 hours of receiving a notification from the Office of Environmental Health Hazard Assessment that no threat to human health exists from the spill or discharge or that no contaminant from the spill or discharge is present that could contaminate fish or shellfish, the director shall reopen the areas closed pursuant to this section. The director may maintain a closure in any remaining portion of the closed area where the Office of Environmental Health Hazard Assessment finds contamination from the spill or discharge persists that may adversely affect human health.

(2) The director, in consultation with the commission, may also maintain a closure in any remaining portion of the closed area where commercial fishing or aquaculture occurs and where the department determines, pursuant to this paragraph, that contamination from the spill or discharge persists that may cause the waste of commercial fish or shellfish as regulated by Section 7701.

(g) To the extent feasible, the director shall consult with representatives of commercial and recreational fishing associations and subsistence fishing communities regarding the extent and duration of a closure, testing protocols, and findings. If a spill or discharge occurs within the lands governed by a Native American tribe or affects waters flowing through tribal lands, or tribal fisheries, the director shall consult with the affected tribal governments.

(h) The director shall seek full reimbursement from the responsible party or parties for the spill or discharge for all reasonable costs incurred by the department in carrying out this section, including, but not limited to, all testing.

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INTRODUCTION

Aquatic oil spills may lead to contamination of local seafood, temporarily rendering it unfit for human consumption. Commercial and recreational fisheries[3] have been closed, at least on a precautionary basis, following numerous oil spills in the United States and other countries. In California, fisheries were closed following the 2007 Cosco Busan and 2009 Dubai Star oil spills in San Francisco Bay; in 2010, a significant portion of the Gulf of Mexico was closed to fishing during the Deepwater Horizon incident (see Gohlke et al., 2011 and Yender et al., 2002, for other examples).

California law (Fish & Game Code §5654) requires that the Office of Environmental Health Hazard Assessment (OEHHA) evaluate the potential human health risks associated with seafood consumption following aquatic oil spills. If OEHHA determines that these activities pose a likely public health threat, or cannot make a determination, then the California Department of Fish and Wildlife (CDFW) will close fisheries in the affected area. If a closure is in effect for more than 48 hours after notification of the spill, expedited testing of seafood is required before fisheries can be re-opened. CDFW and its Office of Spill Prevention and Response (OSPR) estimate the volume of spilled oil and identify the species found in the area and open to take at the time of the spill; OEHHA is responsible for preparing a sampling plan, establishing human health toxicity values, and evaluating the analytical results before making a recommendation to CDFW regarding fisheries re-opening.

The science underlying fishery closure and re-opening decisions is very complex. Physical and chemical characteristics of oil products vary significantly and, along with environmental and biological factors such as wind, water temperature, solar radiation, shoreline type, and species, influence the degree to which seafood may become contaminated (Yender et al., 2002). If a fishery is closed, establishing re-opening criteria is complicated by the large and diverse number of chemical components in petroleum products and the need to calculate or assume factors about the population at risk, such as how much fish people eat relative to how much they weigh, and how long the seafood may remain contaminated. This document outlines the general procedure that will be used to evaluate whether fish and shellfish can be safely consumed following oil spills in California waters.

SEAFOOD RISK ASSESSMENT PROCEDURE

If a fishery is closed for more than 48 hours, OEHHA will conduct an expedited human health risk assessment to determine whether seafood has accumulated unsafe levels of oil spill-related contaminants. As part of that process, concentrations of chemicals of

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[3] Under Fish & Game Code §94, "Fishery" means both of the following:
(a) One or more populations of marine fish or marine plants that may be treated as a unit for purposes of conservation and management and that are identified on the basis of geographical, scientific, technical, recreational, and economic characteristics.
(b) Fishing for, harvesting, or catching the populations described in (a).

concern in seafood are compared to a "level of concern" (LOC), i.e., a concentration that is considered to pose an unacceptable health risk if consumed at the stated rate and for the predicted duration. If contaminants of concern are detected in seafood at concentrations at or above an LOC, continued closure of the affected fishery is warranted. The general procedure for conducting a seafood risk assessment involves the following steps:

- Determine the chemicals of concern and methods of analysis
- Develop toxicity values for chemicals of concern
- Select the species and sites to be sampled and evaluated
- Measure the concentrations of chemicals of concern for each species and site
- Compare chemical concentrations for each species at each site with LOCs established by OEHHA for each chemical of concern

CONTAMINANTS AND SPECIES OF CONCERN FOLLOWING AQUATIC OIL SPILLS

CONTAMINANTS OF CONCERN:

Oil, as defined under California Government Code §8670.3, is "any kind of petroleum, liquid hydrocarbons, or petroleum products or any fraction or residues therefrom, including, but not limited to, crude oil, bunker fuel, gasoline, diesel fuel, aviation fuel, oil sludge, oil refuse, oil mixed with waste, and liquid distillates from unprocessed natural gas." The following description of petroleum and its constituents is summarized from the National Academy of Sciences (NAS, 2003) and Yender et al. (2002).

Petroleum is made up of thousands of compounds, the vast majority of which are hydrocarbons and related compounds. Sulfur, nitrogen, oxygen, and the trace metals nickel, chromium and vanadium, comprise a relatively small percentage of petroleum products. Petroleum hydrocarbons are usually classified by their structure, i.e., saturates, olefins, aromatics (containing one or more benzene rings), and polar compounds. Aromatics are further divided into the more volatile monoaromatics (e.g., benzene, toluene, ethylbenzene, and xylene, or BTEX) and the more environmentally – persistent polycyclic aromatic hydrocarbons (PAHs), which usually have two to six benzene rings. The PAHs formed by petrogenic (petroleum-derived) processes tend to contain higher concentrations of lower molecular weight (two- or three-ringed compounds), with substituted alkyl groups on one or more aromatic carbons (referred to as alkylated homologues of the parent PAH). In petroleum, alkylated homologues are usually found in higher concentrations than the parent compound and tend to increase with the degree of substitution (e.g., C2-naphthalene >C1-naphthalene >parent naphthalene). PAHs formed from the combustion of fossil fuels (pyrogenic PAHs) contain higher concentrations of higher molecular weight (four- to six-ring) PAHs and parent PAHs are usually found in higher concentrations than their alkylated homologues. Following an oil spill, this information is useful in identifying whether any PAHs detected in seafood likely resulted from the spill or a pyrogenic source.

Of the array of constituents found in petroleum products, PAHs are considered to be of greatest potential human health concern with respect to consumption of oiled seafood. Monoaromatic hydrocarbons and hydrogen sulfide, on the other hand, pose an inhalation risk to oil spill responders. While not generally considered acutely toxic to humans, several of the higher molecular weight PAHs are potent carcinogens, most notably benzo[a]pyrene (BaP) (Eisler, 2000). Carcinogenic PAHs are referred to in this document as cPAHs. Lower molecular weight PAHs can cause a variety of non-cancer adverse effects following long-term exposure to high concentrations; however, these are not likely to result from consumption of seafood after an oil spill. Thus, cancer is the effect of greatest concern related to consumption of oiled seafood.

For seafood risk assessment, PAHs are usually analyzed by gas chromatography/mass spectrometry using a Modified EPA Method 8270 (or comparable) for multiple semi-volatile compounds including PAHs and their alkylated homologues. Using the selected ion monitoring (SIM) mode allows for a detection limit in the parts per billion (ppb), wet weight, range (Yender et al., 2002).

Species of Concern Relating to Seafood Consumption:

The determination of species and locations to sample following an oil spill is dependent on knowledge of the environmental fate of oil and its constituents and the specific spill scenario (e.g., volume, product, location, shoreline type, trajectory, and weather). Fish and shellfish accumulate PAHs to considerably varying degrees, depending on seafood species and chemical structure. Finfish, in particular, can often swim away from a spill, unless caged in an aquaculture environment. Bivalve mollusks such as mussels, on the other hand, are not mobile and do not metabolize PAHs as rapidly as do finfish and some other shellfish (Meador et al. 1995; NAS, 2003; Yender et al., 2002). Finfish tend to accumulate lower molecular weight, less toxic, PAHs, whereas mussels accumulate higher molecular weight PAHs that are more likely to be carcinogens. Crustaceans, such as crabs, have an intermediate ability to metabolize PAHs and generally accumulate lower molecular weight PAHs (Eisler, 2000; Meador et al., 1995; Topping et al., 1997).

Following the *Cosco Busan* oil spill in San Francisco Bay, PAH levels in fish and crabs were very low and did not pose a human health concern. PAH concentrations in mussels at some sites, however, were high enough that OEHHA issued a temporary advisory recommending against their consumption (Brodberg et al., 2007). Because of these results, only mussels were targeted for sampling following the *Dubai Star* oil spill – a much smaller spill of the same product in the same general location (Klasing and Brodberg, 2010).

Limited research has provided insight into the bioaccumulation and depuration rates of PAH compounds in mussels. Pruell et al. (1986), for example, measured levels of several PAH compounds in mussels exposed to contaminated sediment in the laboratory at 3, 10, 20, and 40 days during a 40-day exposure period. Of those time periods, most five- and six-ring PAHs were found at the highest concentration in mussels following 20 days of laboratory exposure and had begun to depurate by 40 days. PAH concentrations of greatest human health concern are thus expected to peak in mussels somewhere between 10 and 40 days. Based on the Pruell study, mussel sampling was conducted at approximately weekly intervals following the *Dubai Star* spill. cPAH concentrations were observed to rise quickly before returning toward ambient levels over a two to three week time period in most cases; sampling to evaluate seafood as it related to fisheries closure was thus concluded after three weeks. Subsequent mussel sampling conducted for other purposes confirmed continued PAH depuration.

For seafood risk assessment, the focus of sampling efforts will be to analyze PAHs in aquatic species of concern for an adequate time period to ensure that maximum accumulation has occurred and depuration has begun. Although mussel sampling alone will likely be considered sufficient following relatively small spills, finfish or other shellfish may also be sampled for larger spills. In some cases, this may be necessary to instill public confidence in the safety of the seafood supply.

DEVELOPMENT OF TOXICITY VALUES

As noted, PAHs are the chemicals of human health concern in seafood following oil spills. Other chemicals that might be present during a specific oil spill (e.g., dispersants) will be evaluated in a similar manner on an *ad hoc* basis. LOCs are derived separately and shown below for PAHs that have established cancer risks and/or non-cancer hazards. Because of the variability in toxicity and composition of individual PAHs in PAH mixtures, total PAH levels are not useful for this purpose and are thus not evaluated. Alkylated homologues of PAHs, when detected, are assumed to have the same potency/toxicity as their parent compound and are summed with the parent concentration to yield a single value. For example, concentrations of the C1-C4 alkylated homologues of the cPAHs naphthalene and chrysene are commonly detected in seafood after a spill and are summed with parent naphthalene and chrysene, respectively.

Expression for Calculating the LOC (cancer):

Because of the sensitivity of children to carcinogens and the fact that fish consumption rates are age-dependent, cancer risks may differ based on the population exposed. Cancer risk is also determined, in part, by the length of time oil is expected to remain in the environment and be bioaccumulated in consumed seafood tissues (exposure duration). Exposure duration, in turn, is dependent on the specific factors associated with each spill (e.g., product, volume, location, season, seafood species in the area, etc.). For the purposes of this document, three LOC (cancer) values are derived in order to determine the most sensitive population with respect to consuming seafood following an oil spill. In doing this, OEHHA used age sensitivity factors (ASFs, see discussion below; OEHHA, 2009b), combined with reasonable maximum estimates for age-dependent consumption rates (OEHHA, 2012) and exposure duration (two years, see discussion below) for spills that might occur in California waters.

- LOC (cancer) Option 1: the population with the highest sensitivity to carcinogens during the exposure duration period (third trimester to 1 ¾ years; see Table 3)
- LOC (cancer) Option 2: the population with the highest fish consumption rate during the exposure duration period (two years during the period 16 to <30 years; see Table 1)
- LOC (cancer) Option 3: the population with the highest combination of sensitivity to carcinogens and consumption rate during the exposure duration period (1 to <3 years)

The lowest LOC (cancer) (i.e., most health protective) will be compared to the concentration of the sum of cPAHs in seafood, plus their alkylated homologues, normalized to the concentration of BaP (see discussion in the *Evaluation of Analytical Results with respect to Toxicity Values* section below).

The following general equation is used to set the LOC (cancer), in micrograms per kilogram (μg/kg), or parts per billion (ppb), wet weight, for cPAH compounds potentially found in fish or shellfish:

$$LOC\ (cancer) = \frac{(RL \times AT \times CF_1 \times CF_2)}{(CSF \times ED \times CR \times ASF)^{4}}$$

where *RL* is the risk level; *AT* is the averaging time; CF_1 *and* CF_2 are the unit conversion factors (1000 micrograms/milligram [µg/mg]); 1000 grams/kilogram [g/kg]; *CSF* is the cancer slope factor; *ED* is the exposure duration; *CR* is the consumption rate (the daily amount of fish or shellfish consumed normalized by body weight of the consumer); and ASF is the age sensitivity factor.

For conducting a seafood risk assessment under Fish and Game Code §5654, the following specific factors and assumptions are used in the above equation:

- *Risk Level (RL):* Risk-based criteria are designed to prevent consumers from being exposed to the carcinogenic components of spilled oil in doses that result in cancer risks exceeding an RL of 1×10^{-5} (1 in 100,000). This RL is provided as one example of an acceptable risk level in U.S. EPA's Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories (U.S. EPA, 2000).
- *Averaging Time (AT):* The default value for averaging time is assumed to be 70 years (yr) (the presumed lifespan; OEHHA, 2012).
- *Cancer Slope Factor (CSF, also known as a Cancer Potency Factor):* The CSF used to evaluate the carcinogenic potency of cPAH mixtures potentially found in seafood following an oil spill is the CSF for BaP of 1.7 $(mg/kg\text{-}day)^{-1}$ (OEHHA,

[4] The denominator will vary depending on the specific population assessed and the exposure scenario. The use of multiple CRs, EDs, and ASFs is required for some scenarios. In these cases, exposure scenarios will be summed in the manner shown in the equations for options 1 and 3 below.

2010). The potency of other cPAH compounds is estimated relative to BaP using a Potency Equivalency Factor (PEF) approach (described below).

- *Exposure Duration (ED):* The total ED is assumed to be two years. If necessary, the ED is divided into separate periods that sum to two years in order to accommodate varying consumption rates or ASFs for different population groups.

  Although low levels of total PAHs (dry weight) were found to persist in isolated subsurface interstitial waters and mussels more than 10 years following the Exxon Valdez spill (e.g., Thomas et al., 2007), wet weight BaP equivalent (BaPE) concentrations (see discussion below) in edible portions of seafood, even if initially elevated, are typically very low within days to months after a spill (e.g., Pruell, 1986; Klasing and Brodberg, 2010). Mussels collected for the California Mussel Watch program showed significantly elevated BaPE levels at a San Francisco Bay site that had been oiled less than two months earlier as a result of the 2007 Cosco Busan spill of more than 53,000 gallons of IFO 380 bunker fuel. Mussel Watch sampling at the same location one year later showed that mussel BaPE levels had returned to near ambient levels (data not shown).

  When selecting an ED, there is an implicit assumption that BaPE concentrations will remain at the LOC for the entire ED period. Because of the breakdown of PAHs in the environment and the relatively rapid depuration of PAHs from biota, choosing a multi-year ED is a very conservative assumption – especially for finfish and crustaceans. Additionally, serial sampling of seafood following a spill will ensure that chemicals related to the oil spill, if present, will have peaked and are already declining before a fishery is re-opened. Using an exposure duration of two years to assess cancer risk offers ample protection from lingering pockets of subsurface oil, and will likely result in a lower than estimated cancer risk for most, if not all, seafood in a post-spill environment.

- *Consumption Rate (CR):*

  OEHHA (2012) evaluated numerous fish consumption surveys and provided the following default CRs for specified age groups (Table 1). CRs were derived from the San Francisco Bay Seafood Consumption Study (SFEI, 2000). For conducting a seafood risk assessment under F&G Code §5654, OEHHA will use the high-end CR estimates in order to protect high-level consumers who might be present in an area (e.g., subsistence fishers).

TABLE 1. POINT ESTIMATE VALUES FOR SPORT FISH CONSUMPTION BY AGE GROUP

	Third Trimester	**0 to <2 Years**	**2 to <9 Years**	**2 to <16 Years**	**16 to <30 Years**	**16-70 Years**
Consumption rates in g/day						
Average	-	2.1	7.9	13.3	28.8	28.8
High-End[a]	-	6.6	25.4	42.9	92.4	92.4
Consumption rates normalized by body weight, in g/kg-day						
Average	0.38*	0.18	0.36	0.36	0.38	0.36
High-End[a]	1.22*	0.58	1.16	1.16	1.22	1.16

OEHHA, 2012. OEHHA recommends using the g/kg-day values.
*Maternal consumption rate.

For high-end consumers, the CR (g/day) is based on the 95th percentile avidity-bias corrected lognormal distribution of adult fish consumption. For CRs normalized by body weight, the CR for adults (g/day) was divided by the mean body weight for adults (Table 2) for the age groups 16 to <30 years (75.9 kg) and 16-70 years (80 kg), leading to high-end CRs of 1.22 and 1.16 g/kg-day, respectively. For example, a high-fish-consuming 175 pound, 40-year-old is assumed to eat an average of about 3.3 ounces of seafood per day (equivalent to approximately three 7.5-ounce servings per week). Individuals who weigh more or less than 175 pounds are assumed to eat proportionately more or less, respectively.

As described in OEHHA (2012), the CR for children age 1 to <16 years is assumed to be proportional on a g/kg-body weight basis to the CR for adults 16-70 years (1.16 g/kg-day for a high-end consumer). For example, a high-fish-consuming two-year-old child weighing about 30 pounds is assumed to eat an average of about 0.6 ounces of seafood per day (equivalent to approximately two, 2-ounce servings per week). Children who weigh more or less than 30 pounds are assumed to eat proportionately more or less, respectively. Children in the first year of life are not expected to eat fish. Thus, the CR for children from birth to <2 years is derived by dividing the CR for children 1 to <2 years (1.16 g/kg-day for a high-end consumer) by two to represent an average of the first two years of life (0.58 g/kg-day) (OEHHA, 2012).

TABLE 2. MEAN POINT ESTIMATE FOR BODY WEIGHT (KG)

Age Range (years)	Mean
0 to <2	9.7
2 to <9	21.9
2 to <16	37.0
16 to <30	75.9
16-70	80.0

OEHHA, 2012

Based on this information, CRs used for the three options are:

- LOC (cancer) Option 1:
  - CR_1 (Third trimester, 0.25 years): 1.22 g/kg-day (maternal consumption rate)
  - CR_2 (Birth to 1 ¾ year): 0.5 g/kg-day (no fish consumption for the first year; 1.16 g/kg-day for ¾ year; averaged over a 1.75 year period)
- LOC (cancer) Option 2:
  - A two-year period during the ages 16 to <30 years: 1.22 g/kg-day
- LOC (cancer) Option 3:
  - 1 to <3 years: 1.16 g/kg-day

The consumption rate used in this protocol is based on *total fish and shellfish* consumption reported in the SFEI study. However, when evaluating the risk posed by oil contaminants in seafood, OEHHA will assess each species independently and make the health-protective assumption that each individual species is consumed at the maximum total consumption rate for all species, combined. This will overestimate consumption and thus risk for consumption of individual seafood species. This is especially true for bivalve mollusks, which are typically consumed at a much lower rate. This conservative approach is appropriate for developing a LOC to protect the most sensitive members of the population.

- *Age sensitivity factor (ASF)*: Cancer risk is adjusted for early-in-life exposures as described in OEHHA, 2009a. In short, ASFs are used to estimate the presumed greater lifetime cancer risk resulting from exposures to carcinogens during critical developmental periods. In lieu of chemical-specific data, recommended default ASFs are presented in Table 3; these are used as appropriate for the different time periods associated with the three options below.

TABLE 3. DEFAULT AGE SENSITIVITY FACTORS

Third trimester to Age 2 years	10
Age 2 to age 16 years	3
Age 17 to 70 years	1

- Option 1:
  - Third trimester to 1 ¾ years: 10
- Option 2:
  - A two-year period during the ages 16 to <30 years: 1
- Option 3:
  - *ASF_1* (1 to <2 years): 10
  - ASF_2 (2 to <3 years): 3

CALCULATION OF THE LOC (CANCER):

Applying the specific factors and assumptions for the three options to the equation above results in the following criterion for cPAH cancer risk:

LOC (cancer) Option 1:

$$\frac{(1\text{x}10^{-5})(70\text{ yr})(1000\ \mu\text{g/mg})(1000\text{ g/kg})}{(1.7\ [\text{mg/kg-day}]^{-1}\text{ x }1.22\text{ g/kg-d x }0.25\text{ yr x }10\text{ ASF})+(1.7\ [\text{mg/kg-day}]^{-1}\text{ x }0.5\text{ g/kg-day x }1.75\text{ yr x }10\text{ ASF})}$$

= **34 µg/kg or ppb (wet weight)**

LOC (cancer) Option 2:

$$\frac{(1\text{x}10^{-5})(70\text{ yr})(1000\ \mu\text{g/mg})(1000\text{ g/kg})}{(1.7\ [\text{mg/kg-day}]^{-1}\text{ x }1.22\text{ g/kg-d x }2\text{ yr x }1\text{ ASF})}$$

= **169 µg/kg or ppb (wet weight)**

LOC (cancer) Option 3:

$$\frac{(1\text{x}10^{-5})(70\text{ yr})(1000\ \mu\text{g/mg})(1000\text{ g/kg})}{(1.7\ [\text{mg/kg-day}]^{-1}\text{ x }1.16\text{ g/kg-d x }1\text{ yr x }10\text{ ASF})+(1.7\ [\text{mg/kg-day}]^{-1}\text{ x }1.16\text{ g/kg-day x }1\text{ yr x }3\text{ ASF})}$$

= **27 µg/kg or ppb (wet weight)**

In evaluating the three LOC (cancer) options, option 3 is the most health protective. Thus, 27 µg/kg or ppb (wet weight) is the LOC (cancer) chosen to use in support of fishery re-opening decisions for aquatic oil spills in California.

In summary, no more than one additional cancer case (beyond what would otherwise occur) would be expected in a population of 100,000 of the most sensitive individuals eating seafood at the above described rate containing a total of 27 ppb (wet weight) of cPAHs (normalized to BaP concentrations) every day for 2 years.

EXPRESSION FOR CALCULATING THE LOC (NON-CANCER):

The LOC (non-cancer) will be compared to concentrations of individual PAHs in seafood for which non-cancer hazard estimates are available: acenaphthene, anthracene, fluoranthene, fluorene, naphthalene, pyrene, and their alkylated homologues. The following general equation is used to set the LOC (µg/kg or ppb, wet weight) for non-cancer hazards of PAH compounds potentially found in fish or shellfish:

$$LOC\ (non\text{-}cancer) = (RfD)(CF_1 \times CF_2)/(CR)$$

where *RfD* is the reference dose; *CFs* are the unit conversion factors (1000 µg/mg; 1000 g/kg); and *CR* is the consumption rate.

The following specific factors and assumptions are used in the above equation:

- *Reference Dose (RfD):* RfDs for the non-cancer effects of PAHs were obtained from U.S. EPA's Integrated Risk Information System (IRIS) and are listed in Table 4 below. RfDs are set to protect the sensitive population.

- *Consumption Rate (CR):* The consumption rate is assumed to be 1.22 g/kg-d for seafood risk assessment under Fish and Game Code §5654. This CR was chosen because it is the highest CR for any population group as described in OEHHA (2012). See discussion on page 7.

In addition to comparing individual concentrations of PAHs to the LOC (non-cancer), a Hazard Index (HI) approach can be used to address PAHs with similar critical effects (i.e., a significant adverse impact that occurs at a dose lower than other significant adverse impacts), for example, acenaphthene, fluoranthene, and pyrene. However, concentrations of PAHs in seafood following an oil spill are generally orders of magnitude below LOCs for non-cancer effects; the HI approach will have no impact on fisheries re-opening decisions when this is the case. Exceptionally, an HI approach may be undertaken if levels of PAHs approach the non-cancer LOC.

TABLE 4. REFERENCE DOSES (RfDS) FOR SELECTED PAH COMPOUNDS

Chemical	UF*	RfD**	Critical Effect	Reference
Acenaphthene	3000	$6x10^{-2}$	Hepatotoxicity	U.S. EPA, 1994
Anthracene	3000	$3x10^{-1}$	No observed effects (NOEL)	U.S. EPA, 1993a
Fluoranthene	3000	$4x10^{-2}$	Nephropathy, increased liver weights, hematological alterations, clinical effects	U.S. EPA, 1993b
Fluorene	3000	$4x10^{-2}$	Decreased red blood cells, packed cell volume and hemoglobin	U.S. EPA, 1990
Naphthalene	3000	$2x10^{-2}$	Decreased mean terminal body weight in males	U.S. EPA, 1998
Pyrene	3000	$3x10^{-2}$	Renal tubular pathology, decreased kidney weight	U.S. EPA, 1993c

*UF = uncertainty factor; used in development of the RfD
**RfDs, in mg/kg-d were obtained from U.S. EPA's Integrated Risk Information Service (IRIS) in September, 2013.

CALCULATION OF THE LOC (NON-CANCER):

Using the above equation, the LOCs for non-cancer hazards for individual PAHs were calculated and are shown in Table 5.

TABLE 5. LEVELS OF CONCERN (LOCS) FOR NON-CANCER HAZARDS FOR SELECTED PAH COMPOUNDS

Chemical	LOCs for Non-Cancer Effects (ppb, wet weight)
Acenaphthene	49,200
Anthracene	245,900
Fluoranthene	32,800
Fluorene	32,800
Naphthalene	16,400
Pyrene	24,600

EVALUATION OF ANALYTICAL RESULTS WITH RESPECT TO TOXICITY VALUES

CHARACTERIZING MIXTURES OF CPAHS:

As noted above, the LOC (cancer) is compared to the sum of all cPAHs, normalized to the concentration of BaP. Characterizing mixtures of cPAHs is difficult, in part because CSFs have not been developed for most cPAHs. However, studies have been conducted to estimate the carcinogenic potency of other cPAHs relative to BaP, which is then expressed as a ratio called the potency equivalency factor, or PEF. BaP is considered the index compound and, as such, has a PEF of 1.0, or unity (OEHHA, 2009b). PEFs used for seafood risk assessment were selected based on the quality of the studies, exposure route for which the PEFs were derived and other relevant factors. PEFs for BaP, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, indeno[1,2,3-cd]pyrene, chrysene, dibenz[a,h]anthracene, and naphthalene are listed in Table 6. OEHHA has developed CSFs for dibenz[a,h]anthracene and naphthalene (4.1 and 0.12 $(mg/kg\text{-}day)^{-1}$, respectively). To facilitate calculation of total carcinogenic exposure (see below), these were converted to PEFs by dividing their respective CSFs by the CSF for BaP.

TABLE 6. POTENCY EQUIVALENCY FACTORS (PEFS) FOR CPAH COMPOUNDS

Chemical	PEF	Reference
Benz[a]anthracene	0.1	OEHHA, 2009b
Benzo[a]pyrene	1	OEHHA, 2009b
Benzo[b]fluoranthene	0.62	OEHHA, 2004
Benzo[k]fluoranthene	0.1	OEHHA, 2009b
Chrysene	0.17	OEHHA, 2004
Dibenz[a,h]anthracene	2.4*	OEHHA, 1992
Indeno[1,2,3-cd]pyrene	0.1	OEHHA, 2009b
Naphthalene	0.07*	OEHHA, 2005

*PEFs for dibenz[a,h]anthracene and naphthalene were calculated from their cancer slope factors of 4.1 and 0.12 $(mg/kg\text{-}day)^{-1}$, respectively.

Calculation of cPAH Exposure Equivalents in Seafood:

In order to determine exposure equivalents for cPAHs in seafood, the wet weight concentration of each cPAH is first converted to an equivalent concentration of BaP. To do this, individual cPAHs plus their alkylated homologues are multiplied by their respective PEF to derive a BaPE concentration for that chemical. For example, the BaPE for chrysene in a seafood sample is derived by multiplying the concentration of chrysene + alkylated homologues in that sample by the PEF for chrysene (0.17):

$$[BaPE_{chrysene}] = [\text{Chrysene + alkylated homologues}] \times 0.17$$

Once each cPAH has been converted to a BaPE for that compound, all BaPEs are then summed to determine the total (or ∑) BaPE for that sample.

Evaluation of PAH Concentrations in Seafood Samples Collected from Oil Spill Sites:

If a fisheries closure has been in effect for more than 48 hours, individual or composite samples for each species of concern will be collected from sites impacted by the spill as well as from control (reference) sites. If possible, initial samples will be collected prior to oil stranding the shoreline in order to provide ambient PAH concentrations in seafood from that specific location. An arithmetic mean concentration for each PAH having non-cancer hazards and an arithmetic mean ∑BaPE will be calculated for each species at each site and sampling period. The mean value for PAHs having non-cancer hazards will be compared to the individual PAH LOCs (non-cancer); the mean ∑BaPE value will be compared to the LOC (cancer), which is also referred to as the LOC (∑BaPE).

Results from each sampling period and other information (e.g., oil spill trajectories, Shoreline Cleanup and Assessment Technique [SCAT] data) will be used to guide further sampling efforts and re-opening decisions. When PAH concentrations for each species and site fall below all LOCs (with indications that they are stable or declining), then the fishery will be considered for re-opening.

Seafood cPAH levels attributable to an oil spill are expected to decline over time. However, in some areas, seafood cPAH levels (particularly in mussels) may remain elevated above the LOC as a result of pyrogenic sources of these chemicals in the local environment (e.g., from fossil fuel burning). Pyrogenic versus the petrogenic oil spill sources are generally readily identifiable in the laboratory results. In these situations, fisheries cannot remain closed pursuant to Fish & Game Code §5654. Instead, a seafood consumption advisory will be issued to protect public health, if deemed appropriate.

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