HEALTH AND ENVIRONMENTAL SCIENCES DEPARTMENT

API PUBLICATION NUMBER 4594

JANUARY 1995

A Critical Review of Toxicity Values and an Evaluation of the Persistence of Petroleum Products for Use in Natural Resource Damage Assessments

STEP Strategies for Today's Environmental Partnership

American Petroleum Institute

API PUBL*4594 95 ■ 0732290 0542887 915 ■

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SEPTEMBER 1994

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ACKNOWLEDGMENTS

THE FOLLOWING PEOPLE ARE RECOGNIZED FOR THEIR CONTRIBUTIONS OF TIME AND EXPERTISE DURING THIS STUDY AND IN THE PREPARATION OF THIS REPORT:

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PREFACE

This study addresses the quality and reliability of values used for denoting the acute toxicity of crudes and oil products in aquatic environments. The scientific literature was reviewed and acute toxicity data were selected using strict quality control and quality assurance criteria. The goal of this effort was to compile, analyze, and present an overview of these data by oil product* and taxonomic group. There were a variety of data gaps and problems in comparing conventional LC50 values between studies. Methodological differences between data sets were an important consideration, and special care must be used in predicting biological impacts using these acute toxicity data. Very little published data exists for gasoline, jet fuel, and lube oil product groups. Additionally, acute toxicity data were sparse for the algal taxonomic group. Majority of data were available for the diesel, crude and bunker oil groups. Only oil product toxicity data were utilized in this study and not oil product component data (e.g., naphthalenes, benzene, etc.). Statistical comparisons were performed at a conservative level in order to determine significance. In all cases, the number of data points available in each comparison should be considered when reviewing the statistical results. Additionally, oil products were ranked based upon their median toxicity values, and a relative ranking scale is provided. Relative product toxicity rankings are based on comparisons of median toxicity values and differences shown may or may not be statistically significant.

A limited level of effort was applied for providing a relative persistence scale for oil products released into the environment. It should be emphasized that this analysis has a number of qualifications. This treatment is not compound specific. Crudes and oil products are characterized with a broad range of physiochemical data. An equilibrium-based model was used to estimate relative persistence and differentiate between classes of petroleum products (independent of site- and spill-specific information). The scope of this effort did not allow specific consideration of several important environmental parameters that influence the fate of spilled petroleum products (e.g., wind speed, wave energy, currents, water depth, and habitat).

*Note: The term "oil product(s)" is used in this report to include crude oil and oil products.

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EXECUTIVE SUMMARY

State agencies (e.g., Alaska, Washington and Florida) have initiated tabular methods and formulas for assessing natural resource damages associated with oil product or crude oil spills within their jurisdictions. An important aspect in each of the state initiatives deals with the toxicity and persistence of the spilled hydrocarbons. A central aspect of toxicity evaluations are the LC50 values used to denote acute toxicity of oil products. How reliable are LC50s for ranking oil product toxicity? The quality and reliability of the values used for denoting oil product toxicity are the main topics of this investigation. In addition, a more limited effort was made to compare the relative persistence of oil products released into the environment. Finally, a discussion regarding the relative roles of product toxicity and persistence in predicting biological injury is presented. The results of this effort are presented in 3 chapters as follows:

CHAPTER 1: REVIEW AND RANKING OF TOXICITY VALUES
CHAPTER 2: ANALYSIS AND RANKING OF OIL PRODUCT PERSISTENCE
CHAPTER 3: OIL PRODUCT TOXICITY AND PERSISTENCE: A PERSPECTIVE

Chapter 1: Approximately 8,000 references on the fate and effects of oil products in aquatic systems were screened. The majority of the selected articles were published in the mid to late 1970's. While there was an adequate number of high quality articles, comparability between papers was limited due to variability in test methodologies. In order to determine the relative impact of the methodological differences on LC50 values, key method parameters were selected and added to a computerized database. This allowed investigators to sort on key methodological differences between studies and evaluate if and how laboratory methods impacted the actual LC50 values. The final database contained 748 toxicity values.

The majority of the data was on crude oils (55%) and diesel (31%). Gasoline, jet fuel, and lube oil comprised less than 7% of the total number of toxicity values in the database. Invertebrate data comprised 65.4% of the data in the database. Fish comprised 26.6% of the data, while algae comprised only 8% of the data.

As the basic data on methods and results were analyzed it became apparent that one of the major factors in influencing LC50 values was the presence or absence of free product in the test chambers. Since the presence or absence of free product in the test chamber was found to have the largest impact on reported LC50 values, it was maintained as the major sorting factor throughout this study.

In many cases, methodological procedures had an effect on the resulting LC50 values. Reported LC50 values for the same oil product often differed significantly based on: whether the test chambers were open or closed, if the test was conducted in freshwater or saltwater, and how long oil water solutions were mixed prior to adding test organisms. Finally it was found that LC50s calculated and reported for similar products were very different based on which "concentration" values were used in the final calculations. Some were based on dissolved hydrocarbons from single oil:water ratio test solutions, others were based on multiple ratio test solutions, others were based on tests that used measured concentration data from individual test chambers, and finally some were based on nominal concentrations. The importance of methods was expected and investigators planned from the outset to utilize a database that was designed to allow comparisons of toxicity values developed and based on similar methods.

The database was developed into a computer program referred to as "OILTOX". With the help of this program, the user can find, review, sort, and print out individual LC50 values used in this study. The user is also able to query the database and ask for data on select test species, products, and toxicity test method characteristics. The program also allows the user to link the individual LC50 value to a specific reference. The program does not include every possible LC50 value available since certain quality criteria were used prior to deciding whether data should be included in this study. The database was provided to API as a separate diskette along with a brief users manual.

Median toxicity values were computed for each oil product and taxonomic group once the data were sorted by the absence and presence of free product in the test solutions. In all cases for a given product type, tests conducted with "free product absent" solutions reported lower LC50 values when compared to respective "free product present" LC50 values. Approximately 75% of the data records were for "free product absent" studies while 25% of the data records were for "free product present" studies. Suitable algal data sets were not found for the bunker, gasoline and lube oil groups. Gasoline data (12 values) were available only for the invertebrate "free product absent" data set. Only twelve data values were available for the jet fuel data set.

Median effect concentrations calculated for saltwater and freshwater "free product absent" tests did make a difference in the overall product ranking. It appears that, for invertebrates, the toxicity of crude is higher in freshwater when compared to bunker and diesel, but that under saltwater conditions, bunker and diesel appear much more toxic than crude.

Median effect concentrations calculated for saltwater and freshwater "free product absent" tests with fish did make a difference in the overall ranking. The toxicity of crude appeared higher to fish in freshwater when compared to bunker and diesel, but under saltwater conditions, bunker and diesel appear more toxic than crude.

Median effect concentrations calculated for saltwater and freshwater studies with "free product present" in tests did make a difference in the overall ranking. It appears that the toxicity values of crude to fish, when free product is present, are lower when compared to all other oil product groups. The median acute effect concentrations for crude in freshwater was 1525 mg/l, while across the other oil product groups the median effect concentration ranged from 12.70 mg/l to 560 mg/l. In saltwater the median effect concentration of crude was 1365 mg/l, while across the other product groups the median effect concentration ranged from 55.00 mg/l to 70.50 mg/l.

The present review indicates that the more toxic oil product groups are the diesel and bunker oils. Lube oil shows some very low LC50 values but the data set is very limited and should not be equated to those products with significantly more information. Furthermore, lube oil toxicity can be affected significantly by special additives which can vary considerably based on the manufacturer. The least toxic oil product groups were the crude, jet fuel and gasoline groups. Published data were sparse for the jet fuel, gasoline and lube oil groups.

Based on the interpretational difficulty associated with a single LC50 value, existing data were sorted using a new criteria and notation. This term, the Lethal Loading factor or LL50, expresses the results in what could prove to be a more appropriate context for oil product rankings. In short, the Lethal Loading concept attempts to quantitate the toxicity of a product in terms of the amount of whole product added to water to cause a 50% mortality of test organisms (LL50). Another limiter to the data set is that all LL50 test results must be based on multiple ratio test solutions. This means that test solutions were developed using different oil:water ratios (i.e., loadings), and the resultant water soluble components were not diluted prior to adding organisms. The importance of this selection to ranking oil products becomes evident when the data are sorted and compared using the three resultant criteria, (i.e., the LL50, the LC50-free product present, and the LC50-free product absent). This recognizes that there is no single "concentration" of any one compound in oil product toxicity test solutions, and the LC50 nomenclature is not appropriate for whole oil product toxicity tests.

Regardless of the criteria used to rank toxicity, crude oil was consistently the least toxic product. The value of the LL50, however, was that it demonstrated that the relative amounts of various products that are needed in water to cause a given effect (i.e., 50% mortality) varies considerably. This relative loading factor is transparent with typical LC50 results. The significance of the LL50 factor can be seen in Table ES-1 below.

Table ES-1.
Pairwise comparisons of median effect concentration values by LL50 and the absence of free product, taxon and oil product group. Critical value = 0.05. Bold indicates significance.

Oil Product	Taxon	Median Free Product Absent LC50 (mg/l)	Median LL50 (mg/l)	Ratio LL50 to Free Product Absent	Significance Level
Crude	Invertebrates	6.31	475	(75x)	**(p<0.001)**
Crude	Fish	3.12	3200	(1,026x)	**(p<0.001)**
Diesel	Invertebrates	3.36	9.4	(3x)	**(p<0.002)**
Diesel	Fish	3.50	162.5	(46x)	**(p<0.001)**

The differences in relative toxicity of both crude and diesel are lost when compared via the reported LC50 values. The median values represent many data points and the differences between fish and invertebrates or diesel and crude are shown only as a factor of 2 (6 / 3). The impact of sorting literature test results based on LL50 criteria is quite dramatic. Using conventional comparisons or LC50 values, it would appear that only 2X as much crude is required to have the same impact as diesel on invertebrates. Based on the amount of product actually required in water (the basis of the LL50 calculation), however, over 50X more crude than diesel is required to produce the same lethal impact on invertebrates. This distinction is lost using conventional LC50 values and thus can easily mislead efforts comparing relative toxicities of products. LC50 values developed via this study are basically reporting dissolved component levels which further mask actual product levels needed to create the acute effect. Thus by lumping all the reported literature values together with a single designation (LC50), regardless of methodology, the key *whole product* differences are lost. This in effect masks the relative differences in potential impact between various products. The grams per liter basis of the LL50 calculation helps relate the relative toxicities to a whole product basis and environmental loading levels. The LL50 value should prove to be a more realistic and useful predictor of actual acute impacts in the event of a product spill.

Chapter 2: Besides the toxicity of an oil product, the persistence, or length of exposure of an oil product, is also an important parameter for assessing the effects of an oil spill. The primary processes determining the fate of crude oils and oil products after a spill are spreading, evaporation, emulsification, dispersion, dissolution, reaction, and sedimentation. These processes are influenced by the spill characteristics, environmental conditions, and the nature of the spilled material.

An equilibrium-partitioning model was used for assessing the relative persistence of oil and oil products in aquatic environments. The ultimate fate of the petroleum products is based solely on their physiochemical properties (i.e., molecular weight, solubility, vapor pressure, and octanol/water partition coefficient). Because of the many confounding effects influencing the fate of oil in the sea (e.g., physical conditions involving wind speed and direction, surface currents, water depth, and habitat), a model based on physiochemical data will only provide a relative scale as to which oil and oil products will persist in aquatic environments.

Oil products consist of many individual components; therefore, a broad range of physio-chemical data was used to characterize the individual crude oil or oil product. Two model runs for each substance were conducted to provide both a conservative (worst case) and non-conservative (best case) prediction of product persistence.

A numerical scale was developed for crude oils and oil products based on their persistence in aquatic environments. Persistence is defined as the fraction remaining in the water, soil, and sediment. The relative persistence is estimated at the midpoint of the best case and worst case scenarios. Generally, it can be concluded that gasoline, jet fuel, and fuel oil #2 are relatively nonpersistent in the marine environment. Lube oils are slightly persistent, Bunker C (fuel oil #6) is relatively persistent, and asphaltenes are highly persistent. Crude oils, on average, are considered persistent; however, some components are nonpersistent and others are highly persistent.

Chapter 3: Two operating definitions associated with persistence were developed. The first deals with a toxicity-based connotation (i.e., persistent compounds or products are undesirable because they cause chemical toxicity in terms of biomagnification, bioaccumulation, or chronic toxicity). The second definition deals with habitat impacts associated with residual or persistent components of oil products or crudes.

With these two aspects of persistence in mind, a better understanding of the appropriate use of the term "persistence" can be developed. After the initial phases of a spill, when most of the active dissolution and volatilization has been accomplished, oil spill residuals from heavier products and crudes become less bioavailable with time. Thus, from the toxicity based persistence perspective, these residuals represent less of an acute threat. Thus when estimating an acute toxicity concerns in oil spills, it is not appropriate to utilize a direct proportion for estimating acute injury (i.e., multiplication of two numerical factors one representing acute toxicity and another persistence). However, based on the habitat aspects of the term, the use of injury estimators (numerical values), developed through direct proportions between appropriate persistence and toxicity ratings is somewhat more defensible. If realistic persistence values are utilized along with appropriate chronic toxicity functions, some estimate of long term habitat and chronic injury is possible. This estimate could be viewed as an overall estimator of both a habitat based concerns and, if appropriately developed, also serve as a substitute for the general lack of chronic toxicity considerations in the injury formulas.

Summary: LC50 values were evaluated regarding their usefulness in ranking oil product acute aquatic toxicity. This study clearly demonstrates that methodological differences in conducting oil product toxicity tests have a significant impact on the actual LC50 calculated for an oil product. Using selected criteria and a new notation referred to as the Lethal Loading factor, actual differences in whole product toxicities are shown to be quite pronounced although these differences have in the past been difficult to assess using the generic LC50 designation. LC50 values for the same product class can vary over three orders of magnitude. Rankings based on common methodological groupings demonstrate that, for example, diesel can be 29 times more toxic than crudes using the LL50 grouping but only 1.5 times more toxic using the "free product absent" test solution grouping. This disparity in reported toxicity values demonstrates the need for standardization of the methods used to test, calculate and compare oil product toxicities. The LL50 method is suggested as the more relevant and useful method to assess relative acute values for oil products. The method, based on multiple oil:water ratios, also yields more robust empirical information regarding the true differences that whole oil products have in their ability to cause acute aquatic injuries in the environment.

1.0 CHAPTER 1: REVIEW OF TOXICITY VALUES

1.1 INTRODUCTION

The overall objectives of the toxicity value review were to:

- Review and select toxicological information appropriate for analysis,
- Evaluate toxicity values for selected oil products, and
- Rank oil products based upon their toxicity values.

A database of toxicological information was developed from literature sources. A key feature of the organization of the database was the ability to describe the methodological parameters associated with the development of toxicity values. This is crucial in evaluating LC50 values since methods used in the aquatic testing procedures have a dramatic impact on the results.

The database allowed for a comparison of the key methodological aspects of the toxicity tests reviewed including a determination of which methodological procedures had a significant impact on the results. Areas where data are lacking or where there are low confidence levels in developed toxicity values are also discussed.

Toxicity values and ranges were determined from literature sources for the following major taxonomic groups:

- Fish,
- Invertebrates, and
- Algae.

The major categories of oil products for which toxicity was evaluated include:

- Bunker,
- Crude,
- Diesel,
- Gasoline,
- Jet Fuel, and
- Lube Oil.

A key factor in the analysis of the data was the consideration of the basis upon which each LC50 (lethal concentration needed to cause 50% mortality of test organisms) had been calculated. This is important to toxicity value development since LC50s are the basis of the Department of the Interior (DOI) Type A toxicity factors and probably have some influence on state directions. With complex mixtures such as oil products, LC50 calculations and their results can cause confusion due to the various methods used in calculating the "concentration" term. The results from these types of tests and calculations can be very different for the same oil product.

Our efforts attempted to identify the confounding factors in study design such that toxicity values could be compared in a "method normalized" manner. As the report describes and demonstrates, this approach proved to be an essential step in evaluating and developing the most accurate and representative set of toxicity values for oil products. If oil products are to be ranked from most to least toxic based on literature data, method normalization is important. The normalization had impacts not only on the relative ranking of one product to another but also demonstrated that reported LC50 values on the same product class can vary over three orders of magnitude depending on the methods used in conducting the test. As the basic data on methods and results were analyzed it became apparent that one of the major factors in influencing LC50 values was the presence or absence of free product in the test chambers.

Since the presence or absence of free product in the test chamber was found to have a sizable impact on reported LC50 values, it was maintained as the initial sorting mechanism throughout this Chapter. In addition to assessing the relative importance of other methodological factors (e.g. open or closed test chambers, duration of oil agitation), the methods and conventions used in expressing the results of oil product aquatic toxicity tests were also evaluated.

Traditional LC50 notations for oil products, as used in any number of literature reviews and rankings on oil products (e.g. DOI assessments), do not denote the basis of the LC50 value. Actually, the term LC (lethal concentration) is basically inappropriate for oil products since there is no single concentration of any one compound within toxicity test solutions derived from oil products. The term is most appropriate for a single compound dissolved in a test solution tested at a variety of concentrations allowing a true LC50 to be developed. Furthermore, the term LC50 as applied to oil products is quite misleading to a reviewer of oil product data since one immediately assumes that the number associated with the concept (e.g., an LC50 of 1000 mg/l) represents the dissolved fraction which was the *"effective concentration"*.

In oil product testing, the "concentration" tested is developed by either mixing:

- A single oil to water ratio (i.e., 1 gram/litre) and diluting the resulting solution to create a series of test solutions, or

- A series of oil to water ratios (i.e., 10, 5, 2.5, 1.0, and 0.5 grams/litre of product) whereby the resulting solutions are tested without further dilution.

Although the two methods above are extremely different in approach to test solution development, current notation allows both results to be expressed simply as an LC50 result. In addition to the fact that the actual method of test solution development is totally masked by using the LC50 notation, the term "concentration" can take on many meanings that without a detailed review of the study it is difficult, if not impossible, to interpret the significance of the LC50 result. The lethal "concentration" has been found, for example, to be based on :

- Total hydrocarbons (assessed using a variety of methods all of which vary in their ability to measure different components in the test solutions),

- Aromatic hydrocarbons,

- Nominal hydrocarbons, i.e. concentrations estimated from a single measured or unmeasured stock solution which was then diluted to create multiple test concentrations for exposure, and

- Nominal concentrations estimated from multiple ratio test systems. These concentrations of hydrocarbon are developed by mixing four to five different oil to water ratios in separate test chambers thus creating individual test solutions.

Based on the above sources of confusion when viewing a single LC50 value, existing data was reviewed and sorted using a different notation. This term, the Lethal Loading (LL50), expresses the results in what could prove to be a more useful context for oil product rankings. In short, the Lethal Loading concept attempts to quantitate the toxicity of a product in terms of the amount of whole product added to water to cause a 50% mortality of test organisms

(LL50) (Girling et al. 1992). The LL50 concept is described in detail in the Methods Section and is further applied in the Results and the Discussion and Summary Section of this Chapter.

1.2 METHODOLOGY: ANALYSIS AND RANKING OF TOXICITY VALUES

1.2.1 Literature Search and Collection

1.2.1.1 Searching and Screening of Literature Citations

The objective of the literature search was to use only data collected from the original source. This was a necessity since methodological parameters were needed if the toxicity data were to be appropriately reviewed and evaluated. Therefore, the emphasis was placed on obtaining the primary literature. Review articles and secondary literature were also screened for their value in providing primary literature citations.

A vast quantity of oil product literature covering a wide range of subjects is available. It was necessary to focus on the key literature pertinent to this study. The main criteria used to select pertinent literature were that each reference:

- Was post-1970,
- Reported acute toxicity (mortality) data, and
- Reported numeric data.

1.2.1.2 On-line Databases

Informational databases available from Dialog Information Services, Inc. (Dialog) and the Chemical information Service, Inc. (CIS) were searched via computer for references of interest. Keywords were used to select references. Single keywords and keyword strings were developed for our search using words such as:

- Petroleum,
- Oil,
- Toxic,
- Effect,
- Acute,
- Spill,

- Not coal,
- Fuel,
- Crude,
- Hydrocarbons,
- Bioassay, and
- Others.

1.2.1.2.1 Dialog Information Services

The databases searched via Dialog are provided below including a brief description of each database.

Energy Science and Technology

The Energy Science and Technology database of the U.S. Department of Energy includes environmental topics covered in journal articles, report literature, conference papers, books, etc.

Aquatic Sciences and Fisheries Abstracts

Aquatic Sciences and Fisheries Abstracts provide a comprehensive database of abstracts on the science, technology, and management of marine and freshwater environments provided by the U.S. National Oceanic and Atmospheric Administration (Part 1 - Biological Sciences and Living Resources; Part 2 - Ocean Technology, Policy, and Non-living Resources; Part 3 - Aquatic Pollution and Environmental Quality).

National Technical Information Service (NTIS)

The NTIS database includes government sponsored research, development, and engineering as well as analyses prepared by federal agencies, their contractors, or grantees (and some state and local agencies).

Oceanic Abstracts

Oceanic abstracts are an organized index of technical literature published worldwide on marine related subjects.

Pollution Abstracts

Pollution Abstracts are a leading resource for references to environment-related literature on pollution, pollution sources, and pollution control.

Enviroline

Enviroline is a comprehensive environmental bibliography (fields include: management, technology, planning, law, political science, economics, geology, biology, and chemistry as they relate to environmental issues).

Biosis Previews

Biosis Previews are comprised of the following relevant subfiles: Biological Abstracts, Biological Abstracts/RPM (reports, reviews, meetings), and BioResearch Index.

Compendex Plus

Compendex Plus provides abstract information from the world's significant literature of engineering and technology (civil, energy, environmental, geological, and biological engineering and technology).

Toxline

Toxline is comprised of the following relevant subfiles: Toxicity Bibliography, Toxicology Document and Data Depository File, Federal Research in Progress, and Hazardous Materials Technical Center File.

1.2.1.2.2 Chemical Information Services

The databases searched via CIS including a brief description of each database are provided below. These four databases were accessed using Chemical Abstract Service (CAS) numbers and compound names. These are EPA-sponsored databases and contain numeric data (toxicological, physical/chemical properties) for the compound(s) of interest and include reference citations.

AQUIRE

AQUIRE is the Aquatic Information Retrieval database. AQUIRE contains information on acute, chronic, bioaccumulative, and sublethal effects data from experiments performed on freshwater and saltwater organisms.

OHMTADS

OHMTADS is the Oil and Hazardous Materials/Technical Assistance Data System. OHMTADS provides up to 126 different fields of information including physical, chemical, biological, toxicological, and commercial data on over 1,402 materials, with emphasis on their environmental effects and emergency response.

ISHOW

ISHOW is the Information System for Hazardous Organics in Water. Contains melting point, boiling point, partition coefficient, acid dissociation constant, water solubility, and vapor pressure for more than 5,400 chemical substances.

ENVIROFATE

ENVIROFATE is the Environmental Fate Database. ENVIROFATE includes data on environmental transformation rates and on physical-chemical properties for over 800 substances.

1.2.1.3 Other Sources of Data

Pertinent information was also obtained through searches of the following sources:

ENTRIX, Inc. Resource Libraries

ENTRIX possesses a great deal of literature on topics related to petroleum products and the environment. Journal articles, reports, books, and other references, including API document catalogues and spill conference proceedings, were reviewed for pertinent toxicological data on petroleum products to the aquatic organisms of interest.

University of Delaware Library

The University of Delaware's library system includes a main reference/resource library and a marine studies library. The University has an on-line bibliographic database (DELCAT) which is keyword searchable and accesses all library holdings. In addition, the library also offers on-line reference searching of Biological Abstracts and Aquatic Sciences and Fisheries Abstracts. The University's holdings were searched using keyword strings as described in Section 2.1.2.

Bibliographies

Two bibliographies on the fate and effects of aquatic oil pollution and the biological effects of oil pollution in the marine environment were screened and relevant references were selected for acquisition. These were:

- Seakem. 1987. Bibliography on the Fate and Effects of Aquatic Oil Pollution: A Survey of International Oil Pollution Literature to 1987, and

- Filion-Myklebust, C. and K. Johannessen. 1980. Biological Effects of Oil Pollution in the Marine Environment: A Bibliography. International Council for the Exploration of the Sea (ICES), Marine Environmental Quality Committee, C.M. 1980/E:31.

In addition, reference lists provided in review papers, books, and applicable journal articles on the toxicological effects of oil were screened and selected as appropriate.

1.2.1.4 Selection and Collection of Pertinent Literature

References were selected for acquisition if they contained or were thought to contain numeric information on at least one of the oil product categories of interest, a taxonomic group of interest, and a toxicity endpoint of interest (i.e., acute lethality). References with information relating toxicity and persistence of oil products were also selected.

The wide range of information created limitations in acquiring some references. Nearly all English language journals and books with pertinent information were located at the University of Delaware. References which were difficult to obtain included foreign language material, Ph.D. theses and/or specialized foreign or domestic research group reports, seminars, or conference proceedings.

Upon acquisition of literature, it was necessary for us to review each article, extract the appropriate information and transfer this information into a usable format for management and analysis. With this in mind, a computerized database was developed to manage the specific study result (i.e. LC50) and study methodological data contained in the literature reviewed.

1.2.2 Database Development

A computerized data management system (OILTOX) was developed, programmed and compiled using the ARAGO dBXL-Quicksilver software. The developed database includes functions for LC50 data value sorting (e.g., by methodological parameter, species, product), exporting and reporting.

1.2.2.1 Key Study Parameters

The first step in the development of the database was to identify which methodological parameters most influenced the actual LC50 value developed in a study, the interpretation of results, and the comparability of data between studies. A preliminary review of a subset of references was initiated to help identify key study parameters. Based upon this review and ENTRIX experience, twenty one parameters were selected for entry into the database. The database was designed such that these parameters were entered as individual fields for ease of sorting and study grouping. A sample data entry form displaying the key fields selected is presented in Figure 1-1. The fields selected for inclusion in the database are detailed below.

1.2.2.1.1 Oil Product

Each oil product category was assigned an alphabetic code. Oil products within one category were individually identified by numeric code. For instance, all crude oils were assigned the letter "C", with Kuwait crude as C01, Cook Inlet crude as C02, Southern Louisiana crude as C03, etc. In this way, oils could be evaluated either individually or as a group. The following categories of oil products were developed for toxicity evaluations:

- B=Bunker C Fuel (No. 6 Fuel Oil),
- C=Crude Oil,

API TOXICITY DATABASE ENTRY FORM: 712400

Oil Product: ☐☐☐

B = Bunker C (No. 6)
C = Crude Oil
D = Diesel (No. 2)
G = Gasoline
J = Jet Fuel (No. 1)
K = Kerosene
L = Lube Oil

Study Purpose Endpoint: Primary: ☐☐☐☐☐

ENDPOINTS: (LC50 / LC100 / EC50 / EC100 / NOEC / LOEC)

Persistence Data Reported? (Y=yes/N=no): ☐ If Yes, Qualitative (1) or Quantitative(2)? ☐

Chronic Data Reported? (Y=yes/N=no): ☐

Agitation Duration During Preparation (hrs)?: ☐

(0=0/1=0-1/2=1-12/3=12-24/4=>24/5=not reported)

Test Solution Development: (1=single ratio/2=multiple ratio/3=not reported): ☐

Test Chamber: (1=open/2=closed/3=not reported): ☐

Free Product Present: (Y=present/N=absent/U=unknown): ☐

Test Duration (hours): ☐☐☐

Species Identification Code: ☐☐☐

Age/Life-stage Code: (0=egg/1=larvae/2=juvenile/3=adult): ☐

Study Type (1=lab/2=field(deliberate spill)/3=field(accidental spill): ☐

Exposure Method(ST=static, non-renewed/SR= static, renewed/FT= flow-through): ☐☐

Test Condition (FW=freshwater/SW=saltwater): ☐☐

Effect Concentration (mg/l): Primary: ☐☐☐☐☐☐.☐☐

Measured/Unmeasured/Stock (M=measured/U=unmeasured/S=stock): ☐

Reliability Code (L=low/M=medium/H=high): ☐

L = Study does not meet criteria for reliability (low)
M = Study meets some criteria for reliability (medium)
H = Study meets all criteria for reliability (high)

Peer Reviewed? (Y=yes/N=no/U=unknown): ☐

Reference Number: ☐☐☐ Year Published: ☐☐☐☐

Remarks: ______________________________

____

Additional Notes: (Not for Computer Entry):

____

____

Figure 1-1. Example of the database entry form.

- D=Diesel (No. 2 Fuel Oil),
- G=Gasoline,
- J=Jet Fuel (No. 1 Fuel Oil and Kerosene), and
- L=Lube Oil.

Closely related oils were grouped according to similarity of boiling ranges, percent by volume of certain hydrocarbon types, and other components (carbon number, etc.). Individual oil products identified in this study, by oil product group, are provided below.

Bunker Fuels:

- B01 Bunker "C" (unspecified),
- B02 Venezuelan Bunker C,
- B03 Fuel Oil No. 6,
- B04 Bunker C light,
- B05 Heavy Fuel Oil No. 4, and
- B06 Navy Special (reported to be between fuels nos. 4 and 5).

Crude Oils:

- C01 Kuwait (light) crude,
- C02 Cook Inlet crude,
- C03 Southern Louisiana crude,
- C04 Florida Jay crude,
- C05 Prudhoe Bay crude,
- C06 Venezuelan crude (incl. BCF-22),
- C07 Western sweet blend crude,
- C08 Transmountain crude,
- C09 Norman Wells crude,
- C10 Hibernia crude,
- C11 Amauligak crude,
- C12 Tarsuit crude,
- C13 Lago Medio crude,
- C14 Atkinson crude,
- C15 Bent Horn crude,
- C16 Ramashkin crude,

- C17 West Texas crude,
- C18 Dubai crude,
- C19 Nigerian crude,
- C20 Pembina crude, and
- C21 Alaskan crude (ARCO, unspecified).

Diesel Fuels/Heating Fuels (No. 2):

- D01 Diesel,
- D02 Fuel Oil No. 2,
- D03 Fuel Oil No. 2 - furnace fuel,
- D04 Light diesel fuel,
- D05 Heavy diesel fuel,
- D06 Navy distillate fuel, and
- D07 Marine diesel.

Gasolines:

- G01 Leaded gasoline,
- G02 Unleaded gasoline, and
- G03 Low leaded gasoline.

Kerosene/Jet Fuels (incl. Fuel Oil No. 1):

- J01 Jet fuel - JP8,
- J02 Light Fuel Oil No. 1,
- J03 Jet fuel - JP9, and
- J04 Jet fuel - JP4.

Lubricating Oils:

- L01 Auto lube/lubricating oil (unspecified),
- L02 Heavy marine lube, and
- L03 9250 lube oil.

1.2.2.1.2 Study Purpose Endpoint

We anticipated that study endpoints would vary from study to study. Some studies report thresholds that kill 100% of test organisms (LC100) rather than 50% (LC50) while others use immobility rather than mortality as an endpoint. This field was created to select and group endpoint-specific values to ensure legitimate comparisons of data. *Acute toxicity values were the focus of this study.*

1.2.2.1.3 Test Solution Development: Agitation Duration During Preparation

The toxicity of oil products is generally attributed to the portion that dissolves into the water column, in other words, the concentration of dissolved hydrocarbons that results from an oil/water mixture. The amount of dissolved hydrocarbon present in a test solution is somewhat dependent on the amount of time an oil/water mixture is agitated prior to organism exposure. In some cases, oil is added directly to the water with little, if any, agitation. In others, an oil/water solution is mixed for 20 hours, allowed to settle, and the water soluble fraction (WSF) drawn from the bottom of the vessel (containing no neat product, only dissolved hydrocarbons) is used as a toxicant stock solution. The amount of dissolved hydrocarbon to which test organisms are actually exposed could differ significantly in these two situations. Each design produces different test solutions although equal amounts of neat product were used. It was therefore prudent to have the capability to identify agitation duration and subsequently evaluate studies based on this factor.

1.2.2.1.4 Test Solution Development: Free Product Present or Absent

A significant number of oil product tests actually have free product present in the test chambers. Many studies mix oil and water and then decant the water soluble component (after some period of settling) and use only the oil free phase in the tests. In order to assess the importance or impact of this factor on toxicity values, this category was developed in the database. As mentioned earlier, the presence or absence of free product was utilized as the initial sorting mechanism in the analysis of toxicity values.

1.2.2.1.5 Test Solution Development: Analytically Measured or Unmeasured Exposures

Measured/Unmeasured/Stock refers to whether total dissolved hydrocarbons were measured in the test solutions. Endpoint values (LC50s) can be calculated in a variety of ways including:

1) based on actual measured dissolved hydrocarbon concentrations in test chambers (measured), 2) based on nominal neat product levels added to test chambers (unmeasured), or 3) based on measured dissolved hydrocarbon concentrations in a single stock solution and extrapolating this measurement to test chamber concentrations (stock). The final result of the toxicity test will depend on which "concentration measurement" is used in the LC50 calculation. Since oil product tests have been known to have results expressed using all of the above concentration expressions, this parameter requires evaluation regarding its impact on toxicity values.

Even when test solutions are measured regarding the hydrocarbon levels or types, the information is of little value since the measurement is a generic type of analytical term i.e. "total hydrocarbon" or "total organic carbon". Unlike a specific compound LC50 where the concentration of a component can be related to an effect, total hydrocarbon measurements encompass from a few to over 100 components, all of which have varying individual toxicities. This aspect combined with the variability in other methodological procedures gives one cause to question the utility of even measured values in ranking and comparing oil product toxicity values.

1.2.2.1.6 Test Chamber

Due to the volatile nature of many hydrocarbons, it was necessary to try and differentiate between those studies using open test chambers versus those using closed test chambers. Those studies utilizing open test chambers will experience a loss of toxicant during the course of experimentation. Open chamber test systems, using volatile products, could result in higher LC50 values than equivalent tests using closed chambers.

1.2.2.1.7 Test Solution Development: Single Ratio and Multiple Ratio Test Designs

As noted in the above discussions, a number factors can influence the actual concentrations of hydrocarbons found in solutions produced for aquatic toxicity testing. Aside from agitation duration, open or closed test chambers, and the presence or absence of free product, the impact of "single" versus "multiple" ratio test solution development on product toxicity values was evaluated. Hydrocarbon concentrations in the test solutions will vary according to whether the test solutions were derived from a single ratio (oil:water) mix or from a multiple ratio (oil:water) mix (Figure 1-2). Oil:water ratios will have a significant impact on the toxicity results since the ratio of oil to water impacts both the quantitative, and to an extent,

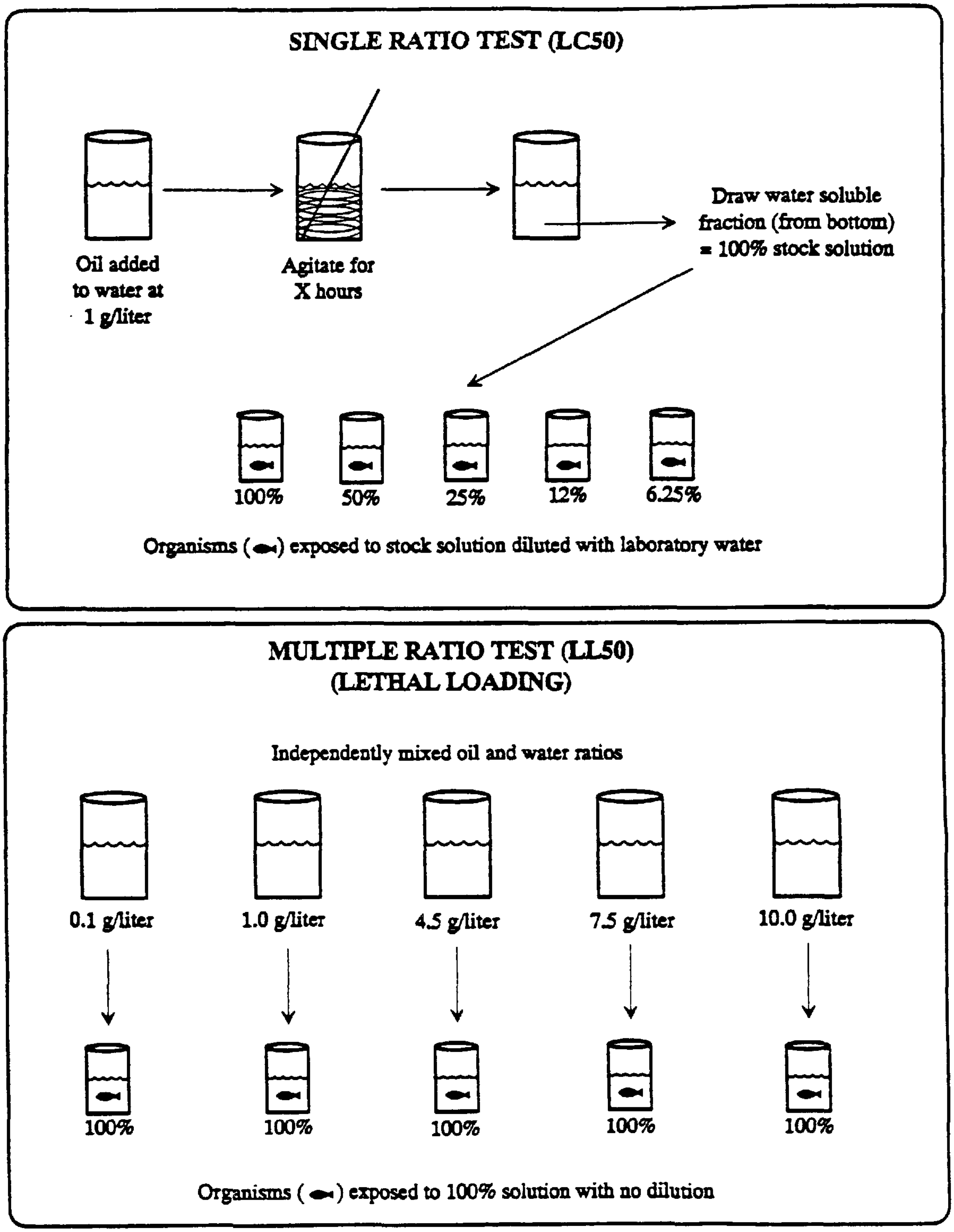

Figure 1-2. Single ratio test versus multiple ratio test

the qualitative characteristics of the test solution being developed for testing (Shiu, et al, 1988). Oil:water ratios need critical assessment as to their role in influencing toxicity value development.

Studies using multiple versus single ratio tests were identified during the data review. Multiple and single ratio test systems are presented in Figure 1-2. The relative amounts of individual hydrocarbon components found in stock solutions using the single ratio design is limited due to the single oil to water mixture. When the single stock solution is diluted to create toxicity test solutions, the ratio of components remains the same and only the amount or concentration of dissolved components change. Toxicity tests conducted with test solutions derived from single oil:water ratio mixtures would be expected to show predictable dose response relationships since solution strength is primarily dependent on levels of dilution.

This is contrasted to the multiple ratio study design. When multiple oil:water test ratios are developed, a number of significant changes occur. First the component concentrations and ratios vary based on the oil:water mixture used. Given a specific percentage by weight of water soluble materials for any given oil product, the absolute amounts of water soluble materials in a 10 g/l versus a 1 g/l oil:water test mixtures will be quite different. One might expect that the total amount of potentially soluble hydrocarbon levels can be estimated by assuming that all soluble materials have an equal tendency to dissolve in water regardless of the oil:water ratio. This is not necessarily the case since surface area considerations become a factor when large amounts of oil are added to water. The multiple ratio approach provides the researcher with an empirical estimate of the importance of oil:water ratios in determining toxicity. Results derived from a multiple ratio experiment provide a more useful predictive tool when applied to real world situations. Since oil:water ratios are site an spill specific, a single ratio test provides a result of questionable utility in predicting oil product impact during a spill.

1.2.2.1.8 Reliability Code

Data extracted from references were evaluated for quality by analyzing the methodologies through which they were generated. Data were assigned to a category of high, medium, or low quality as described below:

Data assigned to the "high" quality category met most or all of the following criteria for quality:

a. the test methodology was judged satisfactory, with appropriate test design and acceptable procedures including:

- controls utilized,
- acceptable survival in controls (80% minimum),
- minimum of 10 organisms per treatment,
- evidence of test organism acclimation,
- minimum of 5 toxicant concentrations used, and
- evidence of quality assurance.

b. the test material was well characterized and dissolved chemical measurements were made in test chambers.

If a paper exhibited a deficiency in one of the above areas, it was not automatically placed in the next lower quality category. Rather, the deficiency was weighed against the remaining strengths of the paper and judged as to its significance to overall data results. If the majority of the remaining information presented in the paper was superior, a single deficiency in the above criteria did not warrant a lower quality ranking.

Data assigned to the "medium" quality category met some of the high quality criteria, but lacked 2 or more items listed in a) above. Data were also assigned to the "medium" quality category if criteria b) above was not satisfied.

Data assigned to the "low" quality category did not meet the criteria for quality. A low quality study may be characterized as not meeting any of the criteria above and may not have sufficient methodological detail to judge the quality of experimental design.

1.2.2.2 Data Entry

The key study parameter data as identified in Section 1.2.2.1 was extracted from each article and transcribed onto the database entry form. Every individual toxicity value within a reference was recorded on a separate data form, i.e., became an individual record. Information on these forms was then entered into the database using the designed database software.

1.2.2.3 Data QA/QC

Data QA/QC is essential in protecting the integrity of the database. A strict QA/QC transmittal sequence was developed to monitor data from initial transcription to final storage into the database. Data transmittal forms (Figure 1-3) accompanied completed data forms as they proceeded through verification and validation checks. The data transmittal form was used to track data to ascertain the immediate status of all data.

The major steps of the data transmittal process were as follows:

- Reference data were transcribed onto a database entry form,
- The date completed and transcriber's initials were entered onto the transmittal form,
- Completed forms were submitted to the data entry personnel who would then enter the data into the computer,
- The data entry personnel would then produce a QA/QC verification table to be checked against the original hard copies,
- Any necessary revisions to the database were made and re-checked against the hard copies, and
- Backup copies of the database were made.

Completion of each of the above transmittal steps were recorded on the data transmittal form by date completed and initialized.

1.2.3 Analysis and Ranking of Toxicity Values

1.2.3.1 Statistical Analyses

Statistical inference testing of effect concentration (LC50 data) values presented in this Chapter was performed using nonparametric test statistics. The use of nonparametric statistics was more appropriate than parametric statistics since the effect concentration data by major taxonomic group for free product presence and absence were not normally distributed as indicated in Figures 1-4 and 1-5. Also, calculated LC50 values for free product present and free product absent data have differing variances. These factors make analysis using nonparametric statistics (i.e., median values) more appropriate than using parametric statistics (i.e., mean values).

DATA TRANSMITTAL FORM — **AMERICAN PETROLEUM INSTITUTE TOXICITY VALUE DATABASE**

BATCH NUMBER: ____________ # OF PAGES SUBMITTED: ____________

STUDY TYPE(S) INCLUDED: ______________________________

FILE NAME:(IF COMPUTERIZED): ______________________________

	DATE COMPLETED:	INITIALS:
PROJECT MANAGER/TECHNICIAN STAFF:	________	____
DATA FORM CHECKED:	________	____
TECHNICIAN STAFF/COMPUTER APP. TECH:	________	____
DATA KEYPUNCHED :	________	____
BACKUPS COPIES MADE:	________	____
DATA FILE REFORMATTED:	________	____
COMPUTER APP. TECH/TECHNICIAN STAFF:	________	____
QA/QC PROCEDURES COMPLETED:	________	____
TECHNICIAN STAFF/COMPUTER APP. TECH:	________	____
DATA FILES UPDATED:	________	____
BACKUP COPIES MADE:	________	____
COMPUTER APP. TECH/PROJECT MANAGER:	________	____
DATA LOADED INTO RAW DATABASE:	________	____
QA/QC TABLES PRODUCED:	________	____
PROJECT MANAGER/COMPUTER APP. TECH:	________	____
QA/QC TABLES VERIFIED:	________	____
DATA FILES UPDATED:	________	____
BACKUP COPIES MADE:	________	____
COMPUTER APP. TECH/PROJECT MANAGER:	________	____
DATA FILES LOADED INTO FINAL DATABASE:	________	____
BACKUP COPIES MADE:	________	____

NOTES: ______________________________

Figure 1-3. Example data transmittal form.

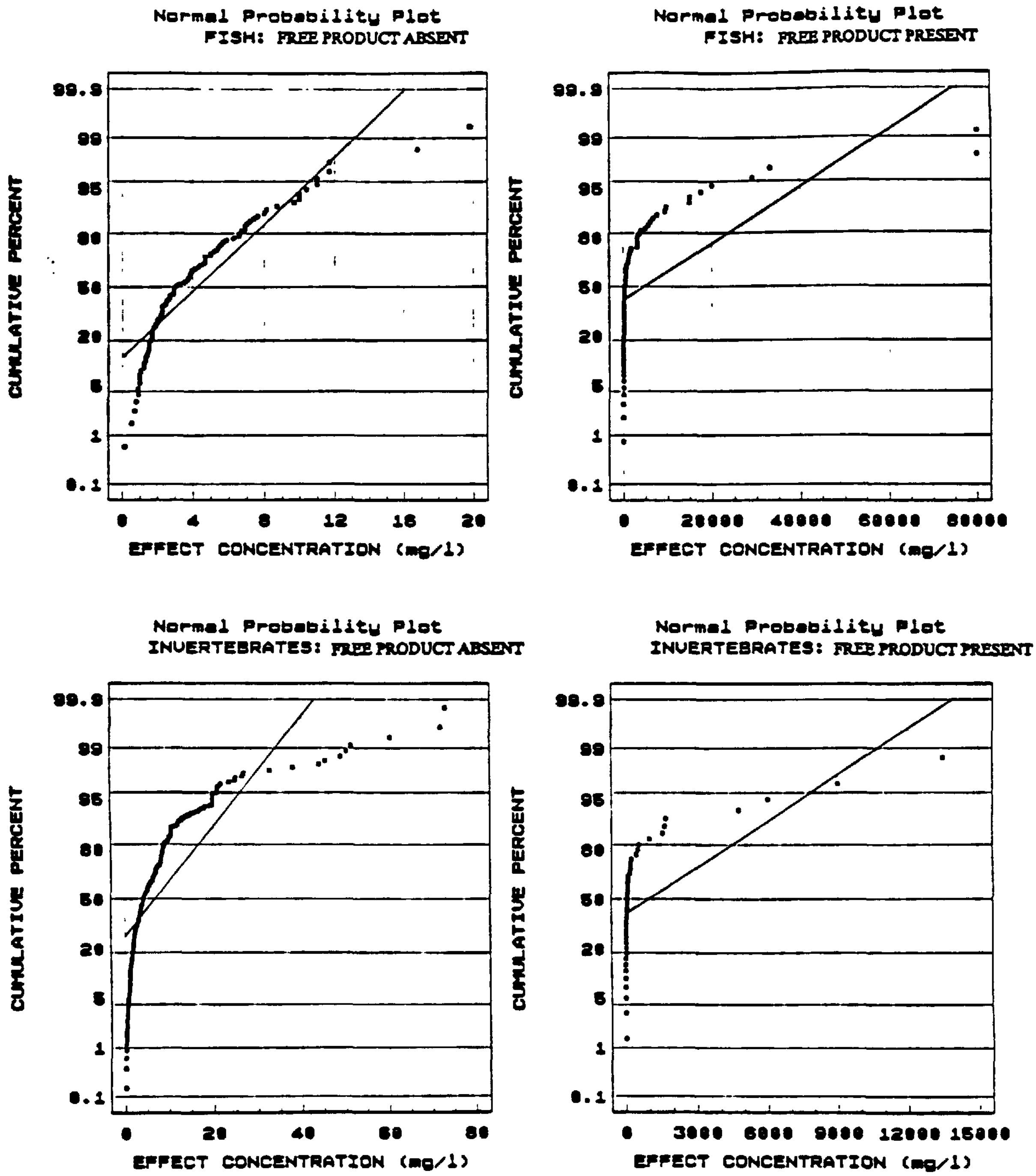

Figure 1-4. Normal probability plots of effect concentration (mg/l) values by taxonomic group.

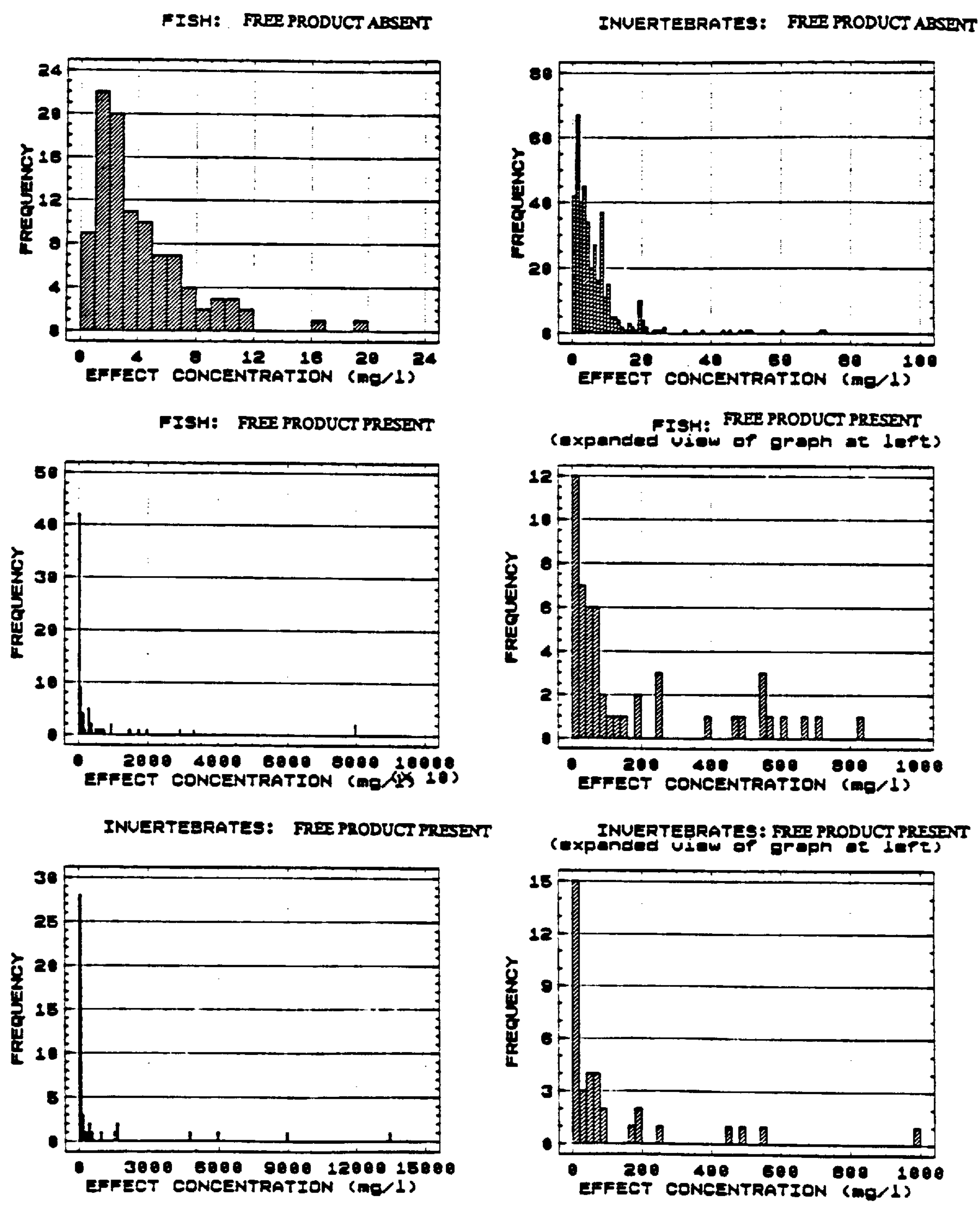

Figure 1-5. Frequency histograms of LC50 values by taxonomic group.

The Mann Whitney test (Zar, 1974) was used to determine whether two independent samples (e.g. bunker versus crude) had the same median. The level of significance used for all analyses refer to significance at the five percent level (alpha=0.05, 95% confidence level).

The Kruskal-Wallis test (Snedecor and Cochran, 1979) was used when more than two classes were compared in a pairwise manner. If the Kruskal-Wallis test produced a significant difference, the Mann-Whitney test was used for all pairs in the comparison with critical values being adjusted by Bonferroni's method (Johnson and Wichern, 1982). Bonferroni's method allows for examination of all possible pairwise combinations without increasing the probability of making a Type I error. A Type I error occurs when a significant difference is found but does not actually exist. The use of Bonferroni's method provided a conservative estimate of significance. In all cases the significance levels are presented as two-tailed p-values. Adjusted statistical critical levels based on Bonferroni's method are presented in Table 1-1.

Table 1-1. Adjusted Critical Values based on Bonferroni's Method (0.05/# of comparisons).

# of Classes	# of Comparisons	Critical Value
2	1	.050
3	3	.017
4	6	.008
5	10	.005
n	[n(n-1)]/2	

Notched box-and-whisker plots are provided for several comparisons tested in this report. *In some cases, more than one plot is provided for the same data set.* In these cases, the additional plots allow an expanded view of the data for easier comparison of the data. Box-and-whisker plots are useful in comparing parallel batches of data. The plot divides the data into four areas of equal frequency. The box encloses the middle 50 percent. The median is drawn as a horizontal line inside of the box. The width of the box is proportional to the square root of the number of observations in the group. A notch is added to each box at the median. The length of the notch represents an approximate 95 percent confidence interval for the median. Comparisons of median values can be made at the 95 percent confidence level by examining whether two notches overlap. If two notches overlap, the medians are not significantly different. An example box-and-whisker plot is presented in Figure 1-6. The letters along the X axis refer to product types (B-Bunker, C-Crude, D-Diesel, J-Jet Fuel, L-Lube Oil).

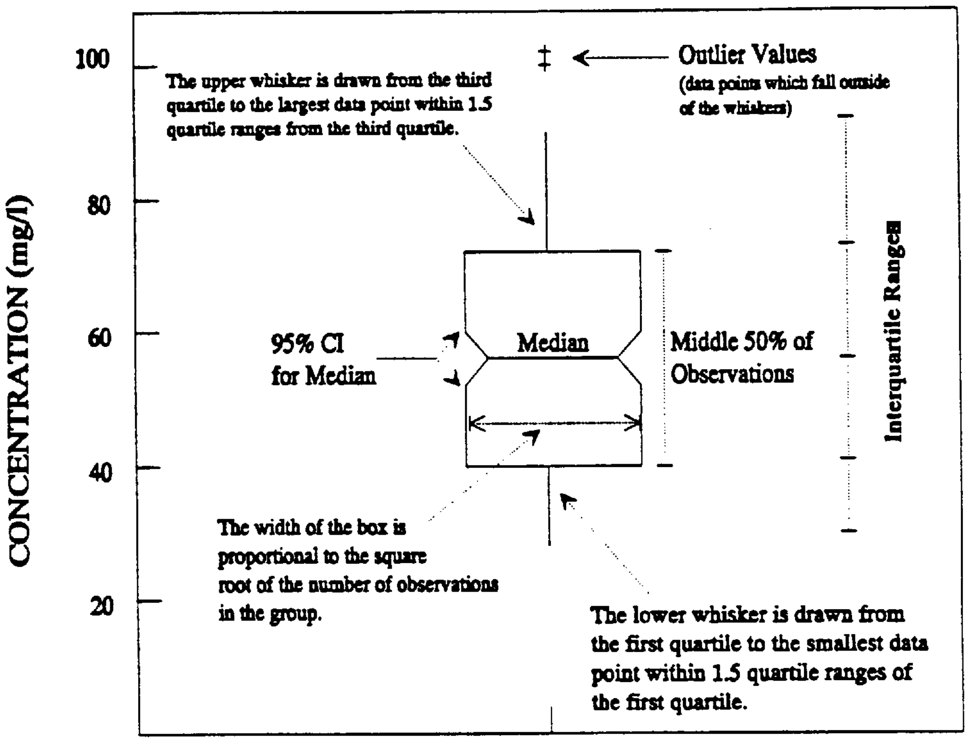

Figure 1-6. Example of a box-and-whisker plot.

All statistics used in the analysis of toxicity values were generated using the Statgraphics Statistical Software, Version 5.0.

1.2.3.2 Approach

1.2.3.2.1 Oil Product Toxicity Values

A main goal of our analysis was to normalize the data set in order to produce the most useful and meaningful toxicity values possible. The first step of our normalization was to exclude, from the analysis, data records classified as "low reliability" (Appendix Table C-1). Data classified as "low reliability" were considered to have insufficient methodological detail to judge the quality of the study or were judged to be deficient in study design or procedures.

As noted earlier, with complex mixtures such as oil products, LC50 data are problematic because the meaning of the term "concentration" can vary extensively depending upon the methodological procedures used. A key methodological parameter which is important in the calculation of a toxicity value for a given oil product is the presence or absence of free product during the study. A preliminary analysis of the free product present data versus free product absent data, by two major taxon groups, indicated that free product presence was significant in calculations of toxicity values (Table 1-2).

In all cases, median effect concentrations for free product present studies were significantly higher when compared to the median effect concentrations of studies with free product absent. With this in mind, free product presence and absence data were analyzed separately. The majority (99.2%) of free product absent LC50 values were derived from single ratio tests while the majority (80%) of free product present LC50 values were derived from multiple ratio tests.

Table 1-2. Pairwise comparisons of median effect concentration values by the presence of free product, taxon and oil product group. Critical value = 0.05. Bold indicates significance.

Oil Product	Taxon	FPA Median LC50 Free Product Absent (mg/l)	FPP Median (LC50) Free Product Present (mg/l)	Ratio of FPP to FPA	Significance Level
Bunker	Invertebrates	3.00	55.85	(19x)	**(p=0.022)**
Bunker	Fish	3.60	55.70	(15x)	**(p<0.004)**
Crude	Invertebrates	6.31	225.00	(36x)	**(p<0.001)**
Crude	Fish	3.12	1365.00	(438x)	**(p<0.001)**
Diesel	Invertebrates	3.36	9.40	(3x)	**(p<0.002)**
Diesel	Fish	3.50	45.10	(13x)	**(p<0.001)**
Lube Oil	Invertebrates	1.58	55.50	(35x)	**(p=0.032)**
Lube Oil	Fish	2.25	68.00	(30x)	**(p=0.0497)**

Since study methods can have substantial impacts on calculated toxicity values, the effects of selected methodological procedures on calculated toxicity values were examined by oil product group, major taxonomic group, and free product presence or absence. The methodological procedures examined include:

- Agitation During Preparation,
- Test Solution Development,
- Test Chamber,
- Test Duration,
- Lifestage Tested,
- Exposure Method
- Test Condition, and
- Measured/Stock/Unmeasured.

The above methodological procedures are described in Section 1.2.2.1. The lack of algal toxicity data precluded an in-depth analysis of the effect of methodological procedures on calculated toxicity values for this taxonomic group.

Median toxicity values were calculated by oil product group, specific oil product, free product presence/absence, and taxonomic group. Methodological parameters found to have a significant effect on toxicity values are described. Toxicity values were calculated for each lifestage of each taxonomic group by oil product where data were available. *When interpreting the effect concentration data, note that the higher the effect concentration value, the lower the toxicity of the product, and the lower the effect concentration value, the higher the toxicity of the product.*

1.2.3.2.2 Ranking of Oil Product Toxicity

A relative ranking of oil product toxicity was developed as part of this study. The major oil product groups (i.e. bunker, crude, diesel, gasoline, jet fuel and lube oil) were ranked, relative to one another, based upon calculated median effect concentrations. Rankings were also developed for each taxonomic group for both free product absent and free product present data. Rankings were also developed for each life stage by taxonomic group. An oil product group which had no data for a particular ranking was excluded from the ranking. Any methodological procedures which may affect the rankings are presented.

Pairwise statistical comparisons of the median effect concentration values of the oil products in each major ranking are presented.

For each ranking presented, an approximate scale is provided for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product. Each scale value was derived by dividing the median value of the least toxic group by the median value of the oil product group being compared. The result of the division was rounded to the nearest integer. ***Since the oil product rankings are derived from the median effect concentration values, rankings with different scale values may or may not be significantly different.*** Tables are provided where statistical differences can be ascertained.

A summary of the types of toxicity value comparisons and rankings performed is presented schematically in Figure 1-7. The figure also provides guidance as to where the toxicity value or ranking results are found within the report.

1.2.3.2.3 The LL50 Concept

Based on all the factors that can influence and confound LC50 values when applied to oil product toxicity data, it is apparent that a different method for expressing toxicity data derived from whole product aquatic tests is needed. Although hydrocarbon toxicity can be investigated using LC50 principles, for the reasons described above, complex solutions from whole product

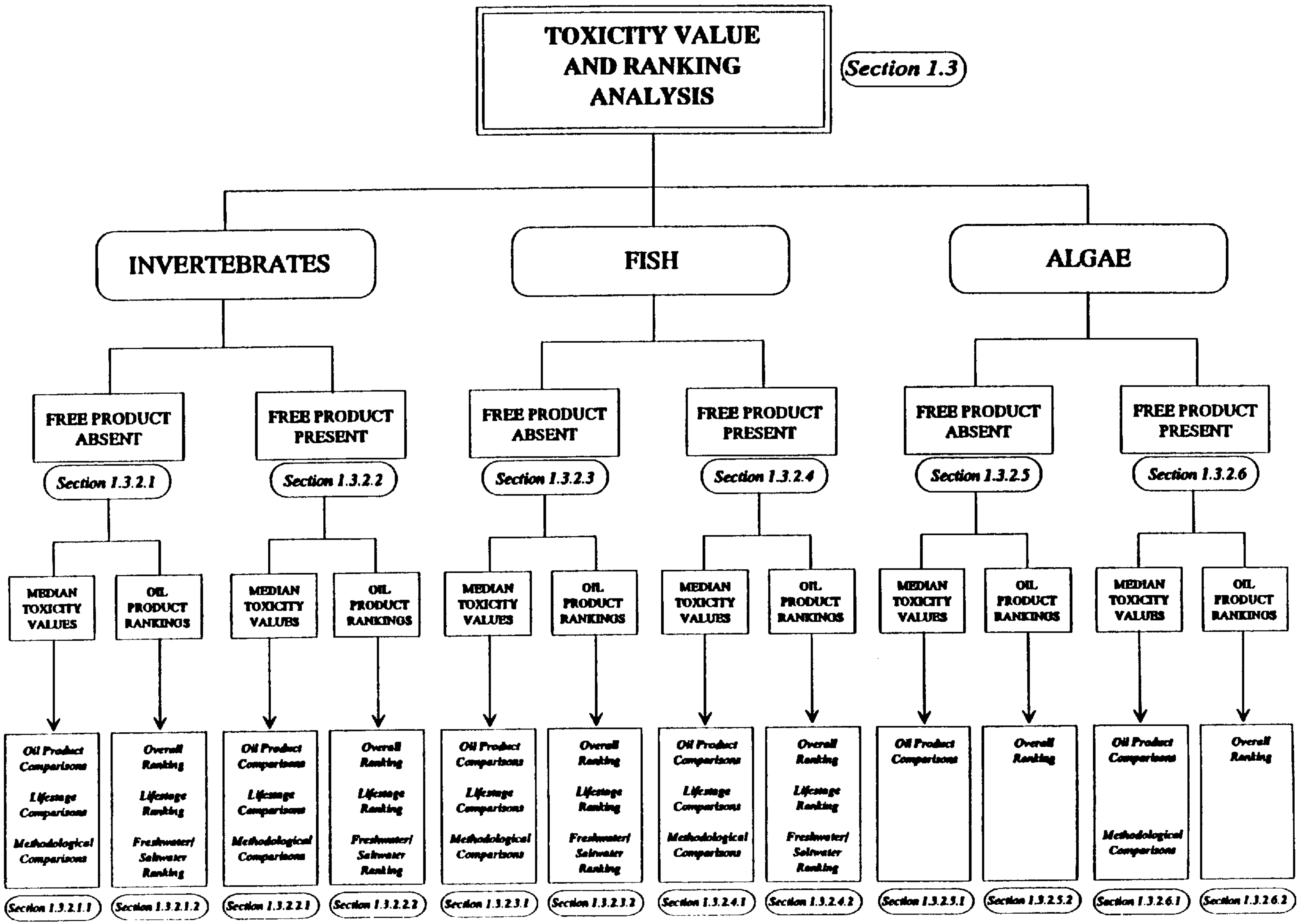

Figure 1-7. Diagram of the toxicity value and ranking analysis scheme.

toxicity tests do not lend themselves well to the LC50 notation. There is no straightforward way to compare relative product toxicity when results are expressed as a function of selected dissolved components. Since API is interested in developing accurate rankings of acute toxicity on oil products, any method which helps place products on a normalized scale should be assessed.

The lethal loading concept (LL50) was developed (Girling, et al, 1992) as a method of expressing actual whole oil product toxicity to aquatic organisms. The method relies on selected toxicity data sets which use whole oil products at multiple oil:water ratios as the method for test solution development. A further restriction inherent in the expression is that oil to water solutions are not diluted further and that all test solutions are independently created using a series of oil:water ratios. The method does not require any measured concentrations in order to be used. Observed mortality based on various oil:water mixtures (as presented in Figure 1-2) is the basis of the calculation resulting in a " lethal loading" level which causes an effect.

The LL50 concept has been developed further through numerous discussions within CONCAWE's Ecology group as the latter assessed the industry needs regarding oil product ecotoxicity data. As the group reviewed oil product data and tried to compare relative toxicities of products, the weakness of the LC50 term as a tool for comparing oil products became apparent (CONCAWE, 1988). Methodological differences between toxicity tests were abundant in the literature although the importance or impacts of the varying methods on toxicity values were not evaluated by CONCAWE.

The database developed in this study allowed for sorting of information by multiple versus single ratio test solution procedure. Since the LL50 approach does not rely on analytical measurements, the comparisons do not suffer from the uncertainties associated with comparing a host of analytical methods within the literature. An LL50 data set was created by selecting literature test results which satisfied the LL50 criteria (i.e., multiple:ration solution and based no dilution). This subset of LL50 values were then used to calculate median toxicity values and rank oil products by major taxon and oil product group. The product ranking results from the LL50 approach were compared to median toxicity values and rankings based on the "free product present" and "free product absent" data sets.

1.3 RESULTS: ANALYSIS AND RANKING OF TOXICITY VALUES

1.3.1 Literature Search and Collection of Toxicity Data

Several databases, bibliographies, and the ENTRIX library were searched for toxicity values. Database searches utilizing the Dialog Information Service yielded approximately 325 relevant references. Titles were screened and abstracts were obtained for approximately 200 of these references. Upon screening the abstracts for content and availability, 115 references were selected for acquisition.

Database searches utilizing the Chemical Information System were not very productive. References selected in OHMTADS were pre-1970 and thus did not meet our search requirements. The search of the AQUIRE, ENVIROFATE and ISHOW databases produced no references meeting our selection criteria.

Through database searches, combined with bibliographies and ENTRIX library resources, approximately 8,000 references on the fate and effects of oil products in aquatic systems were screened. Of these, approximately 250 were selected for acquisition and 140 were actually obtained and reviewed. Of the 140 articles reviewed (Appendix A), 46 references reported data in a usable format for entry into the toxicity database, representing 748 individual data records. The data presented in this report are representative of the 140 articles reviewed.

1.3.1.1 Characterization of Petroleum Toxicity Literature

It became evident through screening the literature references on oil products, that only a small portion (0.6%) of the references were useful to our study. Much of the literature was secondary in nature, discussing laboratory or field observations without generating new data. Many times hydrocarbon toxicity data were developed using only specific components of oil products (e.g., naphthalene) and the toxicity of the whole product was not evaluated. Also, a great number of papers dealt with aspects of petroleum toxicity which are not addressed by this study. These papers included studies on bioaccumulation and chronic, histopathologic, and behavioral effects. As a result, the 8,000 titles originally screened were reduced to approximately 250 pertinent references.

In many cases the titles of references were misleading. Papers frequently did not report mortality data or LC50 values. In some cases results were reported in percent (%) of test solution, which had no meaning independent of that study. In addition, certain references were from sources which were difficult to locate and collect. Consequently, 140 titles were actually collected and reviewed for this study, 46 of which contained usable data. These were papers that computed the median lethal concentration (LC50 or TLM) for a given oil to a test species, or papers whose data allowed the calculation of an LC50 or LL50 value. Generally, the literature is reflective of a component orientation to toxicity and not the whole product approach helpful in ranking products themselves.

The majority of the selected articles were published in the mid to late 1970's. While there was an adequate proportion of high quality articles reviewed, comparability between papers was limited due to variability in test methodologies. The importance of test methodological procedures to calculated toxicity values is presented in Section 1.2.2.1.

1.3.1.2 Characterization of Extracted Data

The final developed database contained 748 data records. Of these 748 data records, LC50 values were reported for 741 records. Seven records contained effect concentration data denoted as "NOEC" (No Observed Effect Concentration).

The "low reliability" data comprised approximately 7% (52 records) of the entire database (Figure 1-8). A statistical evaluation of the data indicated that the median effect concentration of the "low reliability" data records (47.50 mg/l) was significantly higher than the median effect concentration of either the "high reliability" data records (5.04 mg/l) or the "medium reliability" records (6.97 mg/l, $p<0.001$). The "high reliability" and "medium reliability" data sets did not have significantly different median effect concentrations ($p=0.07$).

The data set used in our analysis excluded the 52 "low reliability" records and the 7 "NOEC" data records. Our final dataset was comprised of 689 data records. The number of toxicity values collected by oil product, taxonomic group and free product presence is provided in Table 1-3.

The majority of the data was on crude oils (55%) and diesel (31%). Gasoline, jet fuel, and lube oil combined comprised less than 7% of the total number of data records in the database. Invertebrate data comprised 65.4% of the data records in the database. Fish comprised 26.6% of the data while algae comprised only 8% of the data. Appropriate data for aquatic macrophytes were not found.

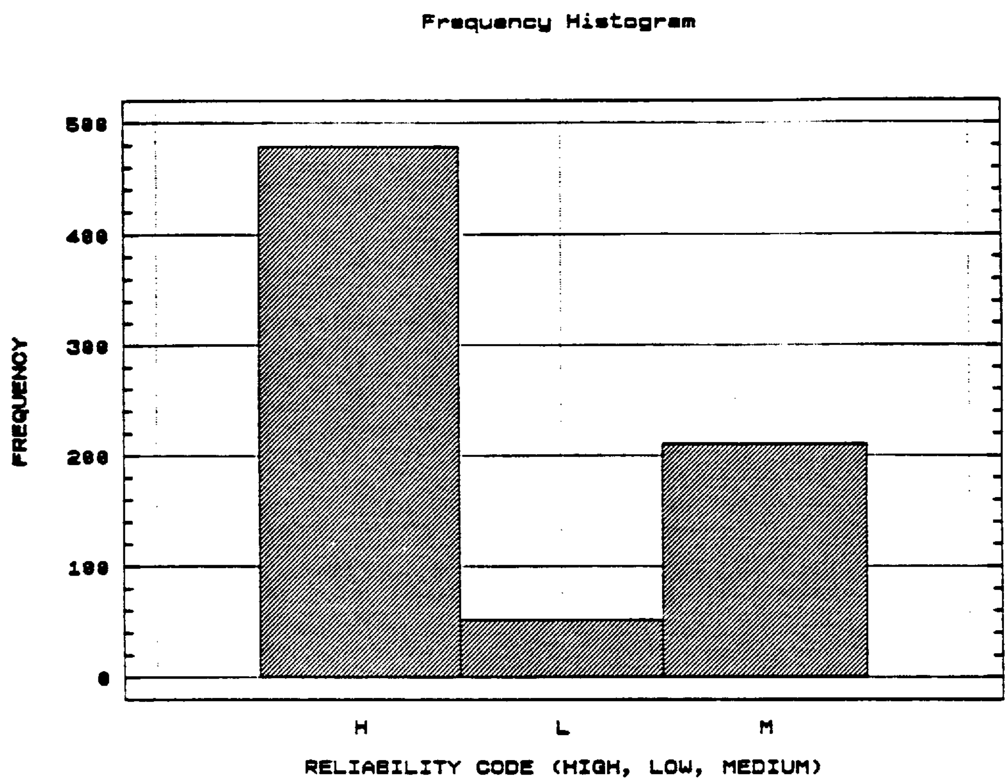

Figure 1-8. Frequency of data records by reliability code.

Table 1-3. Number of toxicity values (data records) by oil product group, taxonomic group, and Free Product Presence/Absence.

	INVERTEBRATES		FISH		ALGAE		TOTAL	
	Free Product Absent	Free Product Present	Free Product Absent	Free Product Present	Free Product Absent	Free Product Present	#'s	(%)
BUNKER	28	2	13	4	-	-	47	6.8%
CRUDE	224	22	54	46	5	28	379	55.0%
DIESEL	129	17	31	20	4	15	216	31.3%
GASOLINE	12	-	-	-	-	-	12	1.7%
JET FUEL	1	-	-	8	1	2	12	1.7%
LUBE OIL	14	2	4	3	-	-	23	3.3%
TOTAL #'s	408	43	102	81	10	45	689*	
(%)	59.2%	6.2%	14.8%	11.8%	1.5%	6.5%		
% BY TAXON	65.4 %		26.6%		8.0%			

**This data set excludes 52 data records classified as "low reliability" and 7 records whose primary endpoints were designated as "NOEC - no observed effect concentration". The database contains a total of 748 records.*

Toxicity studies utilizing algae and plants showed extreme variability in test methodologies and toxic endpoints. Endpoints included effects on photosynthetic rates, growth rates, chlorophyll content, mortality rates, and community structure. Only limited mortality data were available for algal species. In our database, effect threshold concentrations included reductions in growth rates and mortality.

The majority of the studies were saltwater tests (84%), using adult organisms (62%) under static conditions (91%). In addition, the majority of studies utilized open test chambers (72%), with all of the fish data generated under open chamber conditions.

Approximately 75% of the data records were for "free product absent" studies while 25% of the data records were for "free product present" studies. Over 90% of the invertebrate data was comprised of "free product absent" data while approximately 56% of the fish data was "free product absent" data. Only 18% of the algal data was "free product absent" LC50 data.

Toxicity values for "free product absent" studies were typically generated (99.2%) by "single-ratio" tests. This indicates that a single stock solution (water soluble fraction, WSF) was developed from the test oil and diluted to the various test concentrations. Of the data generated by the WSF studies, approximately half were based on measured total dissolved hydrocarbons present in the stock solution. The other half were actual measured concentrations in the test chambers after serial dilution of the stock.

Toxicity values for "free product present" studies were typically generated (80%) from "multiple-ratio" tests. In these studies different oil:water ratios were mixed and each WSF was mixed and tested independently. Endpoint values were reported in the amount of neat oil added to water, i.e., "lethal loading". Only one reference reported LC50 values both in terms of amount of neat product as well as the total dissolved hydrocarbons that resulted from that loading. These two methods represent very different approaches and the concentrations of water soluble components will vary significantly between methods for the same product. A detailed discussion of these phenomena is available in Shiu, et al. (1988).

1.3.2 Analysis and Ranking of Oil Product Toxicity

The results of our analysis of oil product toxicity values and ranking is divided into 6 main areas. These are discussed, in turn, as follows:

1.3.2.1 Invertebrates: Free Product Absent

A schematic of the results included in this Section is presented in bold print in Figure 1-9.

1.3.2.1.1 Median Toxicity Values

Oil Product Group Comparisons

Gasoline exhibited the highest (least toxic) median effect LC50 concentration (20.25 mg/l) while lube oil exhibited the lowest (most toxic) median effect LC50 concentration (1.58 mg/l). Median effect concentration values for bunker, diesel and jet fuel were not significantly different. Crude oil had a significantly higher median effect concentration (6.31 mg/l) when compared to the median effect concentrations of both bunker (3.00 mg/l) and diesel (3.36 mg/l).

The median effect LC50 concentration values for invertebrates by oil product group are presented in Table 1-4 and Figure 1-10. The distribution of invertebrate effect concentration values are presented in Figure 1-11. Only 1 data value for jet fuel was available in this category. Figure 1-9, Table 1-4, Figure 1-10 and Figure 1-11 are presented on the following 4 pages.

Median effect LC50 concentrations for invertebrates were significantly different between several oil product groups ($p<0.001$). Pairwise comparisons of median LC50 values by oil product group are presented in Table 1-5.

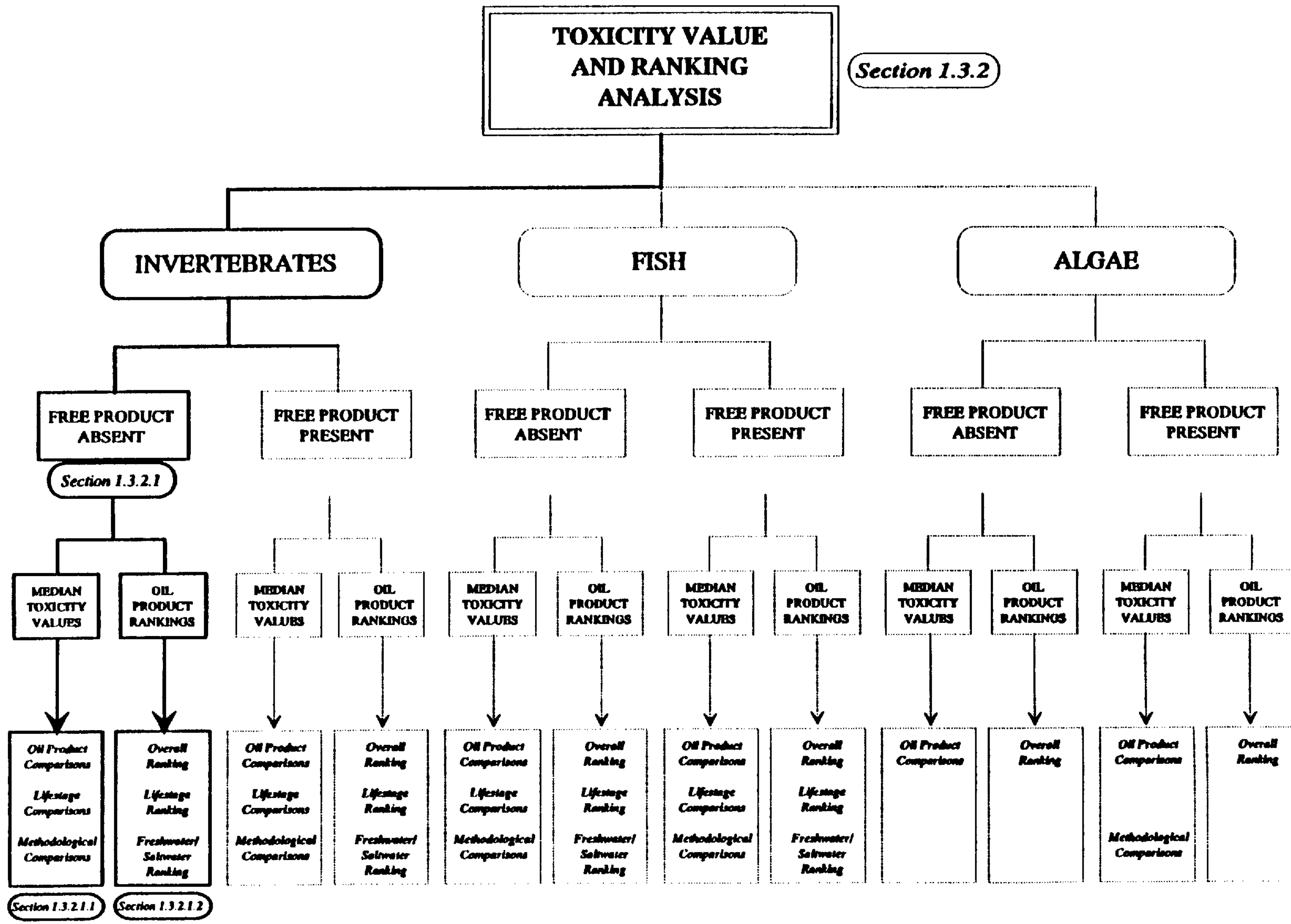

Figure 1-9. Diagram of the toxicity value and ranking analysis scheme for Section 1.3.2.1

Table 1-4. Median effect concentrations (mg/l) for invertebrates by oil product. (Free Product Absent)

Oil Product	Invertebrates			
	Free Product Absent			
	N	Median	Min	Max
Bunker	**28**	**3.00**	**0.90**	**6.30**
Bunker C (unspecified)(B01)	8	3.10	0.90	6.30
Venezuelan Bunker C (B02)	12	2.70	0.90	6.30
Bunker C Light (B04)	6	3.22	2.29	4.50
Navy Special (B06)	2	3.85	3.70	4.00
Crude	**224**	**6.31**	**0.04**	**73.00**
Kuwait (light) Crude (C01)	17	10.40	0.77	25.00
Cook Inlet Crude (C02)	97	5.16	0.04	20.97
Southern Louisiana Crude (C03)	27	16.20	2.10	19.80
Florida Jay Crude (C04)	4	0.17	0.05	0.25
Prudhoe Bay Crude (C05)	16	2.12	0.69	73.00
Venezuelan Crude (C06)	6	4.06	1.72	8.06
Western Sweet Blend Crude (C07)	6	7.23	1.12	10.60
Transmountain Crude (C08)	6	3.94	1.10	5.56
Norman Wells Crude (C09)	7	5.53	0.60	6.84
Hibernia Crude (C10)	6	5.92	1.08	10.60
Amauligak Crude (C11)	6	6.46	1.66	6.73
Tarsuit Crude (C12)	6	7.08	3.47	7.20
Lago Medio Crude (C13)	6	9.24	3.22	12.10
Atkinson Crude (C14)	6	2.02	0.58	2.27
Bent Horn Crude (C15)	6	2.57	1.07	5.30
Ramashkin Crude (C16)				
West Texas Crude (C17)	2	5.00	5.00	5.00
Diesel	**129**	**3.36**	**0.21**	**71.90**
Diesel (D01)	10	22.70	4.07	71.90
Fuel Oil No. 2 (D02)	99	3.20	0.21	10.00
Fuel Oil No. 2, Furnace Oil (D03)	16	3.50	1.00	20.00
Light Diesel Fuel (D04)				
Heavy Diesel Fuel (D05)				
Navy Distillate (D06)	2	5.65	4.60	6.70
Marine Diesel (D07)	2	3.50	3.50	3.50
Gasoline	**12**	**20.25**	**4.90**	**51.40**
Leaded Gasoline (G01)	6	16.35	5.40	27.00
Unleaded Gasoline (G02)	6	28.95	4.90	51.40
Jet Fuel	**1**	**3.50**	**3.50**	**3.50**
Jet Fuel - JP8 (J01)	1	3.50	3.50	3.50
Jet Fuel - JP9 (J03)				
Jet Fuel - JP4 (J04)				
Lube Oil	**14**	**1.58**	**0.08**	**2.40**
Auto Lube (L01)	6	0.41	0.08	1.50
Heavy Marine Lube (L02)	6	1.73	0.92	2.40
9250 Lube Oil (L03)	2	2.00	2.00	2.00

• *Note: Low reliability data excluded*

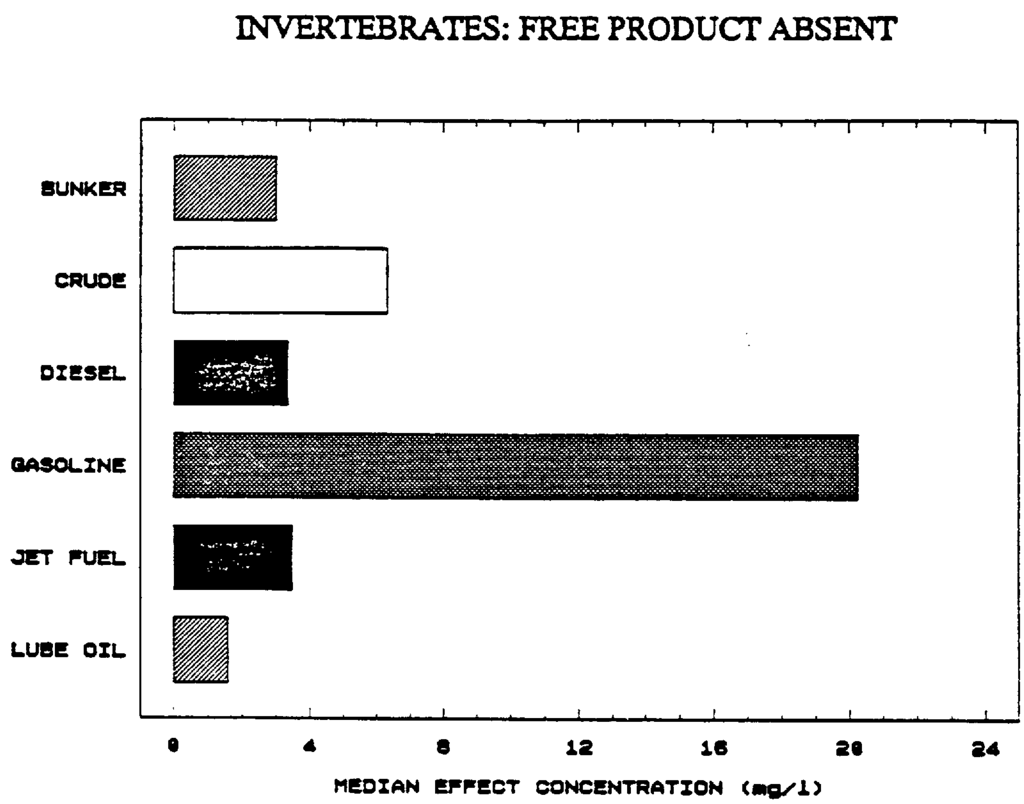

Figure 1-10. Bar chart of median effect LC50 concentrations (mg/l) for invertebrates by oil product group and free product absent.

INVERTEBRATES: FREE PRODUCT ABSENT

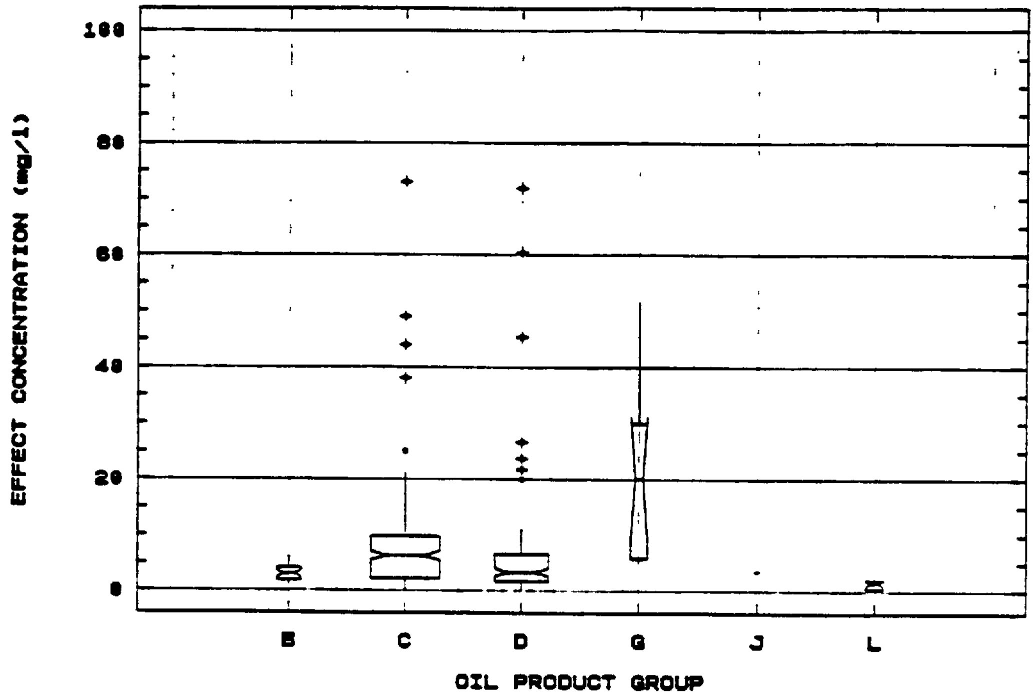

Figure 1-11. Box-and-whisker plot of median effect LC50 concentrations (mg/l) for invertebrates by oil product group and free product absent.

Table 1-5. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.003.

Invertebrates: Free Product Absent

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
BUNKER	———	**(<0.001)**	(0.28)	**(<0.001)**	(0.81)	**(<0.001)**
CRUDE		———	**(<0.001)**	**(<0.001)**	(0.56)	**(<0.001)**
DIESEL			———	**(<0.001)**	(0.92)	**(<0.001)**
GASOLINE				———	(0.14)	**(<0.001)**
JET FUEL					———	(0.13)
LUBE OIL						———

Lifestage Comparisons

The median effect concentration LC50 values for invertebrates by lifestage are presented in Table 1-6 (following page).

There were few data values regarding the egg stage of invertebrates. No egg effect concentration data were available for gasoline, jet fuel and lube oil. Although not significant ($p=0.77$), the median effect concentration for crude was the highest (5.70 mg/l) while diesel had the lowest median effect concentration (0.43 mg/l).

No larval effect concentration data were available for gasoline, jet fuel and lube oil. The median effect concentration values for larval invertebrates for bunker (1.80 mg/l), crude (2.00 mg/l) and diesel (1.30 mg/l) were not significantly different ($p=0.41$).

There were significant differences between juvenile invertebrate median effect concentration values by oil product group ($p<0.001$). Pairwise comparisons of median LC50 values by oil product group for juvenile invertebrates are presented in Table 1-7.

Table 1-6. Effect concentration (mg/l) by lifestage for invertebrates. (Free Product Absent).

Oil Product	Invertebrates: Free Product Absent															
	Eggs				Larvae				Juveniles				Adults			
	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max
Bunker	**1**	**1.00**	**1.00**	**1.00**	**3**	**1.80**	**1.60**	**3.20**	**9**	**3.70**	**1.90**	**4.50**	**15**	**3.20**	**0.90**	**6.30**
Bunker C (unspecified)(B01)									1	1.90	1.90	1.90	7	3.60	0.90	6.30
Venezuelan Bunker C (B02)	1	1.00	1.00	1.00	3	1.80	1.60	3.20					8	3.00	0.90	6.30
Bunker C Light (B04)									6	3.22	2.29	4.50				
Navy Special (B06)									2	3.85	4.50	4.00				
Crude	**3**	**5.70**	**0.23**	**12.00**	**29**	**2.00**	**0.04**	**25.00**	**81**	**5.30**	**0.58**	**19.80**	**111**	**8.20**	**0.69**	**73.00**
Kuwait (light) Crude (C01)	1	12.00	12.00	12.00	3	13.10	2.00	25.00	2	11.3	9.60	13.00	11	10.40	0.77	10.40
Cook Inlet Crude (C02)					19	1.70	0.04	8.00	1	1.71	1.71	1.71	77	6.94	0.81	20.97
Southern Louisiana Crude (C03)	1	5.70	5.70	5.70	3	5.30	2.10	6.00	9	19.80	12.90	19.80	14	15.05	8.70	19.80
Florida Jay Crude (C04)	1	0.23	0.23	0.23	3	0.11	0.05	0.25								
Prudhoe Bay Crude (C05)					1	1.96	1.96	1.96	6	2.90	1.72	8.60	9	2.06	0.69	73.00
Venezuelan Crude (C06)									6	4.06	1.72	8.06				
Western Sweet Blend Crude (C07)									6	7.23	1.12	10.60				
Transmountain Crude (C08)									6	3.94	1.10	5.56				
Norman Wells Crude (C09)									7	5.53	0.60	6.84				
Hibernia Crude (C10)									6	5.92	1.08	10.60				
Amauligak Crude (C11)									6	6.46	1.66	6.73				
Tarsuit Crude (C12)									6	7.08	3.47	7.20				
Lago Medio Crude (C13)									6	9.24	3.22	12.10				
Atkinson Crude (C14)									6	2.02	0.58	2.27				
Bent Horn Crude (C15)									6	2.57	1.07	5.30				
Ramashkin Crude (C16)																
West Texas Crude (C17)									2	5.00	5.00	5.00				
Diesel	**1**	**0.43**	**0.43**	**0.43**	**5**	**1.30**	**0.53**	**1.90**	**31**	**6.60**	**1.40**	**60.40**	**92**	**3.36**	**0.21**	**71.90**
Diesel (D01)									7	21.70	4.07	60.40	3	26.60	7.95	71.90
Fuel Oil No. 2 (D02)	1	0.43	0.43	0.43	4	1.30	0.53	1.90	8	5.15	2.20	8.70	86	3.28	0.21	10.00
Fuel Oil No. 2, Furnace Oil (D03)					1	1.20	1.20	1.20	12	5.15	1.40	20.00	3	2.90	1.00	3.50
Light Diesel Fuel (D04)																
Heavy Diesel Fuel (D05)																
Navy Distillate (D06)									2	5.65	4.60	6.70				
Marine Diesel (D07)									2	3.50	3.50	3.50				
Gasoline									**12**	**20.25**	**4.90**	**51.40**				
Leaded Gasoline (G01)									6	16.35	5.40	27.00				
Unleaded Gasoline (G02)									6	28.95	4.90	51.40				
Jet Fuel									**1**	**3.50**	**3.50**	**3.50**				
Jet Fuel - JP8 (J01)									1	3.50	3.50	3.50				
Jet Fuel - JP4 (J04)																
Lube Oil									**14**	**1.58**	**0.08**	**2.40**				
Auto Lube (L01)									6	0.41	0.08	1.50				
Heavy Marine Lube (L02)									6	1.73	0.92	2.40				
9250 Lube Oil (L03)									2	2.00	2.00	2.00				

• *Note: Low reliability data excluded*

Table 1-7. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.003.

INVERTEBRATES: FREE PRODUCT ABSENT: JUVENILES

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
BUNKER	———	(0.15)	(0.03)	**(<0.001)**	(1.00)	**(<0.001)**
CRUDE		———	(0.13)	**(<0.001)**	(0.67)	**(<0.001)**
DIESEL			———	(0.009)	(0.42)	**(<0.001)**
GASOLINE				———	(0.14)	**(<0.001)**
JET FUEL					———	(0.13)
LUBE OIL						———

The median effect concentration for gasoline was significantly higher when compared to the median effect concentrations of the bunker, crude and lube oil product groups. The median effect concentration for lube oil was significantly lower when compared to the median effect concentration of any of the oil product groups except jet fuel.

No adult effect concentration data were available for gasoline, jet fuel and lube oil. The median effect concentration for adult invertebrates for crude (8.20 mg/l) was significantly higher when compared to both bunker (3.20 mg/l, $p<0.001$) and diesel (3.36 mg/l, $p<0.001$). The median effect concentrations for bunker and diesel were not significantly different ($p=0.98$).

Methodological Procedure Comparisons

The results of statistical tests for effects of methodological procedures on toxicity values are presented in Appendix Tables B-1 and B-2. These tables contain median LC50 values and statistical levels (p-values) calculated for specific methodological procedures. An overview of these statistical comparisons is presented in Table 1-8. The following information details significant differences in the calculated median effect concentration of each oil product group based upon the methodological procedures examined.

<u>Bunker</u>

No significant differences were found between effect concentration and methodological procedure for the bunker oil group.

Table 1-8. Overview of statistical comparisons between methodological procedures and oil product: Invertebrates, Free Product Absent.

INVERTEBRATES: FREE PRODUCT ABSENT

OIL PRODUCT

TEST PROCEDURE

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
Number of Observations	*28*	*224*	*129*	*12*	*1*	*14*
AGITATION DURATION (hours)		*	*			
TEST SOLUTION DEVELOPMENT (single ratio, multiple ratio)		*				
TEST CHAMBER (open, closed)		*	*			
TEST DURATION (24, 48, 96 HOURS)		*	*			
LIFE STAGE (egg, juvenile, adult)		*	*			
EXPOSURE METHOD (static, flow-through)		*				
TEST CONDITION (saltwater, freshwater)		*	*	*		
MEASURED/STOCK/ UNMEASURED		*				

Indicates that not enough data points were available for statistical comparison.

Indicates that no comparisons for the given test procedure and oil product resulted in a statistically significant difference.

* Indicates that at least 1 class comparison resulted in a statistically significant difference.

Crude

For the crude oil group, the duration of agitation during mixing did make a significant difference in the effect concentration calculated for the product. In general, as the amount of agitation increased, so did the toxicity of the crude oil group. The median effect concentration for tests conducted with an agitation level of between 0 and 1 hour (25.50 mg/l) was significantly higher when compared to tests where the agitation was >24 hours (median 4.49 mg/l, $p<0.001$). The median effect concentration for tests conducted with an agitation level of between 12 and 24 hours (8.46 mg/l) was significantly higher when compared to tests where the agitation level was >24 hours (median 4.49 mg/l $p<0.001$).

Test solution development also made a significant difference on the effect concentration. Single ratio tests had a lower median effect concentration (5.70 mg/l) when compared to the median effect concentration (46.50 mg/l) for multiple ratio tests ($p<0.001$).

Whether the test chamber was open or closed also made a significant difference on the effect concentration. If the test chamber was closed the median effect concentration was lower (median 4.49 mg/l) than if the test chamber was open (median 7.40 mg/l, $p<0.003$).

A test duration of 24 hours had a significantly higher median effect concentration than the median effect concentration of tests conducted for > 96 hours ($p<0.001$). A test duration of 96 hours had a significantly higher median effect concentration than the median effect concentration of tests conducted for > 96 hours ($p<0.001$).

The lifestage tested also contributed significantly to effect concentration. The crude oil group was most toxic to larval invertebrates (median 2.00 mg/l) and least toxic to adult invertebrates (median 8.20 mg/l). The median effect concentration of larval invertebrates was significantly lower when compared to juvenile and adult invertebrate median effect concentrations ($p<0.004$ and $p<0.001$ respectively). The median effect concentration of juvenile invertebrates was significantly lower (median 5.30 mg/l) when compared to adults ($p<0.002$).

Exposure method also indicated to be of importance in arriving at an effect concentration value. Static tests had a significantly higher median concentration (6.78 mg/l) when compared to the median effect concentration (1.74 mg/l) of flow-through tests ($p<0.001$).

Whether the test was conducted in freshwater or saltwater also had a significant effect on effect concentration values. Saltwater tests had a significantly higher median effect concentration (6.92 mg/l) when compared to freshwater tests (median 2.31 mg/l, $p<0.001$).

The method of measuring total dissolved hydrocarbons concentrations (as defined in Section 1.2.2.1.5) also had a significant effect on effect concentration values. The median value for the "unmeasured" (based on nominal neat product) effect concentration (19.80 mg/l) was significantly higher when compared to "measured" and "stock" median effect concentrations ($p<0.001$ and $p<0.002$, respectively). The median value for "measured" effect concentration (4.06 mg/l) was significantly lower when compared to the "stock" median effect concentration (8.71 mg/l, $p<0.001$).

<u>Diesel</u>

For the diesel group, the duration of agitation during mixing also made a significant difference in the median effect concentration calculated for the product. The median effect concentration for tests conducted with an agitation of between 1 and 12 hours (0.92 mg/l) was significantly lower when compared to tests where the agitation was > 24 hours (median 9.50 mg/l, $p<0.004$). The median effect concentration for tests conducted with an agitation of between 12 and 24 hours (3.36 mg/l) was also significantly lower when compared to tests where the agitation level was >24 hours (median 9.50 mg/l, $p<0.001$).

Whether the test chamber was open or closed also made a significant difference on the effect concentration. If the test chamber was closed (median 8.35 mg/l) the median effect concentration was higher than if the test chamber was open (median 3.28 mg/l, $p<0.001$).

A test duration of 4 hours had a significantly higher median effect concentration than the median effect concentration of tests conducted for 24 or 96 hours ($p<0.001$, $p<0.001$, respectively). A test duration of 48 hours had a significantly higher median effect concentration than the median effect concentration of tests conducted for 96 hours ($p<0.003$).

The lifestage tested also contributed significantly to effect concentration. Diesel appears to be most toxic to the egg and juvenile life stages. The median effect concentration of larval invertebrates (1.30 mg/l) was significantly lower when compared to the juvenile median effect concentration (6.60 mg/l, $p<0.001$). The median effect concentration of juvenile invertebrates was significantly higher when compared to adults (median 3.36 mg/l, $p<0.001$).

Whether the test was conducted in freshwater or saltwater also made a significant effect on effect concentration values. Saltwater tests had a significantly lower median effect concentration (3.36 mg/l) when compared to freshwater tests (median 7.95 mg/l, $p<0.001$).

Gasoline

Whether the test was conducted in freshwater or saltwater had a significant impact on effect concentration values. Saltwater tests had a significantly higher median effect concentration (26.00 mg/l) when compared to freshwater tests (median 5.83 mg/l, $p=0.045$).

Jet Fuel

No significant differences were found between effect concentration and methodological procedure for the jet fuel group.

Lube Oil

No significant differences were found between effect concentration and methodological procedure for the lube oil group.

1.3.2.1.2 Ranking of Oil Product Toxicity

The following rankings were developed from the calculated median effect LC50 concentration values. In evaluating the rankings presented, one should keep in mind that the placement of jet fuel is based upon 1 data value.

In general, the gasoline and crude groups were the least toxic when compared to the other groups. The bunker, diesel and jet fuel groups appear to be twice as toxic when compared to the crude oil group. Lube oil appears to be 4 times as toxic when compared to the crude oil group and 13 times as toxic when compared to gasoline. Lube oil data were very limited. Also, lube oils contain specific additives which can significantly impact resulting toxicity data.

The relative ranking of each oil product group, from most toxic to least toxic, is presented in Table 1-9. Table 1-9 includes an overall ranking as well as a ranking by life stage.

Table 1-9. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the medium concentration of the least toxic oil product. For example, the overall toxicity of the lube oil, based upon the median values, was approximately 13 times that of gasoline.

INVERTEBRATES: FREE PRODUCT ABSENT

Overall Ranking (across life stages)	Eggs	Larvae	Juvenile	Adult
Lube Oil(13)	Diesel (13)	Diesel (2)	Lube Oil(13)	Bunker (3)
Bunker (7)	Bunker (6)	Bunker (1)	Jet Fuel (6)	Diesel (2)
Diesel (6)	Crude (1)	Crude (1)	Bunker (5)	Crude (1)
Jet Fuel (6)			Crude (4)	
Crude (3)			Diesel (3)	
Gasoline(1)			Gasoline(1)	

The above rankings are subject to variations in the following methodological procedures as described in Section 1.3.2.1:

- Agitation Duration,
- Test Solution Development (single, multiple ratio),
- Test Chamber (open, closed),
- Test Duration,
- Lifestage Tested,
- Exposure Method (static, flow-through),
- Test Condition (freshwater, saltwater), and
- Measured, unmeasured, stock.

Since test conditions significantly impacted the median effect concentration for several oil product groups, the overall ranking was further refined into a saltwater and freshwater ranking for this category (Table 1-10). These rankings may also be more applicable to a given spill situation.

Table 1-10. Relative ranking of each oil product group by test condition from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

INVERTEBRATES: FREE PRODUCT ABSENT

Overall Ranking (Freshwater Conditions)	Overall Ranking (Saltwater Conditions)
Lube Oil(7)	Lube Oil(16)
Crude (3)	Bunker (10)
Jet Fuel (2)	Diesel (8)
Bunker (2)	Crude (4)
Gasoline(1)	Gasoline(1)
Diesel (1)	

Median effect concentrations calculated for saltwater and freshwater "free product absent" tests did make a difference in the overall ranking. It appears that, for invertebrates, the toxicity of crude is higher in freshwater when compared to bunker and diesel, but that under saltwater conditions, bunker and diesel appear much more toxic than crude. In freshwater, the median effect concentration across oil product groups ranged from 1.21 mg/l to 7.95 mg/l. In saltwater, the median effect concentration across oil product groups ranged from 1.66 mg/l to 26.00 mg/l.

1.3.2.2 Invertebrates: Free Product Present

A schematic of the results included in this Section is presented in bold print in Figure 1-12.

1.3.2.2.1 Median Toxicity Values

Oil Product Group Comparisons

Crude oil exhibited the highest (least toxic) median effect LC50 concentration (225 mg/l) while diesel exhibited the lowest (most toxic) median effect LC50 concentration (9.40 mg/l). Median effect concentration values for bunker, diesel and lube oil were not significantly different. Crude oil had a significantly higher median effect concentration when compared to the median effect concentration of diesel. The median effect concentration of crude was not significantly different from the median effect concentration of bunker.

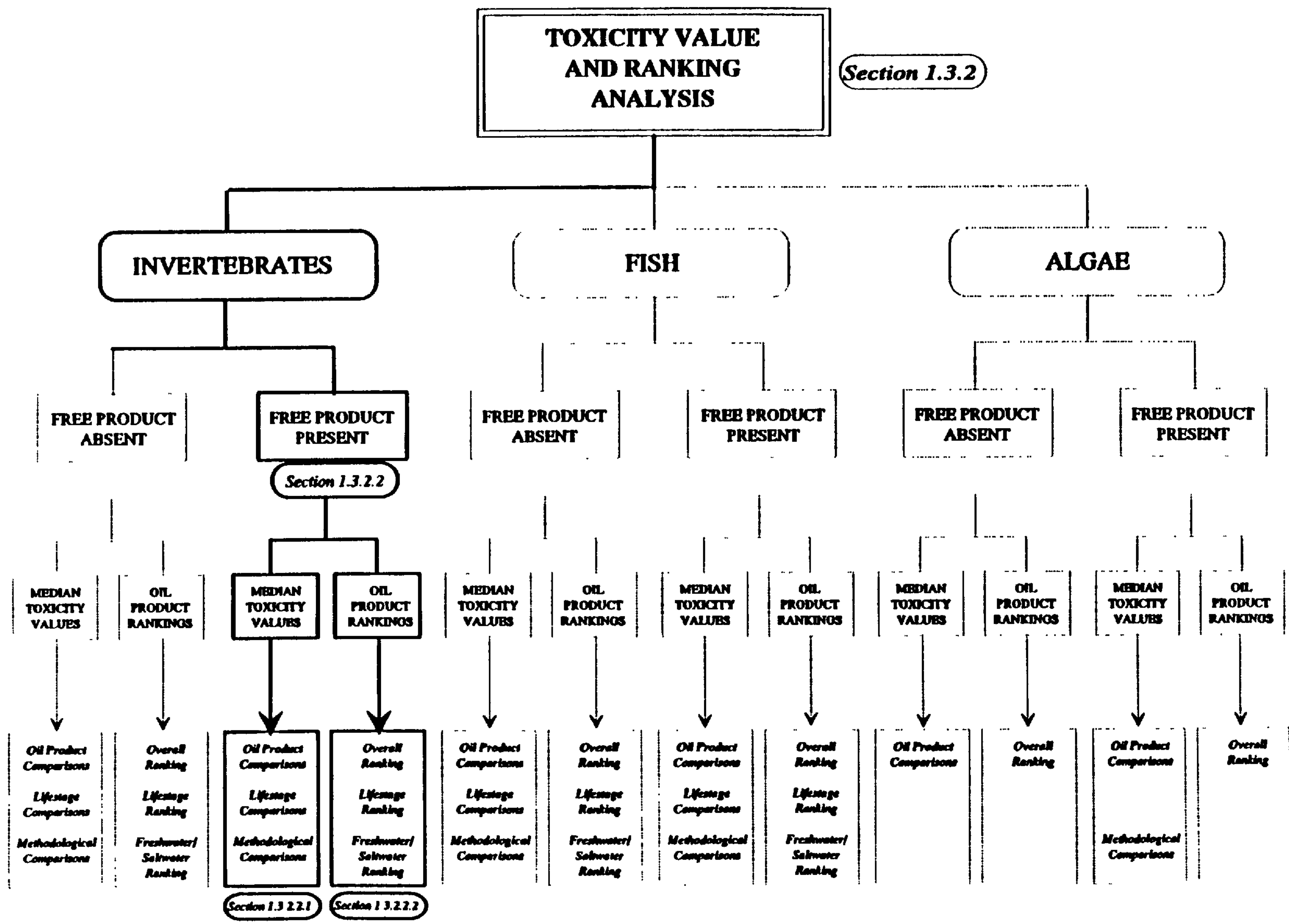

Figure 1-12. Diagram of the toxicity value and ranking analysis scheme for Section 1.3.2.2.

The median effect LC50 concentration values for invertebrates by oil product group are presented in Table 1-11 and Figure 1-13. No data were available for gasoline and jet fuel. The distribution of effect concentration LC50 values for invertebrates are presented in Figure 1-14. Table 1-11, Figure 1-13 and Figure 1-14 are presented on the following 3 pages.

Median effect LC50 concentrations for invertebrates were significantly different between several oil product groups ($p<0.001$). Pairwise comparisons of median LC50 values by oil product group are presented in Table 1-12.

Table 1-12. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.008.

INVERTEBRATES: FREE PRODUCT PRESENT

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
BUNKER	———	(0.19)	(0.21)	no data	no data	(1.00)
CRUDE		———	**(<0.001)**	no data	no data	(0.19)
DIESEL			———	no data	no data	(0.18)
GASOLINE				———	no data	no data
JET FUEL					———	no data
LUBE OIL						———

Lifestage Comparisons

The median effect concentration LC50 values for invertebrates by lifestage are presented in Table 1-13.

No data were available for any of the oil product groups regarding the egg lifestage of invertebrates.

No larval effect concentration data were available for bunker, gasoline, jet fuel and lube oil. Four effect concentration values were available for crude and 2 for diesel. Although a small sample size and not significantly different, the median effect concentration for crude (350 mg/l) was 50 times higher than the median effect concentration for diesel (7.00 mg/l, $p=0.11$).

Table 1-11. Median effect concentrations (mg/l) for invertebrates by oil product. (Free Product Present)

Oil Product	Invertebrates Free Product Present N	Median	Min	Max
Bunker	2	55.85	11.70	100.00
Bunker C (unspecified)(B01)				
Venezuelan Bunker C (B02)				
Bunker C Light (B04)				
Navy Special (B06)	2	55.85	11.70	100.00
Crude	22	225.00	4.70	13500
Kuwait (light) Crude (C01)	10	350.00	58.00	13500
Cook Inlet Crude (C02)				
Southern Louisiana Crude (C03)	8	350.00	37.50	1700
Florida Jay Crude (C04)				
Prudhoe Bay Crude (C05)	1	560.00	560.00	560.00
Venezuelan Crude (C06)				
Western Sweet Blend Crude (C07)				
Transmountain Crude (C08)				
Norman Wells Crude (C09)				
Hibernia Crude (C10)				
Amauligak Crude (C11)				
Tarsuit Crude (C12)				
Lago Medio Crude (C13)				
Atkinson Crude (C14)				
Bent Horn Crude (C15)				
Ramashkin Crude (C16)	1	25.00	25.00	25.00
West Texas Crude (C17)	2	31.85	31.85	31.85
Diesel	17	9.40	1.30	4778
Diesel (D01)				
Fuel Oil No. 2 (D02)	11	4.00	1.30	4778
Fuel Oil No. 2, Furnace Oil (D03)				
Light Diesel Fuel (D04)	1	10.00	10.00	10.00
Heavy Diesel Fuel (D05)	1	20.00	20.00	20.00
Navy Distillate (D06)	2	24.35	7.70	41.00
Marine Diesel (D07)	2	37.80	4.10	71.50
Gasoline				
Leaded Gasoline (G01)				
Unleaded Gasoline (G02)				
Jet Fuel				
Jet Fuel - JP8 (J01)				
Jet Fuel - JP9 (J03)				
Jet Fuel - JP4 (J04)				
Lube Oil	2	55.50	20.00	91.00
Auto Lube (L01)				
Heavy Marine Lube (L02)				
9250 Lube Oil (L03)	2	55.50	20.00	91.00

* *Note: Low reliability data excluded*

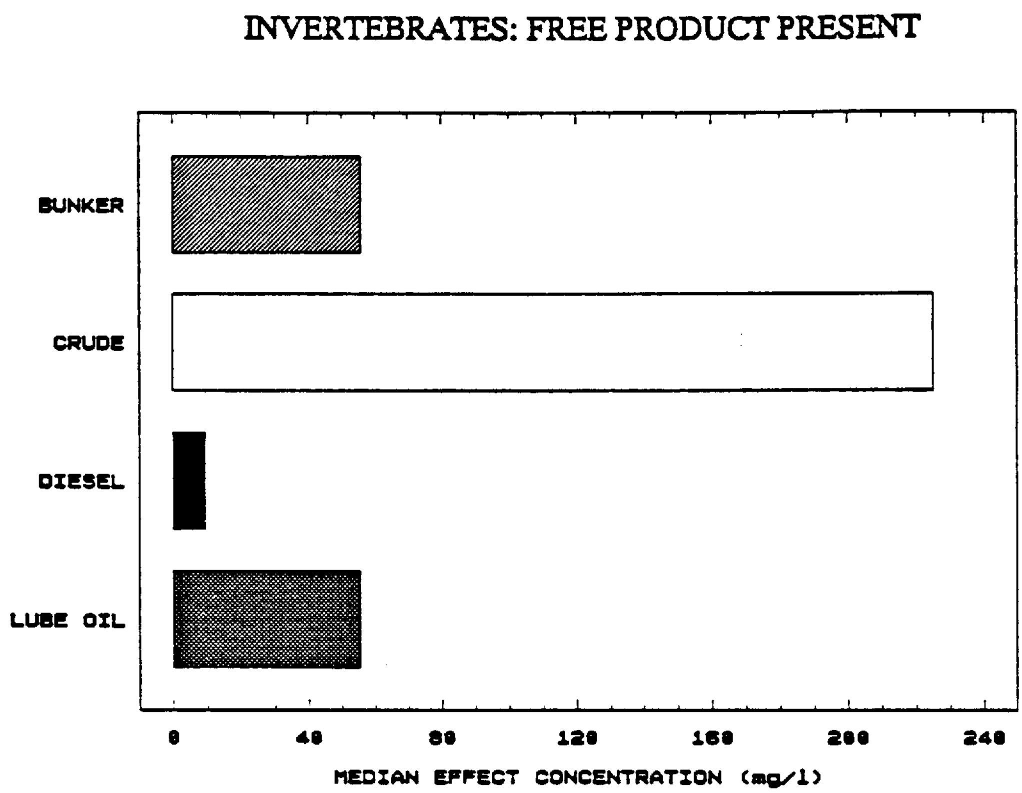

Figure 1-13. Bar chart of median effect LC50 concentrations (mg/l) for invertebrates by oil product group and free product present.

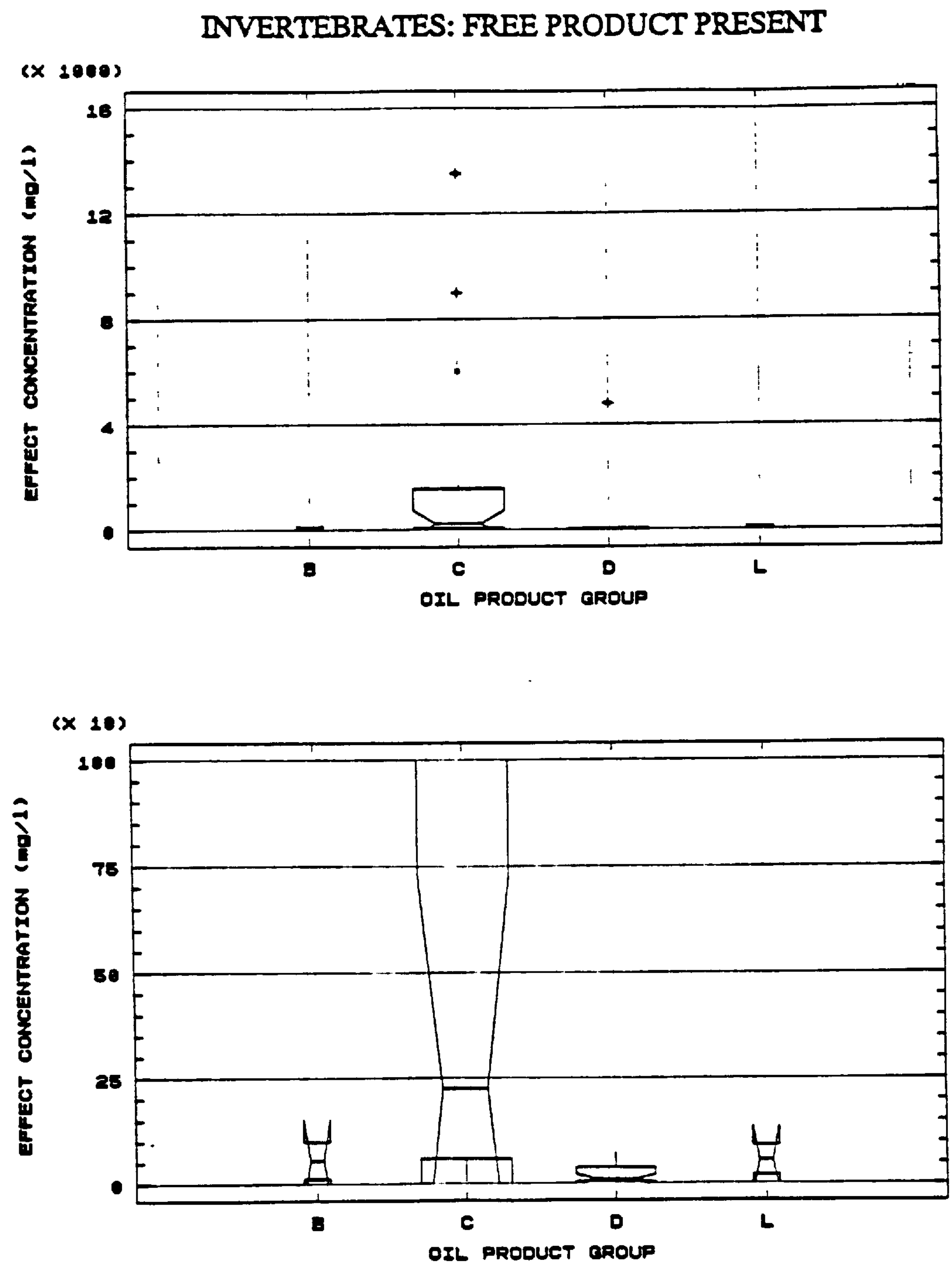

Figure 1-14. Box-and-whisker plot of median effect LC50 concentrations (mg/l) for invertebrates by oil product group and free product present.

Table 1-13. Effect concentration (mg/l) by lifestage for invertebrates (Free Product Present).

Oil Product	Invertebrates: Free Product Present															
	Eggs				Larvae				Juveniles				Adults			
	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max
Bunker									**2**	**55.85**	**11.70**	**100.00**				
Bunker C (unspecified)(B01)		No Data														
Venezuelan Bunker C (B02)																
Bunker C Light (B04)																
Navy Special (B06)									2	55.85	11.70	100.00				
Crude					**4**	**350.00**	**200.00**	**500.00**	**5**	**59.00**	**4.70**	**560.00**	**13**	**1000**	**25.00**	**13500**
Kuwait (light) Crude (C01)					2	350.00	200.00	500.00	2	59.00	58.00	60.00	6	3777.5	63.00	13500
Cook Inlet Crude (C02)																
Southern Louisiana Crude (C03)					2	350.00	250.00	450.00					6	600.00	37.50	1700
Florida Jay Crude (C04)																
Prudhoe Bay Crude (C05)									1	560.00	560.00	560.00				
Venezuelan Crude (C06)																
Western Sweet Blend Crude (C07)																
Transmountain Crude (C08)																
Norman Wells Crude (C09)																
Hibernia Crude (C10)																
Amauligak Crude (C11)																
Tarsuit Crude (C12)																
Lago Medio Crude (C13)																
Atkinson Crude (C14)																
Bent Horn Crude (C15)																
Ramashkin Crude (C16)													1	25.00	25.00	25.00
West Texas Crude (C17)									2	31.85	4.70	59.00				
Diesel					**2**	**7.00**	**4.00**	**10.00**	**5**	**41.00**	**4.10**	**4778**	**10**	**6.60**	**1.30**	**73.00**
Diesel (D01)																
Fuel Oil No. 2 (D02)					2	7.00	4.00	10.00	1	4778	4778	4778	8	3.60	1.30	73.00
Fuel Oil No. 2, Furnace Oil (D03)																
Light Diesel Fuel (D04)													1	10.00	10.00	10.00
Heavy Diesel Fuel (D05)													1	20.00	20.00	20.00
Navy Distillate (D06)									2	24.35	7.70	41.00				
Marine Diesel (D07)									2	37.80	4.10	71.50				
Gasoline																
Leaded Gasoline (G01)																
Unleaded Gasoline (G02)																
Jet Fuel																
Jet Fuel - JP8 (J01)																
Jet Fuel - JP4 (J04)																
Lube Oil									**2**	**55.50**	**20.00**	**91.00**				
Auto Lube (L01)																
Heavy Marine Lube (L02)																
9250 Lube Oil (L03)									2	55.50	20.00	91.00				

• *Note: Low reliability data excluded*

No juvenile effect concentration data were available for either gasoline or jet fuel. The median effect concentrations of bunker (55.85 mg/l), crude (59.00 mg/l), diesel (41.00 mg/l) and lube oil (55.50 mg/l) were not significantly different ($p=0.97$).

No adult effect concentration data were available for bunker, gasoline, jet fuel and lube oil. The median effect concentration of crude (1000 mg/l) was significantly higher than the median effect concentration of diesel (6.60 mg/l, $p<0.001$).

Methodological Procedure Comparisons

The results of statistical tests for effects of methodological procedures on toxicity values are presented in Appendix Tables B-3 and B-4. These tables contain median LC50 values and statistical levels (p values) calculated for specific methodological procedures. An overview of the statistical comparisons is presented in Table 1-14. The following information details significant differences in the calculated median effect concentration of each oil product group based upon the methodological procedures examined.

<u>Bunker</u>

No significant differences were found between effect concentration and methodological procedure for the bunker oil group.

<u>Crude</u>

Test solution development had a significant difference on the effect concentration. Single ratio tests had a lower median effect concentration (58.50 mg/l) when compared to the median effect concentration for multiple ratio tests (475.00 mg/l, $p=0.01$).

The method of measuring total dissolved hydrocarbon concentration (as defined in Section 1.2.2.1.5) also had a significant effect on effect concentration values. The median effect concentration value for "stock" (58.50 mg/l) was significantly lower when compared to "unmeasured" median effect concentration (475 mg/l, $p=0.012$).

Table 1-14. Overview of statistical comparisons between methodological procedures and oil product: Invertebrates, Free Product Present.

INVERTEBRATES: FREE PRODUCT PRESENT

OIL PRODUCT

TEST PROCEDURE	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
Number of Observations	*2*	*22*	*17*	*0*	*0*	*2*
AGITATION DURATION (hours)			*			
TEST SOLUTION DEVELOPMENT (single ratio, multiple ratio)		*				
TEST CHAMBER (open, closed)						
TEST DURATION (24, 48, 96 HOURS)						
LIFE STAGE (egg, juvenile, adult)						
EXPOSURE METHOD (static, flow-through)						
TEST CONDITION (saltwater, freshwater)						
MEASURED/STOCK/ UNMEASURED		*				

Indicates that not enough data points were available for statistical comparison.

Indicates that no comparisons for the given test procedure and oil product resulted in a statistically significant difference.

* Indicates that at least 1 class comparison resulted in a statistically significant difference.

Diesel

For the diesel group, the duration of agitation also made a significant difference in the median effect concentration calculated for the product. The median effect concentration for tests conducted with no agitation (20.00 mg/l) was significantly higher when compared to tests where the agitation was between 0 and 1 hour (median 3.95 mg/l, $p<0.036$).

Gasoline

No data available.

Jet Fuel

No data available.

Lube Oil

No significant differences were found between effect concentration and methodological procedure for the lube oil group.

1.3.2.2.2 Ranking of Oil Product Toxicity

The following rankings were developed from the calculated median effect LC50 concentration values. In evaluating the rankings, one should keep in mind that the placement of lube oil and bunker groups is based upon only 2 lube oil and 2 bunker data values.

Diesel appears to be 24 times as toxic when compared to the crude oil group. Both lube oil and bunker appear to be 4 times more toxic when compared to the crude oil group. Diesel appeared to be six times as toxic when compared to the lube oil and bunker groups.

The relative ranking of each oil product group, from most toxic to least toxic, is presented in Table 1-15. Table 1-15 includes an overall ranking as well as a ranking by life stage.

Table 1-15. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

INVERTEBRATES: FREE PRODUCT PRESENT

Overall Ranking (across life stages)	Eggs	Larvae	Juvenile	Adult
Diesel (24)	no data	Diesel (50)	Diesel (1)	Diesel (152)
Lube Oil(4)		Crude (1)	Lube (1)	Crude (1)
Bunker (4)			Bunker (1)	
Crude (1)			Crude (1)	

The above rankings are subject to variations in the following methodological procedures as described in Section 1.3.2.2:

- Agitation duration,
- Test Solution Development (single, multiple ratio), and
- Measured, unmeasured, stock.

It should be noted that all of the "free product present" data for invertebrates were conducted under saltwater conditions.

1.3.2.3 Fish: Free Product Absent

A schematic of the results included in this Section is presented in bold print in Figure 1-15.

1.3.2.3.1 Median Toxicity Values

Oil Product Group Comparisons

Although not significantly different, bunker exhibited the highest (least toxic) median effect LC50 concentration (3.60 mg/l) while lube oil exhibited the lowest (most toxic) effect LC50 concentration (2.25 mg/l).

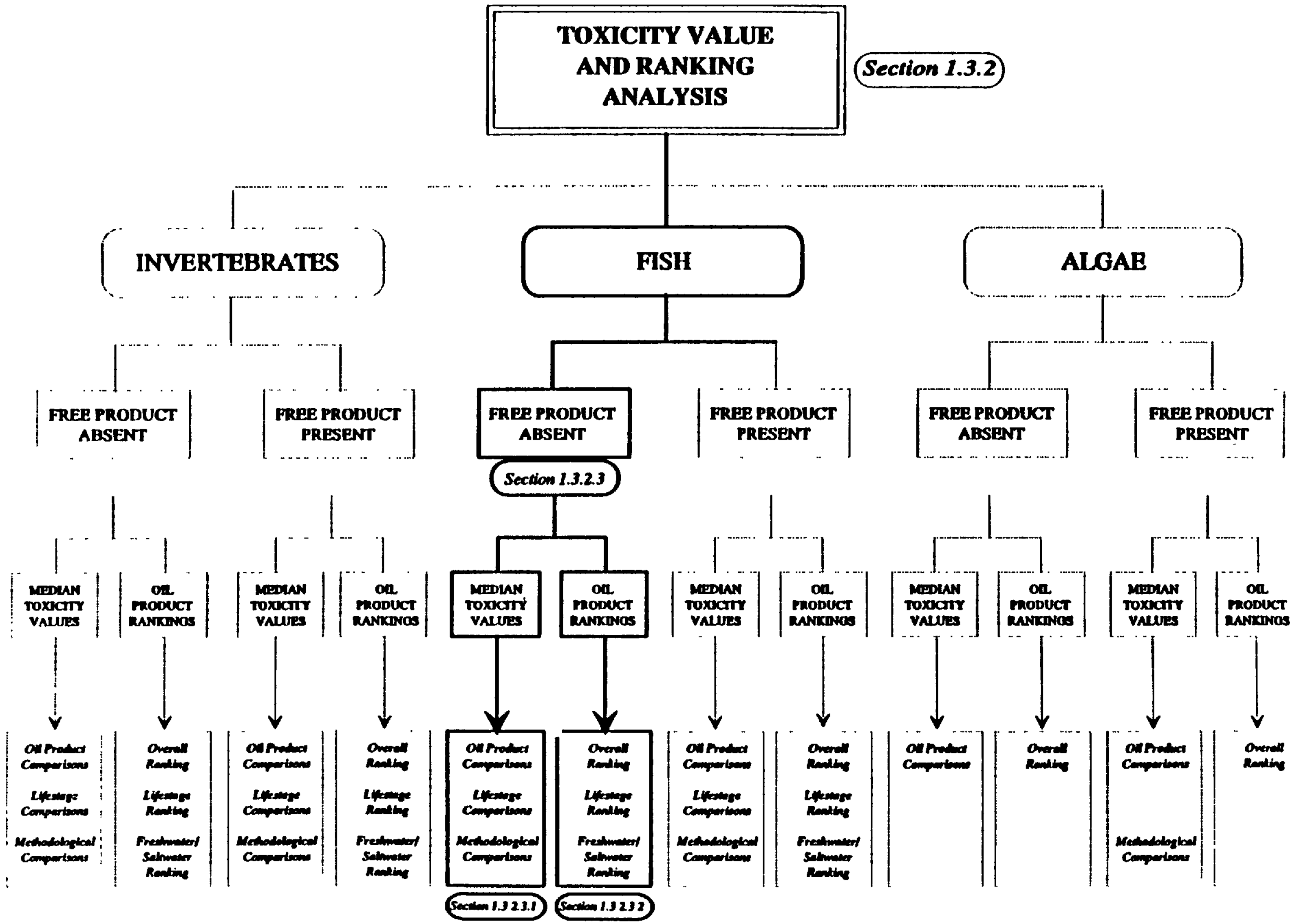

Figure 1-15. Diagram of the toxicity value and ranking analysis scheme for Section 1.3.2.3.

The median effect LC50 concentration values for fish by oil product group are presented in Table 1-16 and Figure 1-16. The distribution of effect LC50 concentration values is presented in Figure 1-17. Table 1-16, Figure 1-16 and Figure 1-17 are presented on the following 3 pages.

Median effect LC50 concentrations for fish were not significantly different between the oil product groups ($p=0.49$). No data were available for gasoline and jet fuel. Pairwise comparisons of median LC50 values by oil product group are presented in Table 1-17.

Table 1-17. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.008.

FISH: FREE PRODUCT ABSENT

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
BUNKER	———	(0.73)	(0.96)	no data	no data	(0.21)
CRUDE		———	(0.19)	no data	no data	(0.33)
DIESEL			———	no data	no data	(0.48)
GASOLINE				———	no data	no data
JET FUEL					———	no data
LUBE OIL						———

Lifestage Comparisons

The median effect LC50 concentration values for fish by lifestage are presented in Table 1-18.

Data for the egg, larval and juvenile lifestages of fish were available for the crude oil product group only.

No adult effect concentration data were available for the gasoline and jet fuel oil product groups. Although the Kruskall-Wallis test indicated a significant difference between the median effect concentrations of oil product groups for adults, ($p=0.03$), pairwise comparisons of median LC50 values by oil product group for adults do not find significance (given Bonferroni's adjustment) between any of the oil product groups (Table 1-19).

Table 1-16. Median effect concentrations (mg/l) for fish by oil product. (Free Product Absent)

Oil Product	Fish			
	Free Product Absent			
	N	Median	Min	Max
Bunker	**13**	**3.60**	**1.50**	**7.00**
Bunker C (unspecified)(B01)				
Venezuelan Bunker C (B02)	9	3.10	1.69	4.70
Bunker C Light (B04)				
Navy Special (B06)	4	4.20	1.50	7.00
Crude	**54**	**3.12**	**0.90**	**19.80**
Kuwait (light) Crude (C01)	6	9.25	6.60	11.00
Cook Inlet Crude (C02)	25	2.48	0.90	11.72
Southern Louisiana Crude (C03)	5	9.70	5.50	19.80
Florida Jay Crude (C04)				
Prudhoe Bay Crude (C05)	14	2.10	1.05	7.99
Venezuelan Crude (C06)				
Western Sweet Blend Crude (C07)				
Transmountain Crude (C08)				
Norman Wells Crude (C09)				
Hibernia Crude (C10)				
Amauligak Crude (C11)				
Tarsuit Crude (C12)				
Lago Medio Crude (C13)				
Atkinson Crude (C14)				
Bent Horn Crude (C15)				
Ramashkin Crude (C16)				
West Texas Crude (C17)	4	7.50	5.00	10.00
Diesel	**31**	**3.50**	**0.15**	**7.60**
Diesel (D01)	1	0.89	0.89	0.89
Fuel Oil No. 2 (D02)	22	2.35	0.15	6.90
Fuel Oil No. 2, Furnace Oil (D03)				
Light Diesel Fuel (D04)				
Heavy Diesel Fuel (D05)				
Navy Distillate (D06)	4	7.05	4.30	7.60
Marine Diesel (D07)	4	4.45	2.90	7.20
Gasoline				
Leaded Gasoline (G01)				
Unleaded Gasoline (G02)				
Jet Fuel				
Jet Fuel - JP8 (J01)				
Jet Fuel - JP9 (J03)				
Jet Fuel - JP4 (J04)				
Lube Oil	**4**	**2.25**	**2.00**	**2.70**
Auto Lube (L01)				
Heavy Marine Lube (L02)				
9250 Lube Oil (L03)	4	2.25	2.00	2.70

• *Note: Low reliability data excluded*

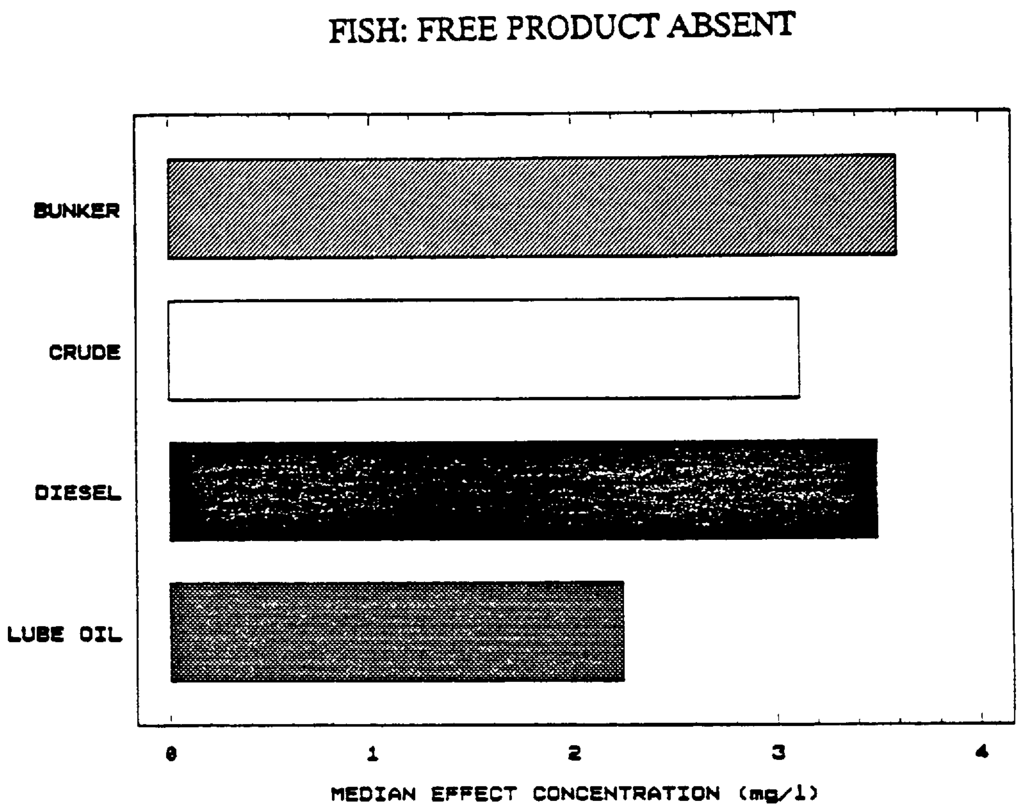

Figure 1-16. Bar chart of median effect LC50 concentrations (mg/l) for fish by oil product group and free product absent.

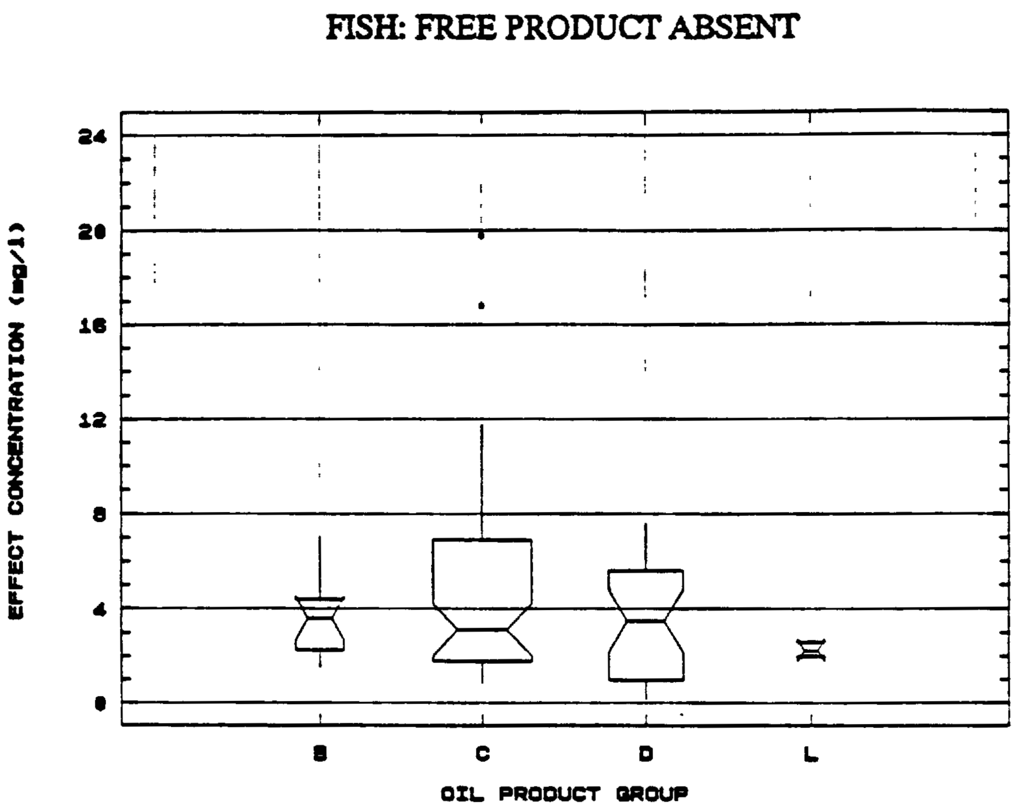

Figure 1-17. Box-and-whisker plot of median effect LC50 concentrations (mg/l) for fish by oil product group and free product absent.

Table 1-18. Effect concentration (mg/l) by lifestage for fish (Free Product Absent).

Oil Product	Fish: Free Product Absent															
	Eggs				Larvae				Juveniles				Adults			
	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max
Bunker													13	3.60	1.50	7.00
Bunker C (unspecified)(B01)																
Venezuelan Bunker C (B02)													9	3.10	1.69	4.70
Bunker C Light (B04)																
Navy Special (B06)													4	4.20	1.50	7.00
Crude	1	2.20	2.20	2.20	2	1.40	0.90	1.90	15	2.04	1.05	7.99	36	5.00	1.22	19.80
Kuwait (light) Crude (C01)													6	9.25	6.60	11.00
Cook Inlet Crude (C02)	1	2.20	2.20	2.20	2	1.40	0.90	1.90	1	1.64	1.64	1.64	21	2.92	1.22	11.72
Southern Louisiana Crude (C03)													5	9.70	5.50	19.80
Florida Jay Crude (C04)																
Prudhoe Bay Crude (C05)									14	2.10	1.05	7.99				
Venezuelan Crude (C06)																
Western Sweet Blend Crude (C07)																
Transmountain Crude (C08)																
Norman Wells Crude (C09)																
Hibernia Crude (C10)																
Amauligak Crude (C11)																
Tarsuit Crude (C12)																
Lago Medio Crude (C13)																
Atkinson Crude (C14)																
Beat Horn Crude (C15)																
Ramashkin Crude (C16)																
West Texas Crude (C17)													4	7.50	5.00	10.00
Diesel													31	3.50	0.15	7.60
Diesel (D01)													1	0.89	0.89	0.89
Fuel Oil No. 2 (D02)													22	2.35	0.15	6.90
Fuel Oil No. 2, Furnace Oil (D03)																
Light Diesel Fuel (D04)																
Heavy Diesel Fuel (D05)																
Navy Distillate (D06)													4	7.05	4.30	7.60
Marine Diesel (D07)													4	4.45	2.90	7.20
Gasoline																
Leaded Gasoline (G01)																
Unleaded Gasoline (G02)																
Jet Fuel																
Jet Fuel - JP8 (J01)																
Jet Fuel - JP4 (J04)																
Lube Oil													4	2.25	2.00	2.70
Auto Lube (L01)																
Heavy Marine Lube (L02)																
9250 Lube Oil (L03)													4	2.25	2.00	2.70

* *Note: Low reliability data excluded*

Table 1-19. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Given Bonferroni's adjustment to the significance level, no statistical differences were found. Critical value = 0.008.

FISH: FREE PRODUCT ABSENT: ADULTS

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
BUNKER	———	(0.07)	(0.96)	no data	no data	(0.21)
CRUDE		———	(0.01)	no data	no data	(0.07)
DIESEL			———	no data	no data	(0.48)
GASOLINE				———	no data	no data
JET FUEL					———	no data
LUBE OIL						———

Methodological Procedure Comparisons

The results of statistical tests for effects of methodological procedures on toxicity values are presented in Appendix Tables B-5 and B-6. These tables contain median LC50 values and statistical levels (p values) calculated for specific methodological procedures. An overview of the statistical comparisons is presented in Table 1-20. The following information details significant differences in the calculated median effect concentration of each oil product group based upon the methodological procedures examined.

Bunker

Whether the test was conducted in freshwater or saltwater had a significant effect on effect concentration values. Saltwater tests had a significantly lower median effect concentration (3.10 mg/l) when compared to freshwater tests (median 5.85 mg/l, $p=0.048$).

Crude

The lifestage tested made a significant difference in effect concentration between juveniles and adults. The median effect concentration of juvenile fish was significantly lower (median 2.04 mg/l) when compared to adults (median 5.00 mg/l, $p<0.002$).

Table 1-20. Overview of statistical comparisons between methodological procedures and oil product: Fish, Free Product Absent.

FISH: FREE PRODUCT ABSENT

	OIL PRODUCT					
	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
Number of Observations	*13*	*54*	*31*	*0*	*0*	*4*
AGITATION DURATION (hours)			*			
TEST SOLUTION DEVELOPMENT (single ratio, multiple ratio)						
TEST CHAMBER (open, closed)						
TEST DURATION (24, 48, 96 HOURS)			*			
LIFE STAGE (egg, juvenile, adult)		*				
EXPOSURE METHOD (static, flow-through)						
TEST CONDITION (saltwater, freshwater)	*		*			
MEASURED/STOCK/ UNMEASURED		*				

Indicates that not enough data points were available for statistical comparison.

Indicates that no comparisons for the given test procedure and oil product resulted in a statistically significant difference.

* Indicates that at least 1 class comparison resulted in a statistically significant difference.

The method of measuring total dissolved hydrocarbon concentrations (as defined in Section 1.2.2.1.5) also had a significant effect on effect concentration values. The median effect concentration value for "measured" (2.21 mg/l) was significantly lower when compared to the "stock" median effect concentration (5.70 mg/l, $p<0.001$).

Diesel

For the diesel group, the duration of agitation during mixing also made a significant difference in the median effect concentration calculated for the product. The median effect concentration for tests conducted with an agitation of between 0 and 1 hour (6.05 mg/l) was significantly higher when compared to tests where the agitation was between 12 and 24 hours (median 2.29 mg/l, $p=0.006$).

A test duration of 24 hours had a significantly higher median effect concentration than the median effect concentration of tests conducted for 96 hours ($p=0.007$).

Whether the test was conducted in freshwater or saltwater also had a significant effect on effect concentration values. Saltwater tests had a significantly lower median effect concentration (2.90 mg/l) when compared to freshwater tests (median 7.30 mg/l, $p=0.004$).

Gasoline

No data available.

Jet Fuel

No data available.

Lube Oil

No significant differences were found between effect concentration and methodological procedure for the lube oil group.

1.3.2.3.2 Ranking of Oil Product Toxicity

The following rankings were developed from the calculated median effect LC50 concentration values.

It appears that in this category the crude, bunker and diesel oil product groups have similar toxicities. Lube oil appears to be slightly more toxic than the other product groups.

The relative ranking of each oil product group, from most toxic to least toxic, is presented in Table 1-21. Table 1-21 includes an overall ranking as well as a ranking by life stage.

Table 1-21. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

FISH: FREE PRODUCT ABSENT

Overall Ranking (across life stages)	Eggs	Larvae	Juvenile	Adult
Lube Oil(2)	no data	no data	no data	Lube Oil(2)
Crude (1)	for	for	for	Diesel (1)
Diesel (1)	ranking	ranking	ranking	Bunker (1)
Bunker (1)				Crude (1)

The above rankings are subject to variations in the following methodological procedures as described in Section 1.3.2.3:

- Agitation duration,
- Test duration,
- Lifestage tested,
- Test condition (freshwater, saltwater), and
- Measured, unmeasured, stock.

As test conditions significantly impacted the median effect concentration for several oil product groups, the overall ranking was refined into a saltwater and freshwater ranking for this category (Table 1-22). These rankings may also be more applicable to a given spill situation.

Table 1-22. Relative ranking of each oil product group by test condition from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

FISH: FREE PRODUCT ABSENT

Overall Ranking (Freshwater Conditions)		Overall Ranking (Saltwater Conditions)	
Lube Oil	(3)	Lube Oil	(2)
Crude	(3)	Diesel	(1)
Bunker	(1)	Bunker	(1)
Diesel	(1)	Crude	(1)

Median effect concentrations calculated for saltwater and freshwater "free product absent" tests with fish did make a difference in the overall ranking. The toxicity of crude is higher to fish in freshwater when compared to bunker and diesel, but under saltwater conditions, bunker and diesel appear more toxic than crude. The range of median effect concentration values in freshwater across oil product groups was 2.60 mg/l to 7.30 mg/l while in saltwater the median effect concentrations across product groups ranged from (2.00 mg/l to 3.73 mg/l).

1.3.2.4 Fish: Free Product Present

A schematic of the results included in this Section is presented in bold print in Figure 1-18.

1.3.2.4.1 Median Toxicity Values

Oil Product Group Comparisons

Crude exhibited the highest (least toxic) median effect LC50 concentration (1365 mg/l) while diesel exhibited the lowest (most toxic) effect concentration (45.10 mg/l).

The median effect LC50 concentration values for fish by oil product group are presented in Table 1-23 and Figure 1-19. The distribution of effect LC50 concentration values are

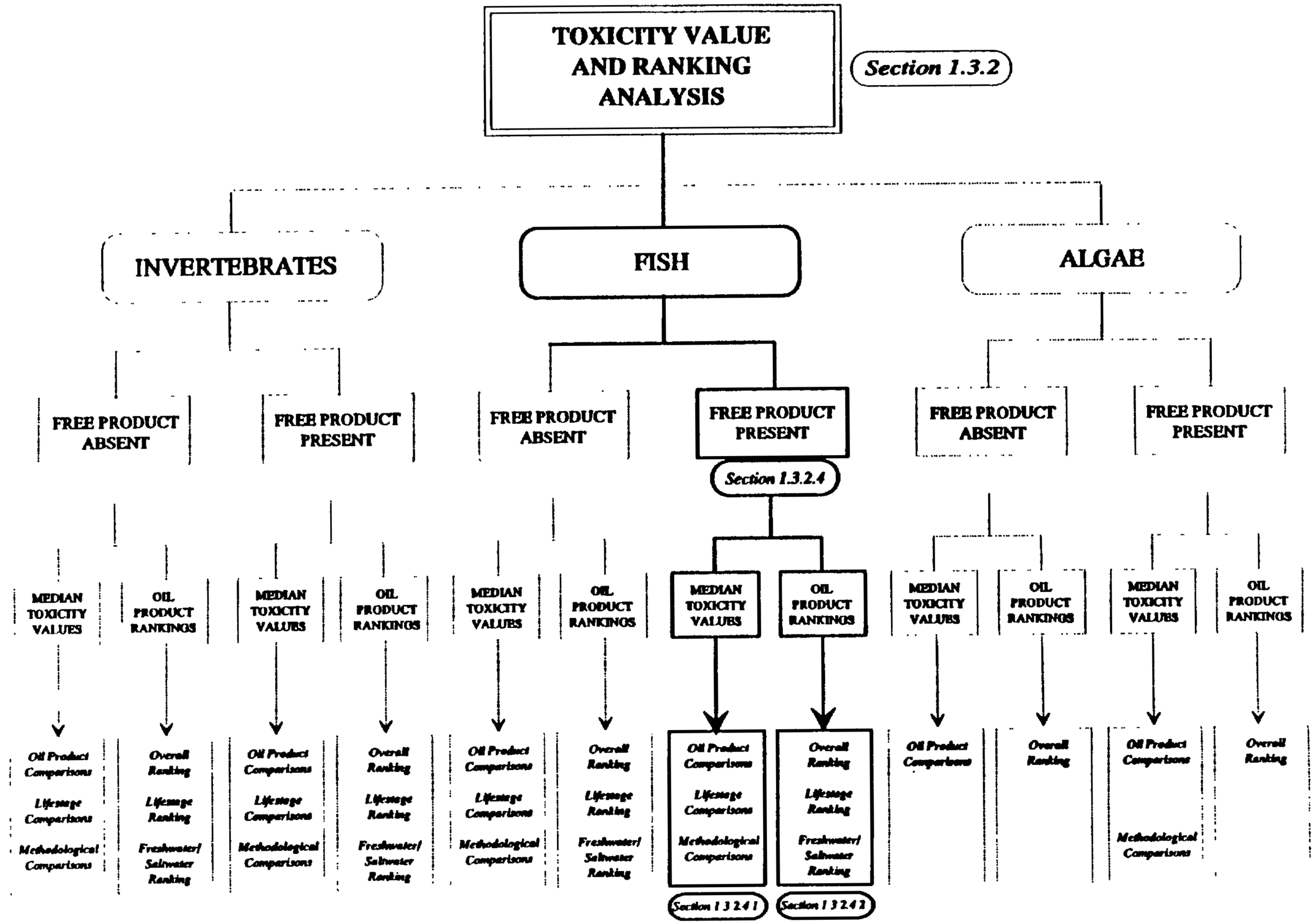

Figure 1-18. Diagram of the toxicity value and ranking analysis scheme for Section 1.3.2.4.

Table 1-23. Median effect concentrations (mg/l) for fish by oil product. (Free Product Present)

Oil Product	Fish — Free Product Present N	Median	Min	Max
Bunker	**4**	**55.70**	**10.00**	**250.00**
Bunker C (unspecified)(B01)				
Venezuelan Bunker C (B02)				
Bunker C Light (B04)				
Navy Special (B06)	4	55.70	10.00	250.00
Crude	**46**	**1365**	**15.00**	**80000**
Kuwait (light) Crude (C01)	16	2615	15.00	80000
Cook Inlet Crude (C02)				
Southern Louisiana Crude (C03)	14	4350	15.00	80000
Florida Jay Crude (C04)				
Prudhoe Bay Crude (C05)	12	1525	40.00	3200
Venezuelan Crude (C06)				
Western Sweet Blend Crude (C07)				
Transmountain Crude (C08)				
Norman Wells Crude (C09)				
Hibernia Crude (C10)				
Amauligak Crude (C11)				
Tarsuit Crude (C12)				
Lago Medio Crude (C13)				
Atkinson Crude (C14)				
Bent Horn Crude (C15)				
Ramashkin Crude (C16)				
West Texas Crude (C17)	4	61.50	27.00	200.00
Diesel	**20**	**45.10**	**3.80**	**9600**
Diesel (D01)				
Fuel Oil No. 2 (D02)	12	162.50	33.00	9600
Fuel Oil No. 2, Furnace Oil (D03)				
Light Diesel Fuel (D04)				
Heavy Diesel Fuel (D05)				
Navy Distillate (D06)	4	11.50	3.80	41.00
Marine Diesel (D07)	4	21.75	5.10	47.20
Gasoline				
Leaded Gasoline (G01)				
Unleaded Gasoline (G02)				
Jet Fuel	**8**	**560.00**	**1.85**	**1600**
Jet Fuel - JP8 (J01)				
Jet Fuel - JP9 (J03)	4	525.00	470.00	560
Jet Fuel - JP4 (J04)	4	595.00	1.85	1600
Lube Oil	**3**	**68.00**	**33.00**	**103.00**
Auto Lube (L01)				
Heavy Marine Lube (L02)				
9250 Lube Oil (L03)	3	68.00	33.00	103.00

• *Note: Low reliability data excluded*

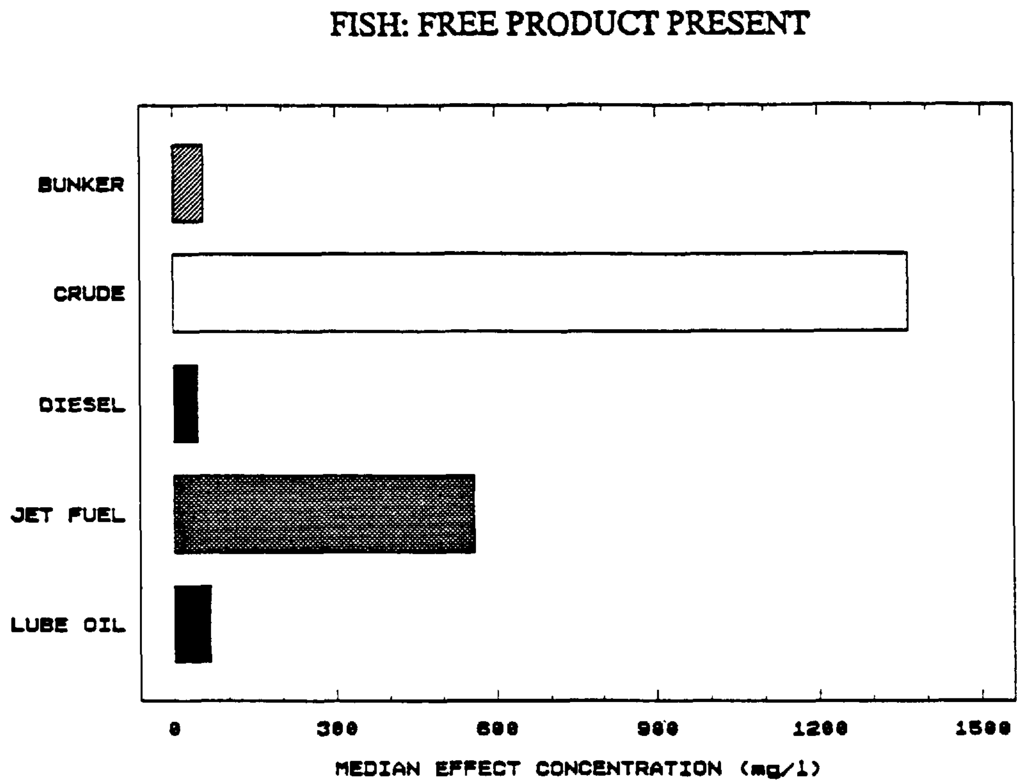

Figure 1-19. Bar chart of median effect LC50 concentrations (mg/l) for fish by oil product group and free product present.

presented in Figure 1-20. Figure 1-20 is presented on the following page.

Median effect LC50 concentrations were not significantly different except between the crude and diesel oil product groups ($p<0.001$). Pairwise comparisons of median LC50 values by oil product group are presented in Table 1-24.

Table 1-24. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.005.

FISH: FREE PRODUCT PRESENT

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
BUNKER	———	(0.028)	(0.82)	no data	(0.05)	(0.86)
CRUDE		———	**(<0.001)**	no data	(0.16)	(0.13)
DIESEL			———	no data	(0.024)	(1.00)
GASOLINE				———	no data	no data
JET FUEL					———	(0.08)
LUBE OIL						———

Lifestage Comparisons of Fish

The median effect LC50 concentration values for fish by lifestage are presented in Table 1-25.

Effect concentration data for fish for life stages egg and juvenile were available only for the crude oil product group. No larval fish data were available.

No acceptable adult effect concentration data were available for the gasoline product group (see Appendix C). There was a significant difference in median effect concentration for adults between the crude oil product group and the other oil product groups. Pairwise comparisons of median LC50 values between the oil product groups are presented in Table 1-26.

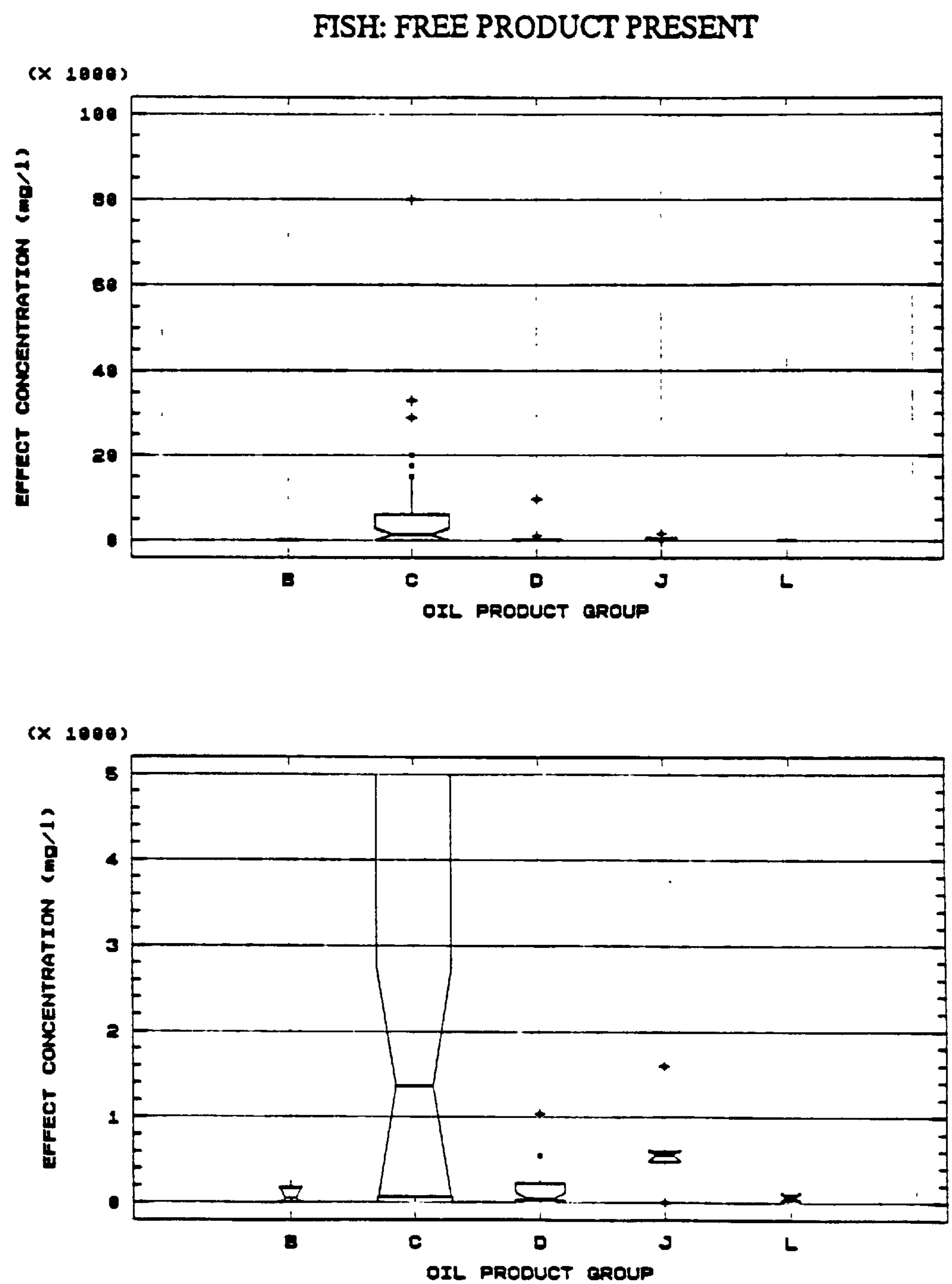

Figure 1-20. Box-and-whisker plot of median effect LC50 concentrations (mg/l) for fish by oil product group and free product present.

Table 1-25. Effect concentration (mg/l) by lifestage for fish (Free Product Present).

Oil Product	Fish: Free Product Present															
	Eggs				Larvae				Juveniles				Adults			
	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max
Bunker													4	55.70	10.00	250.00
Bunker C (unspecified)(B01)						No data										
Venezuelan Bunker C (B02)																
Bunker C Light (B04)																
Navy Special (B06)													4	55.70	10.00	250.00
Crude	4	3200	3200	3200					10	560.00	15.00	3200	32	2550	15.00	80000
Kuwait (light) Crude (C01)													16	2615	15.00	80000
Cook Inlet Crude (C02)																
Southern Louisiana Crude (C03)									2	427.50	15.00	840.00	12	5500	62.00	80000
Florida Jay Crude (C04)																
Prudhoe Bay Crude (C05)	4	3200	3200	3200					8	560.00	40.00	3200				
Venezuelan Crude (C06)																
Western Sweet Blend Crude (C07)																
Transmountain Crude (C08)																
Norman Wells Crude (C09)																
Hibernia Crude (C10)																
Amauligak Crude (C11)																
Tarsuit Crude (C12)																
Lago Medio Crude (C13)																
Atkinson Crude (C14)																
Bent Horn Crude (C15)																
Ramashkin Crude (C16)																
West Texas Crude (C17)													4	61.50	27.00	200.00
Diesel													20	45.10	3.80	9600
Diesel (D01)																
Fuel Oil No. 2 (D02)													12	162.5	33.00	9600
Fuel Oil No. 2, Furnace Oil (D03)																
Light Diesel Fuel (D04)																
Heavy Diesel Fuel (D05)																
Navy Distillate (D06)													4	11.50	3.80	41.00
Marine Diesel (D07)													4	21.75	5.10	47.20
Gasoline																
Leaded Gasoline (G01)																
Unleaded Gasoline (G02)																
Jet Fuel													8	560.00	1.85	1600
Jet Fuel - JP9 (J03)													4	525.00	470.00	560.00
Jet Fuel - JP4 (J04)													4	595.00	1.85	1600
Lube Oil													3	68.00	33.00	103.00
Auto Lube (L01)																
Heavy Marine Lube (L02)																
9250 Lube Oil (L03)													3	68.00	33.00	103.00

* *Note: Low reliability data excluded*

Table 1-26. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.005.

FISH: FREE PRODUCT PRESENT: ADULTS

	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
BUNKER	----------	(0.04)	(0.82)	no data	(0.05)	(0.86)
CRUDE		----------	**(<0.001)**	no data	(0.18)	(0.18)
DIESEL			----------	no data	(0.024)	(1.00)
GASOLINE				----------	no data	no data
JET FUEL					----------	(0.08)
LUBE OIL						----------

Methodological Procedure Comparisons

The results of statistical tests for effects of methodological procedures on toxicity values are presented in Appendix Tables B-7 and B-8. These tables contain median LC50 values and statistical levels (p values) calculated for specific methodological procedures. An overview of the statistical comparisons is presented in Table 1-27. The following information reviews significant differences in the calculated median effect concentration of each oil product group based upon the methodological procedures examined.

Bunker

No significant differences were found between effect concentration and methodological procedure for the bunker oil group.

Crude

Test solution development had a significant difference on the effect concentration. Single ratio tests had a lower median effect concentration (40 mg/l) when compared to the median effect concentration (3200 mg/l) for multiple ratio tests ($p<0.001$).

The method of measuring total dissolved hydrocarbon concentrations (as defined in Section 1.2.2.1.5) also had a significant effect on effect concentration values. The median effect concentration value for "unmeasured" (3200 mg/l) was significantly higher when compared to

Table 1-27. Overview of statistical comparisons between methodological procedures and oil product: Fish, Free Product Present.

FISH: FREE PRODUCT PRESENT

OIL PRODUCT

TEST PROCEDURE	BUNKER	CRUDE	DIESEL	GASOLINE	JET FUEL	LUBE OIL
Number of Observations	*4*	*46*	*20*	*0*	*8*	*3*
AGITATION DURATION (hours)			*			
TEST SOLUTION DEVELOPMENT (single ratio, multiple ratio)		*	*			
TEST CHAMBER (open, closed)						
TEST DURATION (24, 48, 96 HOURS)						
LIFE STAGE (egg, juvenile, adult)						
EXPOSURE METHOD (static, flow-through)			*			
TEST CONDITION (saltwater, freshwater)			*			
MEASURED/STOCK/ UNMEASURED		*	*			

Indicates that not enough data points were available for statistical comparison.

Indicates that no comparisons for the given test procedure and oil product resulted in a statistically significant difference.

* Indicates that at least 1 class comparison resulted in a statistically significant difference.

"measured" and "stock" median effect concentrations ($p<0.002$ and $p<0.001$, respectively). The median effect concentration value for "measured" (42 mg/l) was not significantly different when compared to the "stock" median effect concentration (40 mg/l, $p=1.00$).

Diesel

For the diesel group, the duration of agitation during mixing made a significant difference in the median effect concentration calculated for the product. The median effect concentration for tests conducted with no agitation (795 mg/l) was significantly higher than the median effect concentration for those with an agitation of between 0 and 1 hour (38.75 mg/l, $p=0.02$).

Test solution development had a significant difference on the effect concentration. Single ratio tests had a lower median effect concentration (12.70 mg/l) when compared to the median effect concentration (162.50 mg/l) for multiple ratio tests ($p<0.002$).

The exposure method had a significant difference on the effect concentration. Static tests exhibited a lower median effect concentration (38.75 mg/l) when compared to flow-through tests which had a median effect concentration of 795.00 mg/l ($p=0.02$).

Whether the test was conducted in freshwater or saltwater also had a significant effect on effect concentration values. Saltwater tests had a significantly higher median effect concentration (70.50 mg/l) when compared to freshwater tests (median 12.70 mg/l, $p=0.03$).

The method of measuring total dissolved hydrocarbon concentrations (as defined in Section 1.2.2.1.5) also had a significant effect on effect concentration values. The median effect concentration value for "unmeasured" (162.50 mg/l) was significantly higher when compared to the "stock" median effect concentration (12.70 mg/l, $p<0.002$).

Gasoline

No data available.

Jet Fuel

No significant differences were found between effect concentration and methodological procedure for the jet fuel group.

Lube Oil

No significant differences were found between effect concentration and methodological procedure for the lube oil group.

1.3.2.4.2 Ranking of Oil Product Toxicity

The following rankings were developed from the calculated median effect LC50 concentration values.

It appears than in this category (fish, free product present) that diesel, bunker and lube oil are much more toxic when compared to crude oil or jet fuel.

The relative ranking of each oil product group, from most toxic to least toxic, is presented in Table 1-28. Table 1-28 includes an overall ranking as well as a ranking by life stage.

Table 1-28. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product is compared to the median concentration of the least toxic oil product.

FISH: FREE PRODUCT PRESENT

Overall Ranking (across life stages)	Eggs	Larvae	Juvenile	Adult
Diesel (30)	no data	no data	no data	Diesel (57)
Bunker (25)	for		for	Bunker (46)
Lube Oil(20)	ranking		ranking	Lube Oil(38)
Jet Fuel (2)				Jet Fuel (5)
Crude (1)				Crude (1)

The above rankings are subject to variations in the following methodological procedures as described in Section 1.3.2.4:

- Agitation duration,
- Test solution development (single, multiple ratio),
- Exposure method (static, flow-through),
- Test conditions (freshwater, saltwater), and
- Measured, unmeasured, stock.

Since test conditions significantly impacted the median effect concentration for the diesel oil product group, the overall ranking was refined into a saltwater and freshwater ranking for this category (Table 1-29). These rankings may also be more applicable to a given spill situation.

Median effect concentrations calculated for saltwater and freshwater "free product present" tests did make a difference in the overall ranking. It appears that the toxicity of crude to fish, when free product is present, is low compared to all other oil product groups. The median effect concentration for crude in freshwater was 1525 mg/l while across the other oil product groups the median effect concentration ranged from 12.70 mg/l to 560 mg/l. In saltwater the median effect concentration of crude was 1365 mg/l while across the other product groups the median effect concentration ranged from 55.00 mg/l to 70.50 mg/l.

Table 1-29. Relative ranking of each oil product group by test condition from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

FISH: FREE PRODUCT PRESENT

Overall Ranking (Freshwater Conditions)	Overall Ranking (Saltwater Conditions)
Diesel (120)	Bunker (25)
Lube Oil (22)	Lube Oil (20)
Bunker (12)	Diesel (19)
Jet Fuel (3)	Crude (1)
Crude (1)	

1.3.2.5 Algae: Free Product Absent

A schematic of the results included in this Section is presented in bold print in Figure 1-21.

1.3.2.5.1 Median Toxicity Values

Oil Product Group Comparisons

The median effect LC50 concentration values for algae by oil product group are presented in Table 1-30 and Figure 1-22. The distribution of effect LC50 concentration values is presented in Figure 1-23. Figure 1-21, Table 1-30, Figure 1-22 and Figure 1-23 are presented on the following 4 pages.

A total of 10 algal toxicity values were collected for this category. Data on algal toxicity was for crude (5 records), diesel (4 records), and jet fuel (1 record). The median effect concentrations between each product group were not significantly different (p=0.92). Pairwise comparisons of median LC50 values by oil product group are presented in Table 1-31.

Table 1-31. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.017.

ALGAE: FREE PRODUCT ABSENT

	CRUDE	DIESEL	JET FUEL
CRUDE	———	(0.90)	(1.00)
DIESEL		———	(1.00)
JET FUEL			———

Methodological Procedure Comparisons

Not enough data were available to analyze test procedures for each study group.

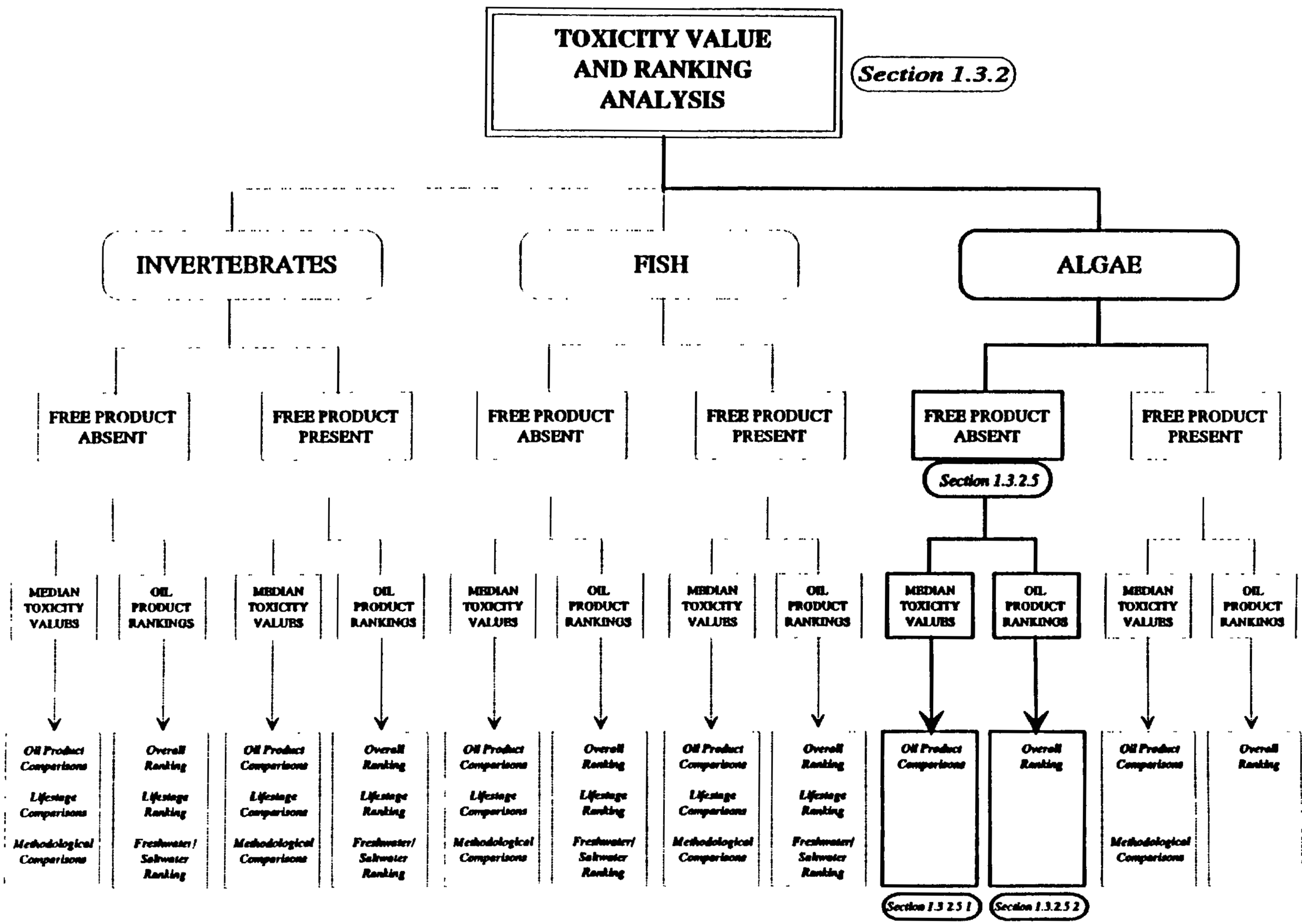

Figure 1-21. Diagram of the toxicity value and ranking analysis scheme for Section 1.3.2.5.

Table 1-30. Median effect concentrations (mg/l) for Algae by oil product. (Free Product Absent)

Oil Product	Algae Free Product Absent N	Median	Min	Max
Bunker				
Bunker C (unspecified)(B01)				
Venezuelan Bunker C (B02)				
Bunker C Light (B04)				
Navy Special (B06)				
Crude	**5**	**4.80**	**1.00**	**5.00**
Kuwait (light) Crude (C01)				
Cook Inlet Crude (C02)				
Southern Louisiana Crude (C03)				
Florida Jay Crude (C04)				
Prudhoe Bay Crude (C05)				
Venezuelan Crude (C06)				
Western Sweet Blend Crude (C07)				
Transmountain Crude (C08)				
Norman Wells Crude (C09)				
Hibernia Crude (C10)				
Amauligak Crude (C11)				
Tarsuit Crude (C12)				
Lago Medio Crude (C13)				
Atkinson Crude (C14)				
Nigerian Crude (C19)	5	4.80	1.00	5.00
Pembina Crude (C20)				
Alaskan Crude-unspec-ARCO(C21)				
Diesel	**4**	**4.30**	**2.00**	**5.00**
Diesel (D01)				
Fuel Oil No. 2 (D02)	4	4.30	2.00	5.00
Fuel Oil No. 2, Furnace Oil (D03)				
Light Diesel Fuel (D04)				
Heavy Diesel Fuel (D05)				
Navy Distillate (D06)				
Marine Diesel (D07)				
Gasoline				
Leaded Gasoline (G01)				
Unleaded Gasoline (G02)				
Jet Fuel	**1**	**4.20**	**4.20**	**4.20**
Jet Fuel - JP8 (J01)	1	4.20	4.20	4.20
Jet Fuel - JP9 (J03)				
Jet Fuel - JP4 (J04)				
Lube Oil				
Auto Lube (L01)				
Heavy Marine Lube (L02)				
9250 Lube Oil (L03)				

* *Note: Low reliability data excluded*

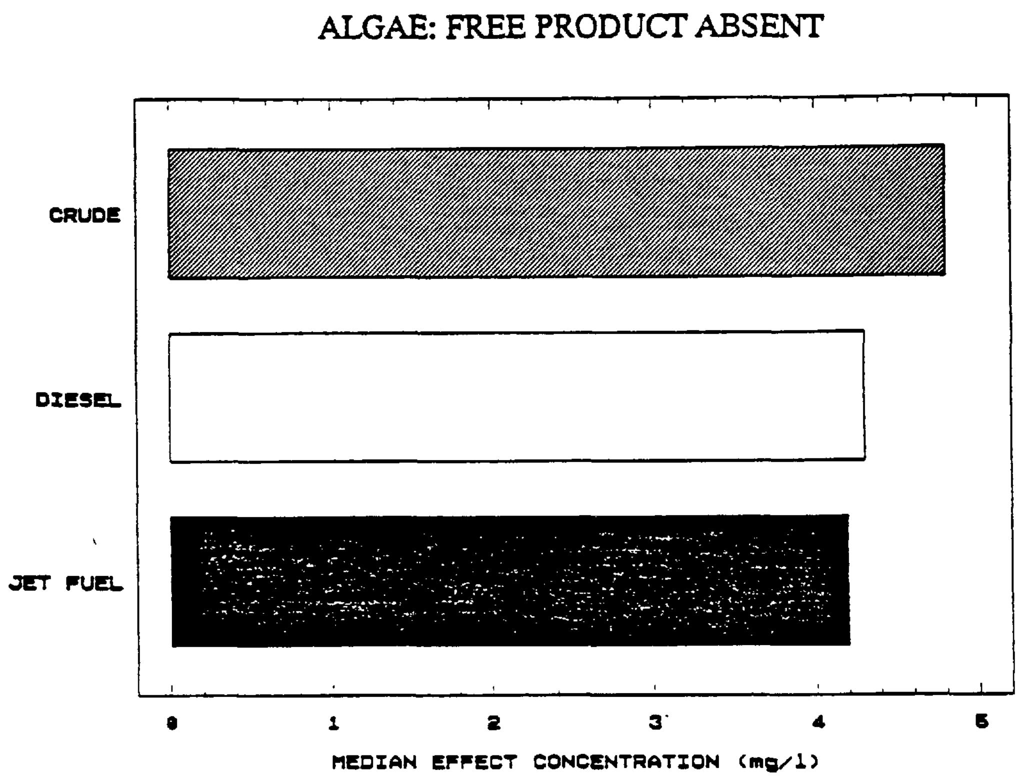

Figure 1-22. Bar chart of median effect LC50 concentrations (mg/l) for algae by oil product group and free product absent.

ALGAE: FREE PRODUCT ABSENT

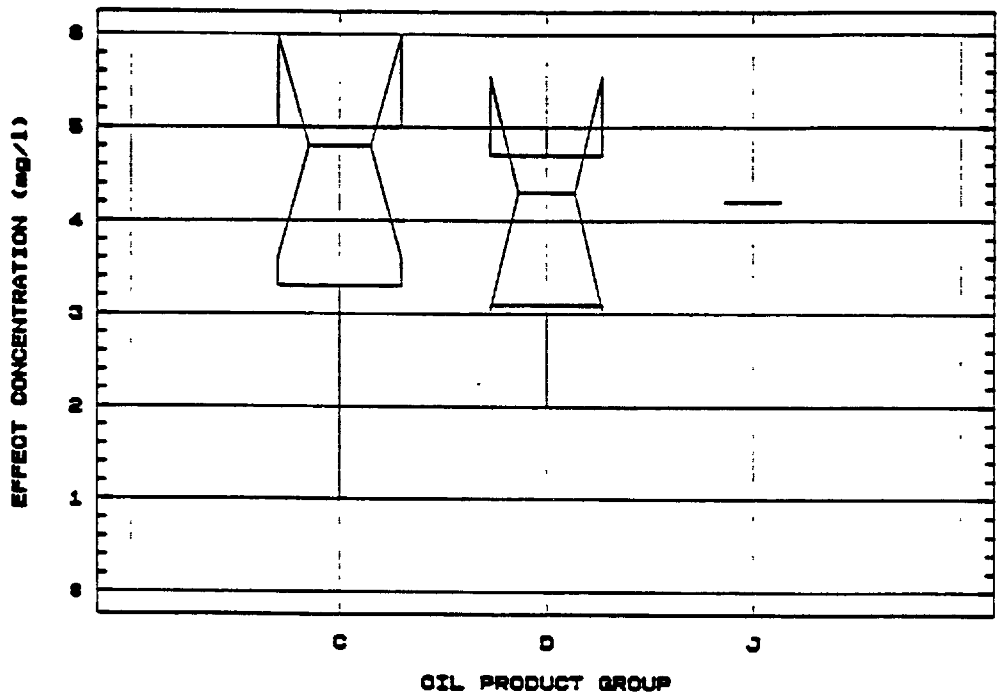

Figure 1-23. Box-and-whisker plot of median effect LC50 concentrations (mg/l) for algae by oil product group and free product absent.

1.3.2.5.2 Ranking of Oil Product Toxicity

The following rankings were developed from the calculated median effect LC50 concentration values. The relative ranking of each oil product group, from most toxic to least toxic, is presented in Table 1-32. Table 1-32 includes an overall ranking only.

Table 1-32. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

ALGAE: FREE PRODUCT ABSENT

Overall Ranking

Jet Fuel (1)
Diesel (1)
Crude (1)

1.3.2.6 Algae: Free Product Present

A schematic of the results included in this Section is presented in bold print in Figure 1-24.

1.3.2.6.1 Median Toxicity Values

Oil Product Group Comparisons

The median effect LC50 concentration values for algae by oil product group are presented in Table 1-33 and Figure 1-25. The distribution of effect LC50 concentration values are presented in Figure 1-26. Table 1-33, Figure 1-24, Figure 1-25 and Figure 1-26 are presented on the following 4 pages.

A total of 45 algal toxicity values were collected for this category. Data on algal toxicity were found for crude (28 records), diesel (15 records), and jet fuel (2 records). The median effect concentrations were not significantly different ($p=0.90$). Pairwise comparisons of median LC50 values by oil product group are presented in Table 1-34.

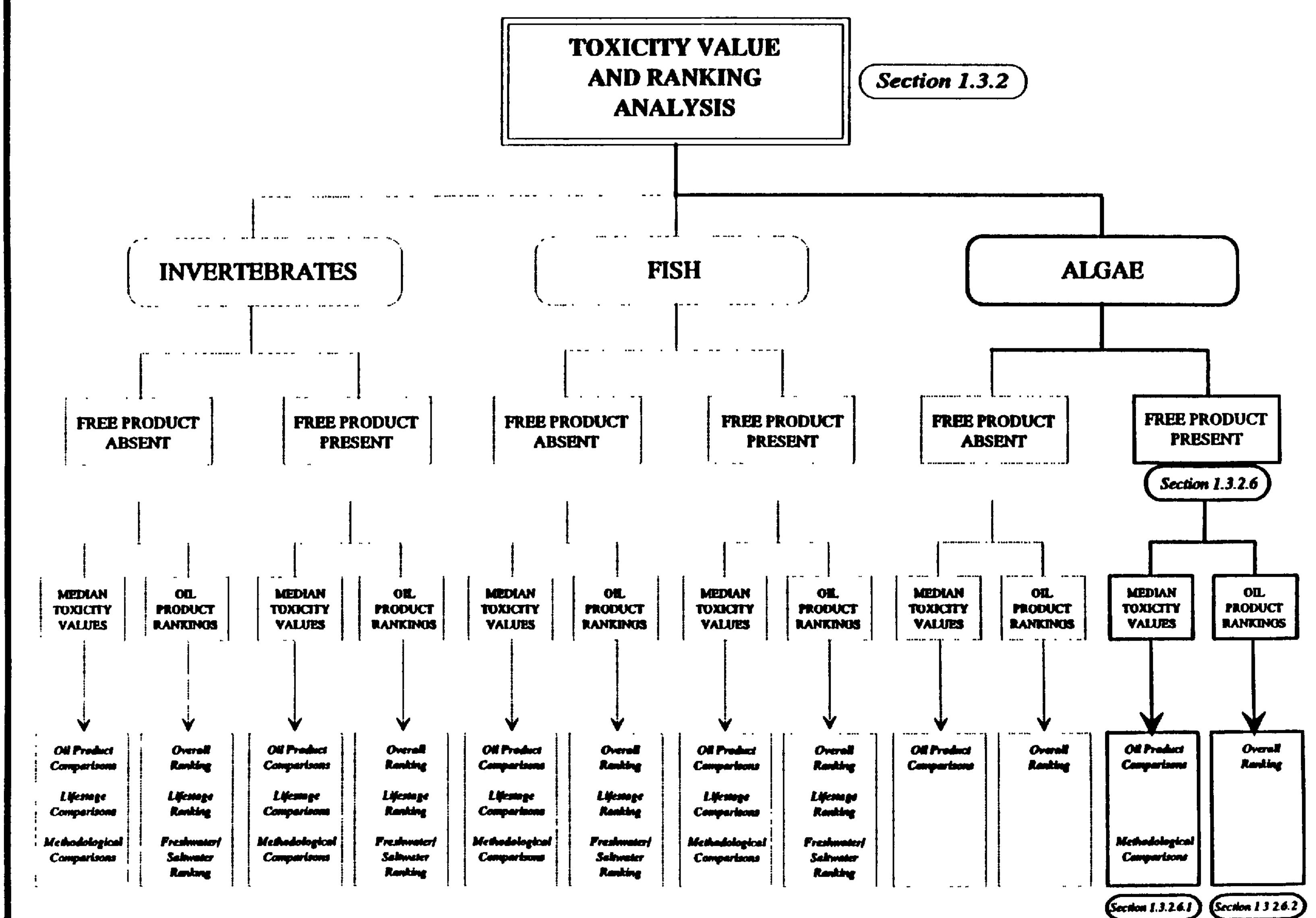

Figure 1-24. Diagram of the toxicity value and ranking analysis scheme for Section 1.3.2.6.

Table 1-33. Median effect concentrations (mg/l) for Algae by oil product. (Free Product Present)

Oil Product	Algae Free Product Present N	Median	Min	Max
Bunker				
Bunker C (unspecified)(B01)				
Venezuelan Bunker C (B02)				
Bunker C Light (B04)				
Navy Special (B06)				
Crude	**28**	**95.00**	**1.00**	**1500**
Kuwait (light) Crude (C01)	3	1500	1500	1500
Cook Inlet Crude (C02)				
Southern Louisiana Crude (C03)	3	1500	1500	1500
Florida Jay Crude (C04)				
Prudhoe Bay Crude (C05)				
Venezuelan Crude (C06)	7	70.00	1.00	1500
Western Sweet Blend Crude (C07)				
Transmountain Crude (C08)				
Norman Wells Crude (C09)	4	1.00	1.00	30.00
Hibernia Crude (C10)				
Amauligak Crude (C11)				
Tarsuit Crude (C12)				
Lago Medio Crude (C13)				
Atkinson Crude (C14)	4	3.00	1.00	600.00
Nigerian Crude (C19)				
Pembina Crude (C20)	4	4.50	1.00	120.00
Alaskan Crude-unspec-ARCO(C21)	3	1500	1500	1500
Diesel	**15**	**50.00**	**50.00**	**1500**
Diesel (D01)				
Fuel Oil No. 2 (D02)	15	50.00	50.00	1500
Fuel Oil No. 2, Furnace Oil (D03)				
Light Diesel Fuel (D04)				
Heavy Diesel Fuel (D05)				
Navy Distillate (D06)				
Marine Diesel (D07)				
Gasoline				
Leaded Gasoline (G01)				
Unleaded Gasoline (G02)				
Jet Fuel	**2**	**210.00**	**160.00**	**260.00**
Jet Fuel - JP8 (J01)	1	260.00	260.00	260.00
Jet Fuel - JP9 (J03)				
Jet Fuel - JP4 (J04)	1	160.00	160.00	160.00
Lube Oil				
Auto Lube (L01)				
Heavy Marine Lube (L02)				
9250 Lube Oil (L03)				

* *Note: Low reliability data excluded*

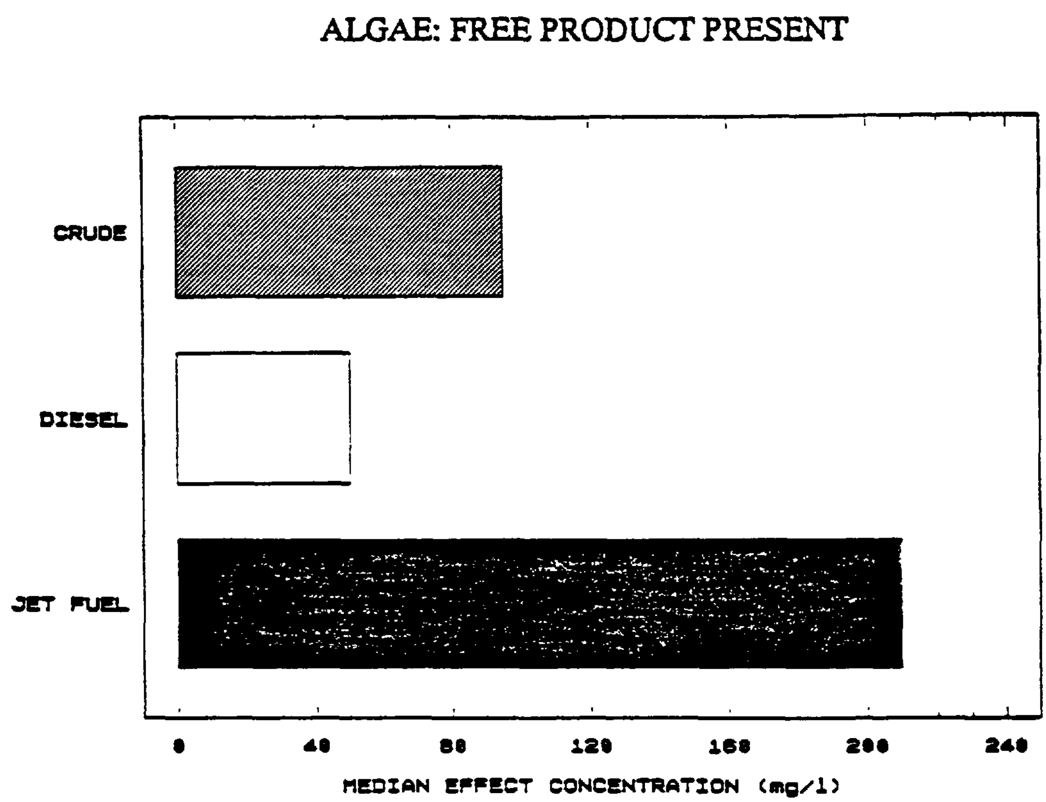

Figure 1-25. Bar chart of median effect LC50 concentrations (mg/l) for algae by oil product group and free product present.

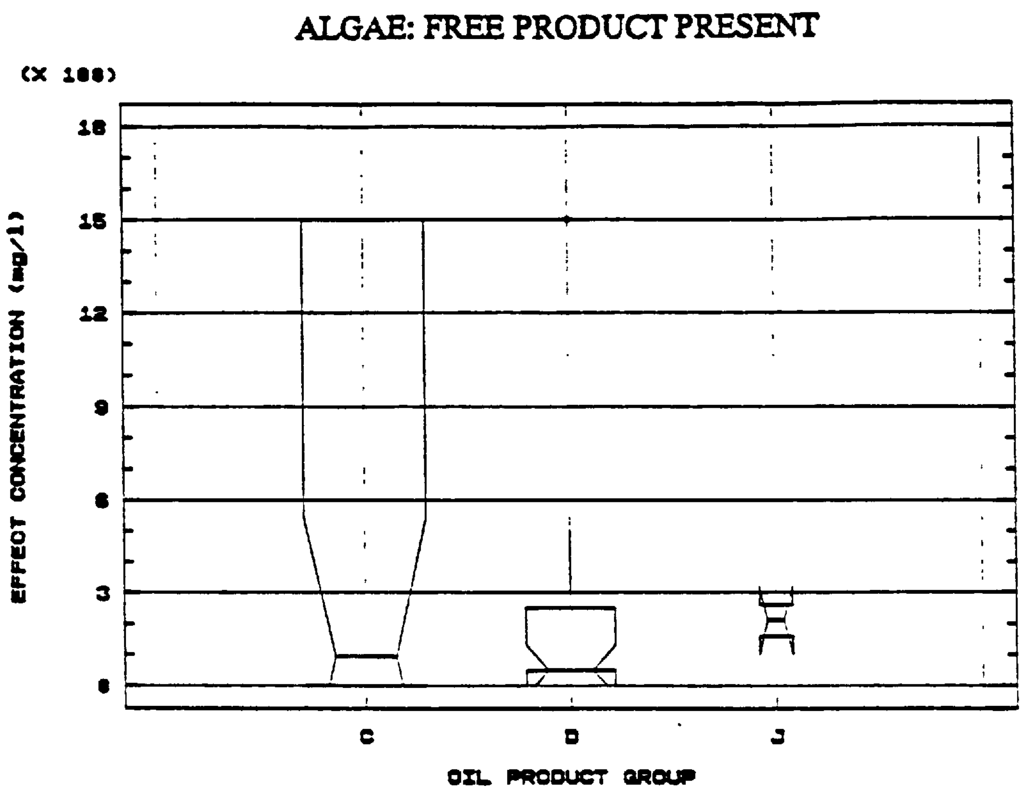

Figure 1-26. Box-and-whisker plot of median effect LC50 concentrations (mg/l) for algae by oil product group and free product present.

Table 1-34. Statistical significance (p-values) of comparisons between oil product groups. Bold indicates significance. Critical value = 0.017.

ALGAE: FREE PRODUCT PRESENT

	CRUDE	DIESEL	JET FUEL
CRUDE	———	(0.93)	(0.90)
DIESEL		———	(0.37)
JET FUEL			———

Methodological Procedure Comparisons

The results of statistical tests for effects of methodological procedures on toxicity values are presented in Appendix Table B-9. This table contains median LC50 values and statistical levels (p values) calculated for specific methodological procedures. An overview of the statistical comparisons is presented in Table 1-35. The following information details significant differences in the calculated median effect concentration of each oil product group based upon the methodological procedures examined.

Crude

No significant differences were found between effect concentration and methodological procedure for the crude group with the exception of closed test chambers vs studies where the test chamber was not reported.

Diesel

No significant differences were found between effect concentration and methodological procedure for the diesel group.

Jet Fuel

No significant differences were found between effect concentration and methodological procedure for the jet fuel group.

Table 1-35. Overview of statistical comparisons between methodological procedures and oil product: Algae, Free Product present.

ALGAE: FREE PRODUCT PRESENT

TEST PROCEDURE	OIL PRODUCT: CRUDE	OIL PRODUCT: DIESEL	OIL PRODUCT: JET FUEL
Number of Observations	*28*	*15*	*2*
AGITATION DURATION (hours)			
TEST SOLUTION DEVELOPMENT (single ratio, multiple ratio)			
TEST CHAMBER (open, closed)	*		
TEST DURATION (24, 48, 96 HOURS)			
LIFE STAGE (egg, juvenile, adult)			
EXPOSURE METHOD (static, flow-through)			
TEST CONDITION (saltwater, freshwater)			
MEASURED/STOCK/ UNMEASURED			

(shaded box) Indicates that not enough data points were available for statistical comparison.

(empty box) Indicates that no comparisons for the given test procedure and oil product resulted in a statistically significant difference.

* Indicates that at least 1 class comparison resulted in a statistically significant difference.

1.3.2.6.2 Ranking of Oil Product Toxicity

The following rankings were developed from the calculated median effect LC50 concentration values. The relative ranking of each oil product group, from most toxic to least toxic, is presented in Table 1-36. Table 1-36 includes an overall ranking only.

Table 1-36. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

ALGAE: FREE PRODUCT PRESENT

<u>Overall Ranking</u>

Diesel (4)
Crude (2)
Jet Fuel (1)

When evaluating these rankings it should be noted that the jet fuel data were conducted in freshwater and the crude oil product group data was conducted under saltwater conditions. Information was not available as to whether the diesel data were from tests conducted under freshwater or saltwater conditions.

1.3.3 LL50 Value Calculations

The LL50 data set was created from the existing database and used to rank oil product toxicity by major taxon and oil product group. The LL50 concept was described in the Methods Section of this chapter. The LL50 data set consisted of 130 LC50 values which were derived using multiple ratio test solutions where the concentrations were "unmeasured". The number of data records (LL50 values) by taxonomic group and oil product are presented in Table 1-37.

Table 1-37. The number of data records (LL50 values) by taxonomic group and oil product.

Oil Product	All Taxon Combined	Fish	Inverts	Algae
CRUDE	80	34	18	28
DIESEL	40	12	13	15
JET FUEL	10	8	---	2

The majority of LL50 data are in the crude and diesel product groups. LL50 data are lacking for the bunker, gasoline and lube oil groups. The median (and range) of LL50 values, where available, by oil product and taxonomic group are presented in Table 1-38.

Table 1-38. The median and range ( ) of LL50 values (mg/l) by taxonomic group and oil product.

Oil Product	Fish	Invertebrates	Algae
CRUDE	3200 (40 - 80,000)	475 (25 - 13,500)	95 (1 - 1,500)
DIESEL	162.5 (33 - 9,600)	9.4 (1.3 - 4,778)	50 (50 - 1,500)
JET FUEL	560 (1.85 - 1,600)	No Data	210 (160 - 260)

The median LL50 value for crude in both the fish and invertebrate groups is significantly higher ($p < 0.001$, less toxic) when compared to diesel. For the algae group, there were no significant differences between the oil products. The relative rankings of the oil products by LL50 values by major taxonomic group are presented in Table 1-39.

Table 1-39. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

LL50 TOXICITY VALUE RANKINGS

Overall Ranking	Fish	Invertebrates	Algae
Diesel (29)	Diesel (20)	Diesel (51)	Diesel (4)
Jet Fuel (3)	Jet Fuel (6)	Crude (1)	Crude (2)
Crude (1)	Crude (1)		Jet Fuel (1)

In the overall ranking, the diesel group appears to be the most toxic with the crude group being the least toxic. The median LL50 value for diesel is significantly higher than the median LL50 value for crude in the above overall, fish and invertebrate rankings. In the algae ranking, there is no significant difference between median values of any of the oil products.

1.4. DISCUSSION AND SUMMARY: ANALYSIS AND RANKING OF TOXICITY VALUES

1.4.1 Literature Search and Collection

In total, approximately 8,000 references on the fate and effects of oil products in aquatic systems were screened. The majority of the selected articles were published in the mid to late 1970's. While there was an adequate proportion of high quality articles reviewed, comparability between papers was limited due to variability in test methodologies. The final developed database contained 748 data records. The dataset used in our analysis excluded 52 "low reliability" records and 7 "NOEC" data records. The final dataset was comprised of 689 data records.

The majority of the data were on crude oils (55%) and diesel (31%). Gasoline, jet fuel, and lube oil combined comprised less than 7% of the total number of data records in the database. Invertebrate data comprised 65.4% of the data records in the database. Fish comprised 26.6% of the data while algae comprised only 8% of the data. Appropriate data for aquatic macrophytes were not found. Approximately 75% of the data records were for "free product absent" studies while 25% of the data records were for "free product present" studies. Over 90% of the invertebrate data was comprised of "free product absent" data while approximately 56% of the fish data was "free product absent" data. Only 18% of the algal data was "free product absent" data.

1.4.2 Analysis and Ranking of Oil Product Toxicity

An analysis was performed for the following 6 oil product groups and 3 taxonomic groups:

Oil Product Group	Taxonomic Group
Bunker	Invertebrates
Crude	Fish
Diesel	Algae
Gasoline	
Jet Fuel	
Lube Oil	

The analysis was further divided into "free product present" and "free product absent" data.

In order to arrive at valid toxicity values and rankings of the oil products, a careful review of test solution and exposure methodology, as well as endpoint computation, was performed. Test methods were shown to provide significantly different results depending upon the procedures used and how endpoint results are calculated. In many cases methodological procedures were important in determining calculated "free product absent" and "free product present" values. These procedures included whether the test chamber was open or closed, the test was conducted in freshwater or saltwater, the duration of agitation prior to testing, the duration of the test, and whether the oil product concentration was measured from a stock solution or other method.

In order to normalize the data to minimize the influence of test methodologies and calculation procedures, the analysis was conducted by taxonomic group for studies where free product was absent and free product was present. LC50 values calculated for "free product absent" data were significantly different than LC50 values calculated for "free product present" data for the same oil products and taxonomic groups.

Median toxicity values were computed for each oil product and taxonomic group by the absence and presence of free product (Table 1-40). In all cases, "free product absent" data had higher median effect concentrations when compared to respective "free product present" median effect concentration data. The median toxicity values presented in Table 1-40 were used to provide a ranking of oil products by taxon and the absence or presence of free product (Figure 1-27). Where data were available, rankings by lifestage were presented.

Algal data were not available for the bunker, gasoline and lube oil groups. Gasoline data (12 values) were available only for the invertebrate "free product absent" data set. Only twelve data values were available for the jet fuel data set.

The present review indicates that the more toxic oil product groups are the diesel, bunker and lube oil groups. The least toxic oil product groups were the crude, jet fuel and gasoline groups. Data were sparse for the jet fuel, gasoline and lube oil groups.

If all the data were combined across taxon and across the presence or absence of free product, the oil products would be ranked as follows in Table 1-41.

Table 1-40. Effect concentration (LC50, mg/l) by oil product, taxonomic group, free product presence and free product absence.

Oil Product	Invertebrates								Fish								Algae							
	Free Product Absent				Free Product Present				Free Product Absent				Free Product Present				Free Product Absent				Free Product Present			
	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max
Bunker	28	3.00	0.90	6.30	2	55.85	11.70	100.00	13	3.60	1.50	7.00	4	55.70	10.00	250.00								
Bunker C (unspecified)(B01)	8	3.10	0.90	6.30																				
Venezuelan Bunker C (B02)	12	2.70	0.90	6.30					9	3.10	1.69	4.70												
Bunker C Light (B04)	6	3.22	2.29	4.50																				
Navy Special (B06)	2	3.85	3.70	4.00	2	55.85	11.70	100.00	4	4.20	1.50	7.00	4	55.70	10.00	250.00								
Crude	224	6.31	0.04	73.00	22	225.00	4.70	13500	54	3.12	0.90	19.80	46	1365	15.00	80000	5	4.80	1.00	5.00	28	95.00	1.00	1500
Kuwait (light) Crude (C01)	17	10.40	0.77	25.00	10	350.00	58.00	13500	6	9.25	6.60	11.00	16	2615	15.00	80000					3	1500	1500	1500
Cook Inlet Crude (C02)	97	5.16	0.04	20.97					25	2.48	0.90	11.72												
Southern Louisiana Crude (C03)	27	16.20	2.10	19.80	8	350.00	37.50	1700	5	9.70	5.50	19.80	14	4350	15.00	80000					3	1500	1500	1500
Florida Jay Crude (C04)	4	0.17	0.05	0.25																				
Prudhoe Bay Crude (C05)	16	2.12	0.69	73.00	1	560.00	560.00	560.00	14	2.10	1.05	7.99	12	1525	40.00	3200								
Venezuelan Crude (C06)	6	4.06	1.72	8.06																	7	70.00	1.00	1500
Western Sweet Blend Crude (C07)	6	7.23	1.12	10.60																				
Transmountain Crude (C08)	6	3.94	1.10	5.56																				
Norman Wells Crude (C09)	7	5.53	0.60	6.84																	4	1.00	1.00	30.00
Hibernia Crude (C10)	6	5.92	1.08	10.60																				
Amauligak Crude (C11)	6	6.46	1.66	6.73																	Pembina Crude (C20)			
Tarsuit Crude (C12)	6	7.08	3.47	7.20																				
Lago Medio Crude (C13)	6	9.24	3.22	12.10													Nigerian Crude (C19)				Alaskan Crude-Unspec.(C21)			
Atkinson Crude (C14)	6	2.02	0.58	2.27																	4	3.00	1.00	600.00
Bent Horn Crude (C15)	6	2.57	1.07	5.30													5	4.80	1.00	5.00				
Ramashkin Crude (C16)					1	25.00	25.00	25.00													4	4.50	1.00	120.00
West Texas Crude (C17)	2	5.00	5.00	5.00	2	31.85	31.85	31.85	4	7.50	5.00	10.00	4	61.50	27.00	200.00					3	1500	1500	1500
Diesel	129	3.36	0.21	71.90	17	9.40	1.30	4778	31	3.50	0.15	7.60	20	45.10	3.80	9600	4	4.30	2.00	5.00	15	50.00	50.00	1500
Diesel (D01)	10	22.70	4.07	71.90					1	0.89	0.89	0.89												
Fuel Oil No. 2 (D02)	99	3.20	0.21	10.00	11	4.00	1.30	4778	22	2.35	0.15	6.90	12	162.50	33.00	9600	4	4.30	2.00	5.00	15	50.00	50.00	1500
Fuel Oil No. 2, Furnace Oil (D03)	16	3.50	1.00	20.00																				
Light Diesel Fuel (D04)					1	10.00	10.00	10.00																
Heavy Diesel Fuel (D05)					1	20.00	20.00	20.00																
Navy Distillate (D06)	2	5.65	4.60	6.70	2	24.35	7.70	41.00	4	7.05	4.30	7.60	4	11.50	3.80	41.00								
Marine Diesel (D07)	2	3.50	3.50	3.50	2	37.80	4.10	71.50	4	4.45	2.90	7.20	4	21.75	5.10	47.20								
Gasoline	12	20.25	4.90	51.40																				
Leaded Gasoline (G01)	6	16.35	5.40	27.00																				
Unleaded Gasoline (G02)	6	28.95	4.90	51.40																				
Jet Fuel	1	3.50	3.50	3.50									8	560.00	1.85	1600	1	4.20	4.20	4.20	2	210.00	160.00	260.00
Jet Fuel - JP8 (J01)	1	3.50	3.50	3.50													1	4.20	4.20	4.20	1	260.00	260.00	260.00
Jet Fuel - JP9 (J03)													4	525.00	470.00	560								
Jet Fuel - JP4 (J04)													4	595.00	1.85	1600					1	160.00	160.00	160.00
Lube Oil	14	1.58	0.08	2.40	2	55.50	20.00	91.00	4	2.25	2.00	2.70	3	68.00	33.00	103.00								
Auto Lube (L01)	6	0.41	0.08	1.50																				
Heavy Marine Lube (L02)	6	1.73	0.92	2.40																				
9250 Lube Oil (L03)	2	2.00	2.00	2.00	2	55.50	20.00	91.00	4	2.25	2.00	2.70	3	68.00	33.00	103.00								

* *Note: Low reliability data excluded*

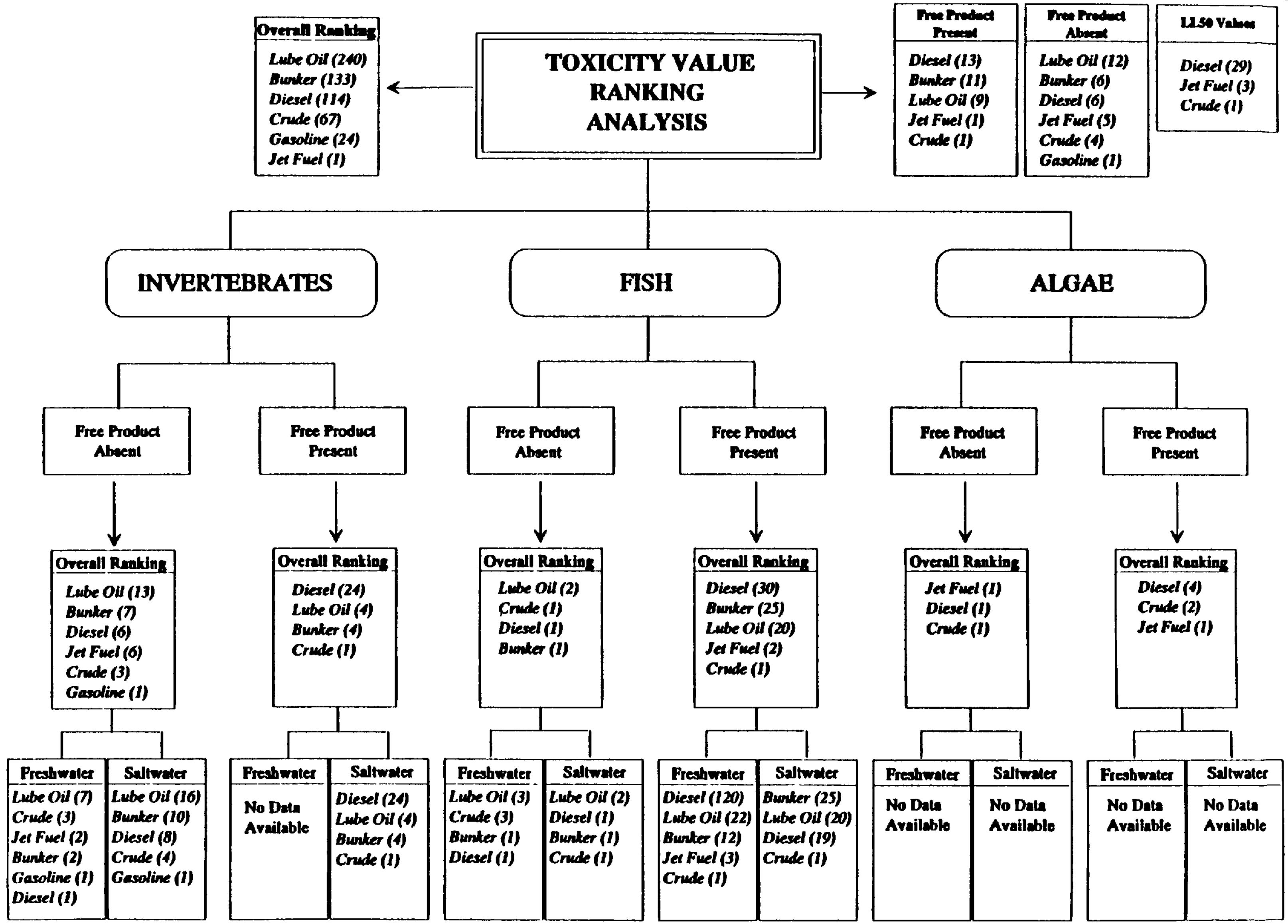

Figure 1-27. Diagram of the toxicity value ranking analysis results.

Table 1-41. Relative ranking of each oil product group from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

ALL DATA COMBINED

Overall Ranking

Lube Oil	(240)
Bunker	(133)
Diesel	(114)
Crude	(67)
Gasoline	(24)
Jet Fuel	(1)

In the above ranking, bunker, diesel and lube oil median toxicity values show no statistically significant differences. Crude, gasoline and jet fuel also are not significantly different.

LL50 Calculated Toxicity Values

The LL50 data set consisted of toxicity studies which were sorted using multiple ratio derived test solutions. Ideally the calculations and the resulting LL50 value is based on nominal loading values used in making the multiple ratio test solutions. By using the same statistical methods as when calculating LC50s, the LL50 notation projects potential effects of various oil:water mixtures (loadings) on aquatic organisms.

The LL50 is quantitatively and conceptually quite different from the LC50. The LL50 does not attempt to express effect based on dissolved concentrations. It also does not attempt to relate specific hydrocarbons to an effect. It simply provides a relative measure of the *product's* total effect on an organism based on a specific range of oil:water loadings. The LL50 notation reflects the overall products toxicity by expressing the amount of product required for a given effect. Since dissolved hydrocarbon concentration is difficult to relate to actual product loading, it would seem logical to express the actual toxicity in terms of the amount of oil product actually required to cause an effect (i.e., the loading). This is inherently more useful when attempting to predict toxic impact in a waterway and it also presents the product in a more realistic light regarding the whole products' true toxicity, i.e., the amount which is required to cause a given effect.

The ranking computed across taxonomic group for LL50 data is provided along with the ranking computed for the "free product absent" and "free product present" groups (Table 1-42).

Table 1-42. Relative rankings for LL50 and "free product present" and "free product absent" groups from most toxic to least toxic. An oil product which does not appear in a ranking did not have data to be included in that ranking. Numbers in parentheses ( ) provide an approximate scale for comparison of the relative median concentration of the oil product as compared to the median concentration of the least toxic oil product.

ALL TAXONOMIC GROUPS COMBINED:

Overall Ranking LL50 Data	Overall Ranking Free Product Present	Overall Ranking Free Product Absent
Diesel (29)	Diesel (13)	Lube Oil (12)
Jet Fuel (3)	Bunker (11)	Bunker (6)
Crude (1)	Lube Oil (9)	Diesel (6)
	Jet Fuel (1)	Jet Fuel (5)
	Crude (1)	Crude (4)
		Gasoline (1)

Using the LL50, "free product present" and "free product absent" data across taxonomic group indicates that diesel, bunker and lube oil are still the most toxic of the oil groups. The crude oil group is consistently low in the rankings and falls to the bottom of the LL50 and "free product present" rankings (least toxic).

State and federal toxicity factor methods which calculate LC50s by either total dissolved petroleum hydrocarbons (TDPH) or a specific weighted chemical component of the oil product, are frequently based on the dissolved constituents. The use of LC50 data creates a narrower range of toxicity across all oil products and it appears reasonable that a scale of 1 to 10 is adequate in comparing toxicity between oil products. This implies that the most toxic and least toxic oil products differ only by a factor of 10. Based on Table 1-42 under "free product absent", the overall ranking would indicate that a 1-10 scale is not unreasonable.

However, the LL50 data provided a wider range of toxicity across oil products and taxonomic groups (Table 1-43). This implies that the scale of comparison between the LL50 and "free product absent" LC50 data are not the same and therefore, if the LL50 values are the most appropriate values to use for toxicity evaluation in a true spill incident, then a scale of 1 to 10 is not appropriate. For example, in Table 1-40, the toxicity of crude in relation to the diesel group is largely dependent upon which ranking you choose. In the LL50 ranking, the toxicity of diesel is approximately 29 times higher than that of crude. In the "free product present" ranking, diesel appears approximately 13 times more toxic than crude. In the "free product absent" group, the toxicity of diesel appears to be only 1.5 times that of crude. The disparity in calculated toxicity values therefore requires a standardization of the toxicity values used by regulators in assessing the toxicity of spilled oil products.

A comparison of the median LL50 and "free product absent" values by taxonomic group and oil product is presented for comparison in Table 1-43.

Table 1-43. Pairwise comparisons of median effect concentration values by LL50 and the absence of free product, taxon and oil product group. Critical value = 0.05. Bold indicates significance.

Oil Product	Taxon	Median Free Product Absent LC50 (mg/l)	Median LL50 (mg/l)	Ratio LL50 to Free Product Absent	Significance Level
Crude	Invertebrates	6.31	475	(75x)	**(p<0.001)**
Crude	Fish	3.12	3200	(1,026x)	**(p<0.001)**
Diesel	Invertebrates	3.36	9.4	(3x)	**(p<0.002)**
Diesel	Fish	3.50	162.5	(46x)	**(p<0.001)**

With complex mixtures such as oil products, LC50 data are problematic because the meaning of the term "concentration" can vary extensively depending on the methods used. It is obvious that the results from these types of tests and calculations can be very different for the same oil product. The meaning of the term LC50 as it pertains to oil products and its application to assessment of impact is under question. This study would indicate that any interpretation using LC50 data for purposes of setting an injury level or ultimately, a toxicity value, must be studied quite carefully to ensure that the leap from the laboratory to an actual vulnerability assessment is a credible and valid one.

2.0 CHAPTER 2: ANALYSIS AND RANKING OF OIL PRODUCT PERSISTENCE

2.1 INTRODUCTION

The persistence, or length of exposure, of an oil product is an important parameter for assessing the effects of an oil spill on the aquatic environment. The propensity of a substance to persist in aquatic environments depends on numerous physical, chemical, and biological processes. The fate of oil and oil products is controlled by spreading, evaporation, emulsification, dissolution, reaction, natural dispersion, and sedimentation. Site-specific factors (e.g., habitat, weather, water depth, currents, and wave energy) alter the effectiveness of these processes; however, the *relative* rates of these processes are controlled by the physiochemical nature of the spilled material (Table 2-1).

The scope of work did not permit an extensive review of all the site- and spill-specific parameters that influence persistence of petroleum hydrocarbons in the aquatic environment. The approach used here only considers the physiochemical properties of the oil or oil products.

Table 2-1. Basic physiochemical properties influencing various spill processes.[1]

Spill Process	Basic Properties
Spreading	Surface Tension, Viscosity
Evaporation	Vapor Pressure, Distillation Curve
Emulsification	Wax and Asphaltene Content
Dispersion	Surface Tension, Viscosity, Density
Dissolution	Solubility
Reaction	Chemical Nature
Sedimentation	Partition Coefficient, Solubility

[1] Adapted from Mackay et al. (1983).

Crude oils are comprised of a broad spectrum of individual hydrocarbons. The composition of each oil product is assumed to follow the fractional distillation model, where the range of boiling point and carbon number increases from gasoline through Fuel Oil #6 (i.e., Bunker C). Crude oils are treated as either light-, medium-, or heavy-weight, depending on the relative amounts of individual oil products. An additional fraction, termed asphaltenes, is added to crude oils to simulate the residue remaining after the distillation of a crude oil.

Persistence is based on the time a chemical is present in a specific media. For example, water column persistence is defined as the time a chemical is detectable in the water column. Factors influencing persistence of a crude oil or oil product in the water column is excessively complicated. Not only must site-specific parameters (e.g., habitat, wave energy, salinity, temperature, winds speed) be considered, but other spill-specific factors also impact persistence (e.g., rate and amount of release, application of dispersants). The definition of a relative persistence scale can not normalize all of these variables; therefore, a relative persistence scale is defined as the amount of material that partitions, at equilibrium, into water, soil, and sediment. This work considers only the fate of the starting material, and does not consider any transformation reactions (e.g., photo de-composition and biodegradation).

An equilibrium-partitioning model is employed to compare the persistence of petroleum products in aquatic environments. The only factors that influence persistence in this application are the physiochemical properties of the crude oils and oil products. Persistence is defined as the amount of original material remaining in the soil, sediment, and water column after a spill. The material released into the atmosphere is considered nonpersistent. The aquatic environment considered in this application (i.e., the unit world) is defined as a closed system; however, the size of the individual compartments are excessively large compared to the amount of hypothetical material released and are appropriately scaled to reflect real world circumstances.

Chemicals move throughout the unit world based on fugacity gradients (i.e., mass in solution flows from high fugacity to low fugacity). The material partitions into the various compartments until the system is in equilibrium, i.e., when all compartments have the same fugacity or chemical potential. However, most oil spills never reach a state of equilibrium. Kinetic factors (e.g., wind speed and water currents) usually determine the extent of a spill, how fast it dissipates, and whether a specific component will volatilize. Nevertheless, the equilibrium approach yields important information on the direction or the tendency of petroleum to partition into various environmental components. The fundamental goal of this chapter is to compare the relative persistence of oil products in aquatic systems, and *not* to predict the characteristics of a spill as a function of time, incorporating site- and spill-specific information. This relative persistence ranking scale requires only certain assumptions of the physiochemical properties of petroleum hydrocarbons.

Quantifying physiochemical properties of petroleum hydrocarbons is no trivial task. Difference in bulk starting material and refinery operations virtually assures no two oils or oil products will have exactly the same chemical composition. Therefore, a fractional distillation model is used to generate the physiochemical data required to run the equilibrium-partitioning model. The exact values of the model output are not as important as the trends detected, and the relative importance of the different environmental compartments.

The overall objectives of this persistence of petroleum product review are to:

- Assess the relative persistence of oil products in the aquatic environment, and
- Rank oil products based upon their persistence in the aquatic environment.

It should be emphasized that this analysis has a number of qualifications. First the crude oil and oil products are characterized with a broad range of physiochemical properties. These data have been estimated, and are not from measurements of actual samples. Second, this treatment is not compound specific; it treats an oil or oil product as a range of chemical components. Third, relative persistence was estimated with an equilibrium partition model. There is no *a priori* reason to assume an oil spill is in equilibrium. Finally, several important environmental parameters (e.g., wind speed, wave energy, currents, water depth, and habitat) are not considered in this study. The fate of petroleum products in the aquatic environment depends on physiochemical, as well as environmental parameters.

2.2 METHODOLOGY

2.2.1 Physical Properties

Crude oil is a complex mixture of alkanes, iso-alkanes, cyclo-alkanes, alkenes, aromatics, napthalenes, and related sulfur, oxygen, and nitrogen hydrocarbon derivatives. Crude oils from different regions of the same field often differ in their proportions of these classes of compounds. Also, differences in refining technologies and practices contribute to the variability of oil and oil product composition. Therefore, a broad range for the physiochemical properties was used to characterize the individual crude oil or oil products, and to demonstrate the relative difference among oil products. It was our intent to estimate a realistic range of data to demonstrate the interactions of physiochemical properties on persistence of petroleum hydrocarbons.

2.2.1.1 *Molecular Weight*

Petroleum products come from the fractional distillation of crude oil, which yields various fractions that are classified according to their boiling points. Boiling points of hydrocarbons are related to their molecular weight (i.e., carbon number); therefore, distillation fractions are enriched in certain hydrocarbons (Figure 2-1). The fractions obtained from the distillation process are complex; each fraction may contain hundreds of individual chemical compounds.

2.2.1.2 *Water Solubility*

Generally, the solubility of hydrocarbons decreases as the carbon number increases. Heavier components of petroleum are generally considered insoluble in water, the lighter components such as C_4 to C_6 paraffins and the aromatic compounds benzene, toluene, and xylene have a small but measurable solubility in water. If the oil and water were in equilibrium, then a specific compound will partition between the two phases to the extent determined by the component's water solubility coefficient. However, most water soluble compounds also have high vapor pressures (see section 2.2.1.3) and are lost to evaporation during the first few hours after a spill. Therefore, the likelihood of loss through solubility is relatively small.

2.2.1.3 *Vapor Pressure*

Vapor pressure is one of the most important properties governing the persistence of a compound in aquatic environments. The pressure of the vapor phase of a substance in equilibrium with its condensed phase is defined as the vapor pressure of the substance. The value of the vapor pressure depends only on the nature of the substance and temperature. Vapor pressure tends to increase directly with temperature. The likelihood of a component to evaporate after an oil spill is directly proportional to the vapor pressure (i.e., the higher the vapor pressure, the greater the chance of volatilization and escape into the atmosphere). Components that evaporate are generally considered nonpersistent. The rate of evaporation of the lighter components is influenced by the percentage of lighter components in the oil, the temperature of the oil, and several spill- and site-specific factors (e.g., oil thickness, surface area of the spill, and physical forces such as wind and wave action). The evaporation process is considered important during the first 24 hours after the spill (Mackay et al., 1983).

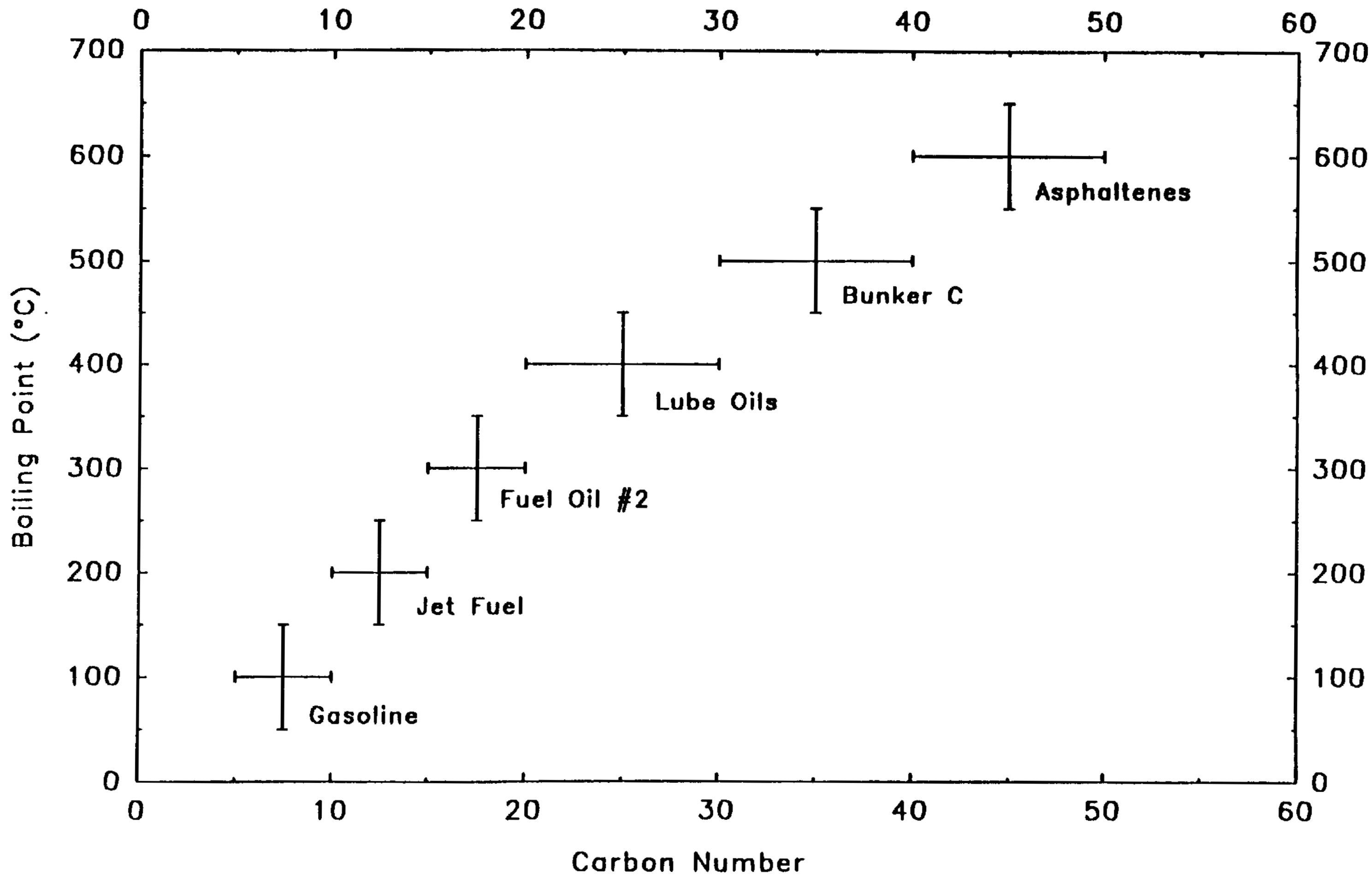

Figure 2-1. Distribution of various petroleum products in a generic crude oil.

2.2.1.4 *Octanol/Water Partition Coefficient*

Only a few crude oils weather to produce residues that are denser than water and sink (CONCAWE, 1983). The majority of components in crude oil are lighter than water, and even if they form emulsions the resultant material is positively buoyant. Nevertheless, floating oil may encounter heavy mineral particles, e.g. sand, silt, etc., especially in near-shore areas. Components of an oil may become adsorbed onto particles, and the resultant conglomerates become negatively buoyant and sink. The oil is transported to the sediments; oil may also adsorb onto beach particles depending on the location of the spill and subsequent migration of the oil. It has been established that the affinity of a specific component to adsorb onto a solid particle can be related to the octanol/water partition coefficient, K_{OW}. A high K_{OW} value indicates that a chemical will adsorb strongly to soil, sediment, and suspended sediment.

2.2.2 Equilibrium Partitioning Model

An equilibrium partitioning model (Mackay and Paterson, 1982; Neely and Mackay 1982) was used for assessing the relative persistence of oil and oil products in aquatic environments. The calculations can be compared for individual oils and oil products to determine the long-term persistence in the environment. The ultimate fate of petroleum products is based solely on their physiochemical properties (i.e., molecular weight, solubility, vapor pressure, and octanol/water partition coefficient). Confounding effects (e.g., habitat, weather, water depth, currents, and wave energy) were not considered in this treatment, and no time-dependent distribution patterns were calculated.

The Mackay Level I environmental fate model (EqP) is based on the thermodynamic principle of fugacity. Fugacity, f, is a measure of chemical potential, which like temperature and voltage can be used to predict whether heat or electricity will flow from one "compartment" to another and how fast. If the driving force or departure from equilibrium (i.e., $f_2 - f_1$) is zero, then there is no net flux or movement from one compartment to another. Chemicals are continually striving towards a state of equal fugacity.

Concentrations are replaced by an equilibrium measure (i.e., fugacity), thus simplifying mathematical expressions for intermedia partitioning and transport. The model partitions 100 moles of a hypothetical compound, defined by the user, into various environmental compartments. After configuring the model with the required physiochemical data, the distribution pattern of oil or an oil product into the unit world (i.e., atmosphere, water column, soil, sediments, suspended sediments, and biota) is calculated. The unit world simulated in the EqP model is a closed system; however, the compartments are excessively large compared to the amount of material released into the system. The dimensions for the compartments are atmosphere (1000m x 1000m x 6000m), water (1000m x 700m x 10m), soil (1000m x 300m x 15cm), and sediment (1000m x 700m x 3cm). The concentration of suspended matter in the water is 5 ppm (total volume = $35m^3$). This application of the EqP model neglects bioaccumulation of hydrocarbons in aquatic organisms.

2.2.3 Ranking of Oil Product Persistence

The EqP model attempts to predict persistence based on the physiochemical properties of each oil or oil product. Since these materials consist of hundreds of individual compounds, a multiple component approach is used to characterize each oil or oil product. The model results will be dependent on input parameters selected for the key chemical characteristics (i.e., molecular weight, solubility, vapor pressure, and K_{OW}) of the oil or oil product. Since oil products are defined as a range of compounds (represented by both low and high ranges of physiochemical data), two runs per product group are conducted to provide both a conservative (worst case) and non-conservative (best case) prediction of product persistence. This helps place a range of persistence for various oils and oil products released into the environment. The best case (least persistent) model run is configured using the values for low molecular weight, high solubility, high vapor pressure, and low octanol/water partition coefficient. The range of physiochemical data is not a measure of analytical uncertainty, but rather a measure of the complex chemical composition of crude oil and oil products.

Persistence in the aquatic environment is considered an aggregate term consisting of the material that partitions into the water, soil, sediment, and suspended matter. For presentation purposes the suspended sediment fraction is combined with the sediment fraction. The material that partitions into the atmosphere is considered nonpersistent. A numerical scale is calculated for crude oils and oil products based on the persistent fraction calculations. The relative persistence is presented as a range delineated by the best case and worst case scenarios.

2.3 RESULTS AND DISCUSSION

2.3.1 Model Input Parameters

Individual oil products are distilled from crude oil. The chemical composition of oil products is considered to be a continuum, represented by different degrees of distillation (Figure 2-1). Each fraction is defined in terms of a boiling point range, and no post-refining blending is considered. The lightest fraction (gasoline) has the lowest boiling point and consists primarily of C_5 - C_{11} hydrocarbons. The distillation process continues through, jet fuel, fuel oil #2, lube oils, and Bunker C (fuel oil #6). Crude oil is considered an aggregate of all the previously listed oil products, plus an additional fraction that represents residual asphaltenes.

The physical properties of oil and oil products are determined by the chemical nature of the individual components. Although certain generalizations can be made, no exact numbers are given for physiochemical data because the composition of an oil product varies depending on the source and refinery. The range of molecular weight, solubility, vapor pressure, and K_{OW} (octanol/water partition coefficient) for each oil and oil product used in this study are shown in Figure 2-2 through 2-5. Low-molecular-weight hydrocarbons are more soluble, have a higher vapor pressure, and have lower K_{OW} than heavier products. It was assumed that solubility, vapor pressure, and K_{OW} decrease logarithmically with increasing molecular weight (Neff, 1979).

2.3.2 Crude Oil and Oil Product Persistence

Two EqP model runs were made for each material under consideration. First, the relative persistence was estimated assuming "best-case" conditions (low persistence). Model input parameters were selected, from the range of physiochemical data in Figures 2-2 through 2-5, to simulate the least persistent components of a particular product. Therefore, the lowest molecular weight, highest solubility, highest vapor pressure, and the lowest K_{OW} values were used to configure the model (Table 2-2). A "worst-case" scenario (high persistence) was simulated using the highest molecular weight, lowest solubility, lowest vapor pressure, and highest K_{OW} estimates available (Table 2-2). These ranges were selected based on the fractional distillation process. Results from this analysis are presented in Figure 2-6.

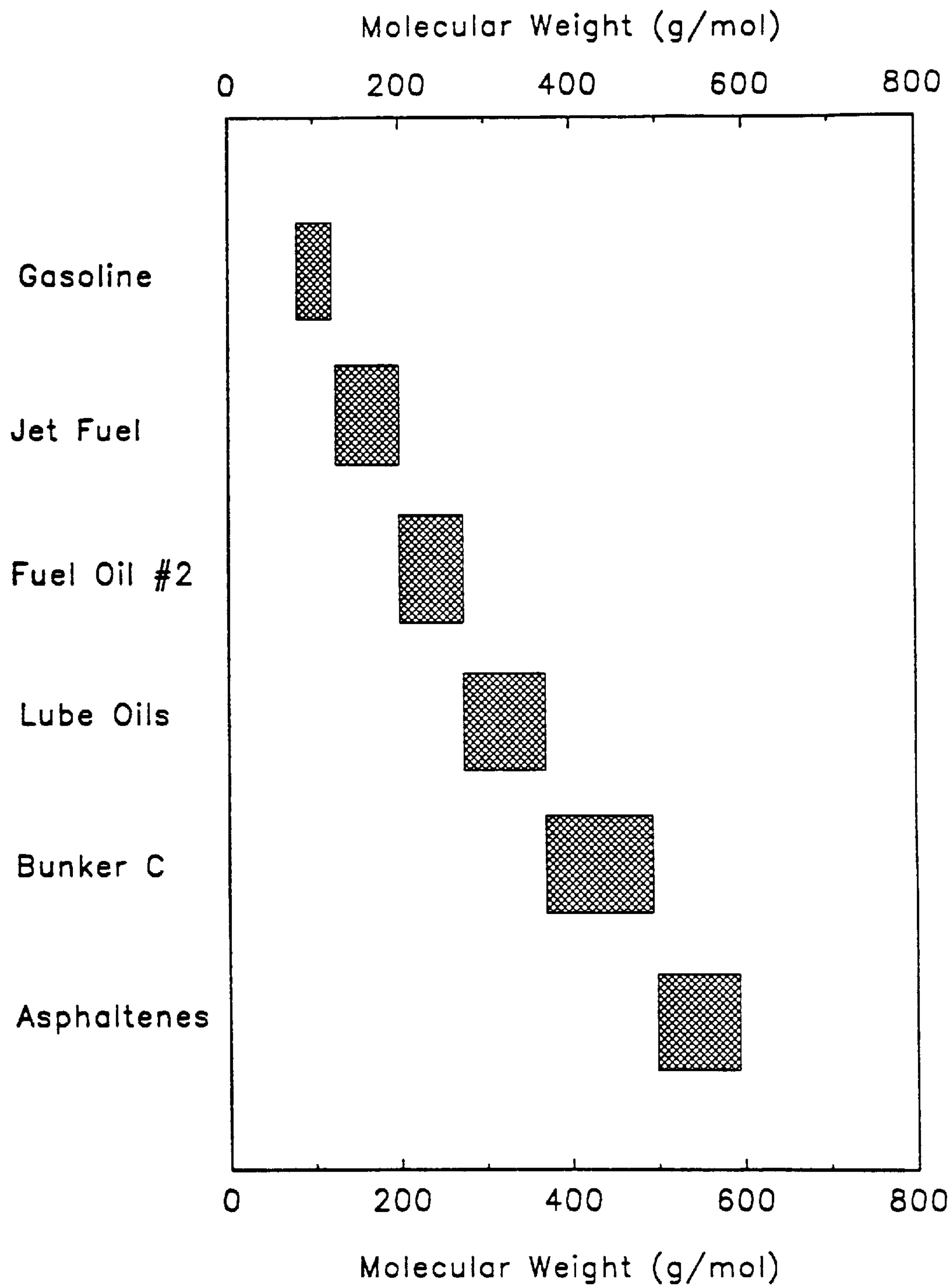

FIGURE 2-2. Estimated ranges of molecular weights (g/mol) of petroleum products.

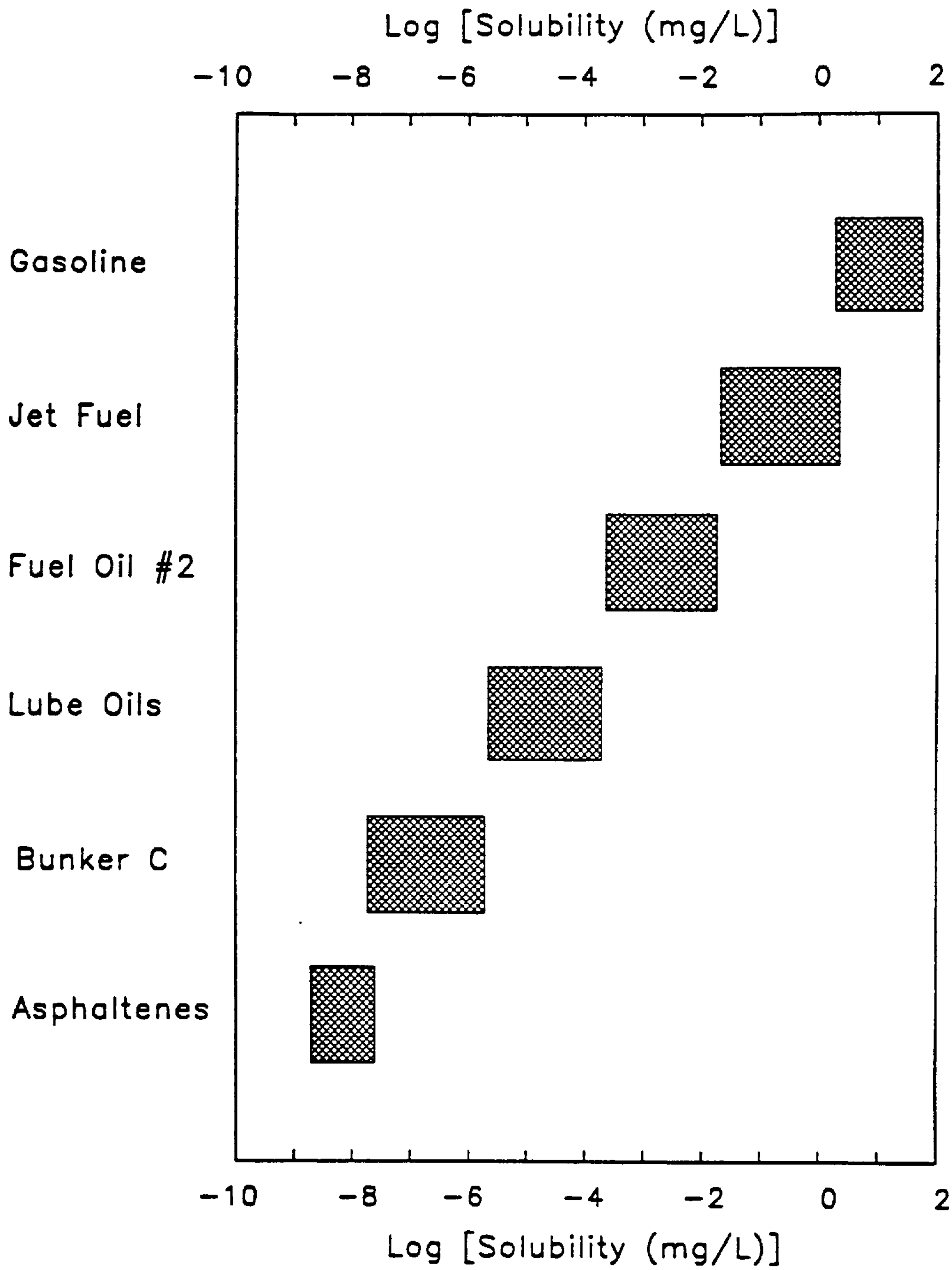

FIGURE 2-3. Estimated ranges of water solubilities (mg/L) of petroleum products. Data are log transformed.

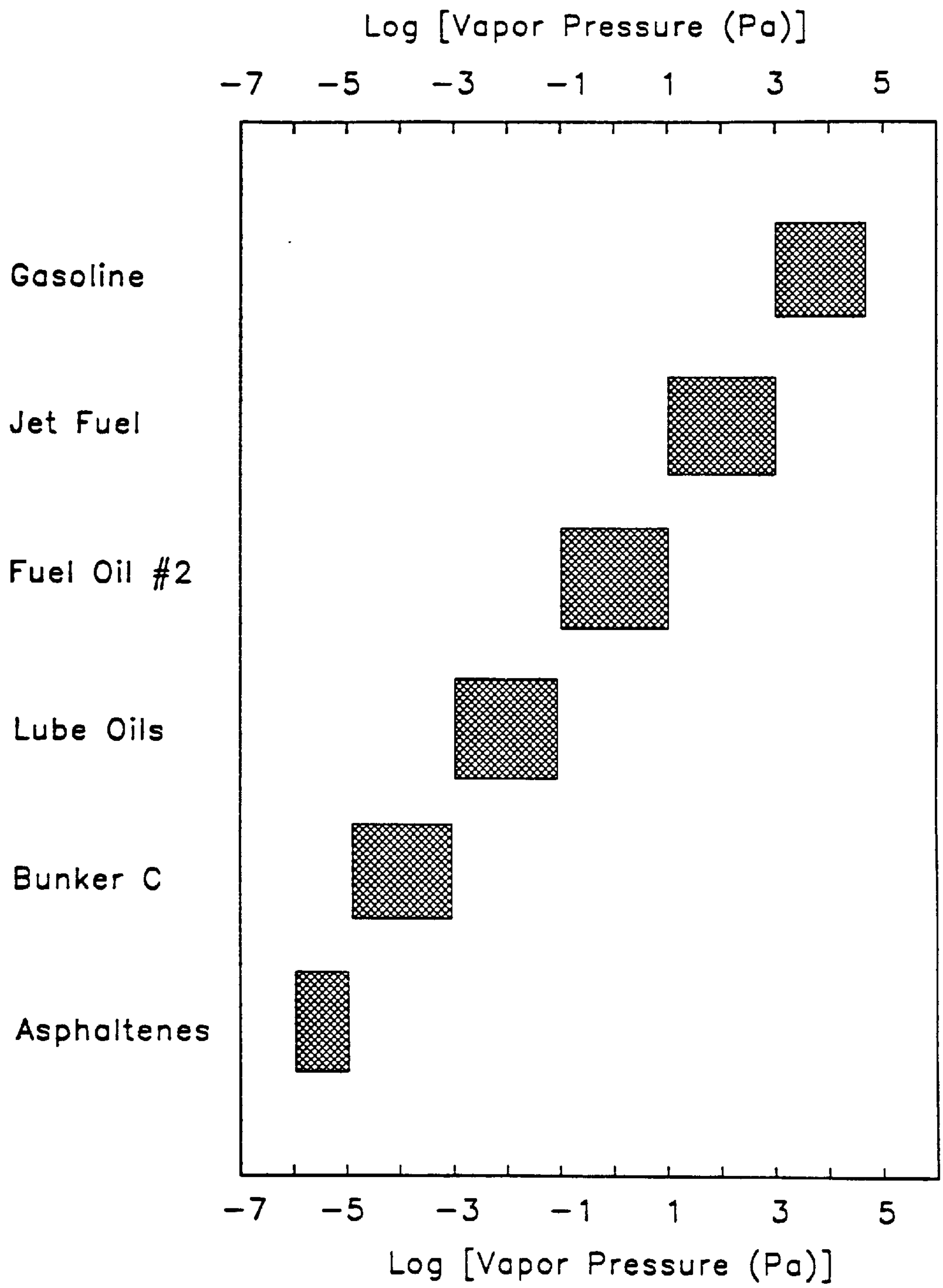

FIGURE 2-4. Estimated ranges of vapor pressure (Pascals) of petroleum products. Data are log transformed.

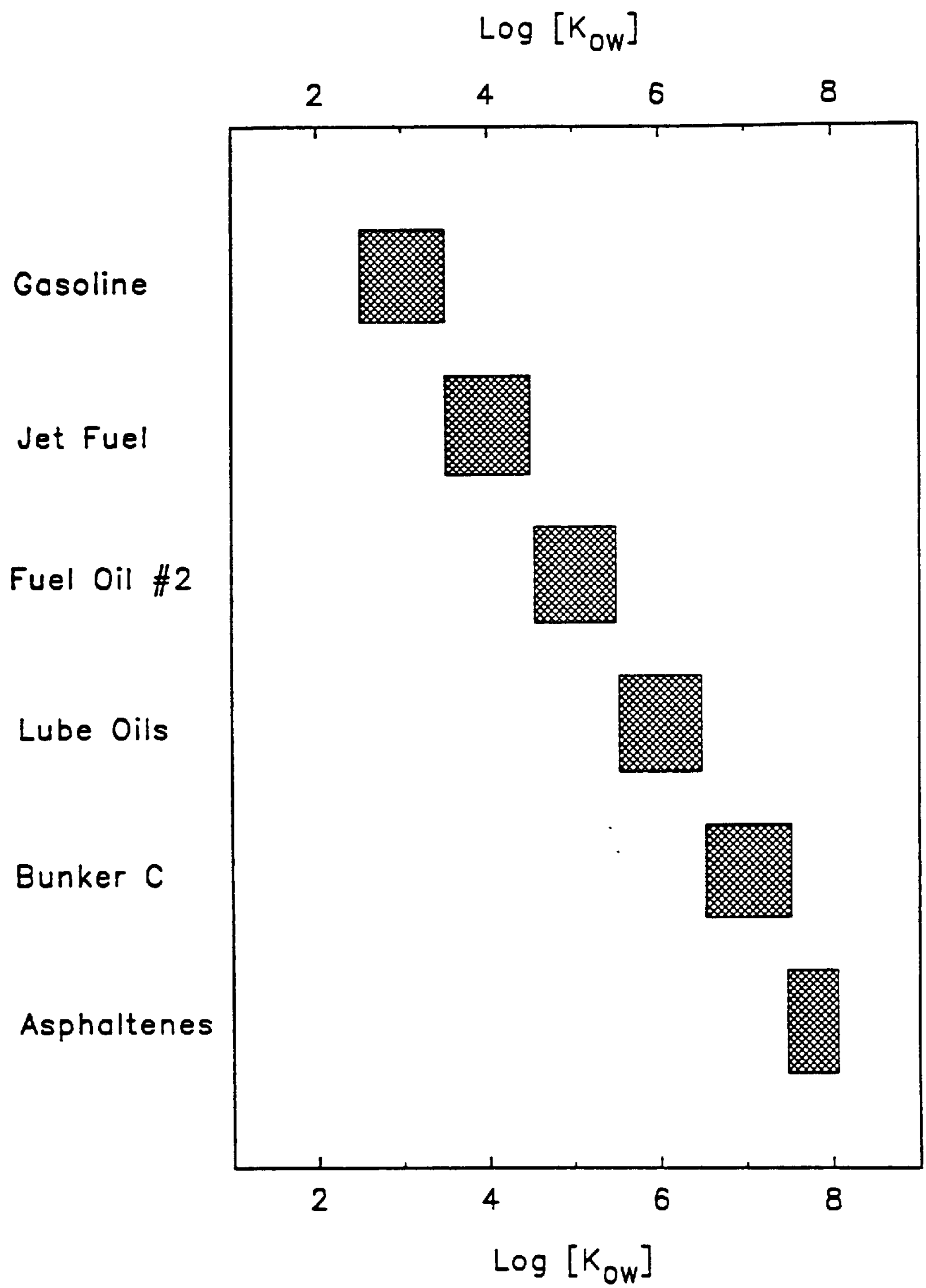

FIGURE 2-5. Estimated ranges of octanol/water partition coefficients (K_{OW}). Data are log transformed.

The relative persistence of oil products in aquatic environments vary from <1% to about 13%. The relative persistence is defined as the number of moles, out of 100, that partition, at equilibrium, into the water column, sediment, or soil. The range of relative persistence, obtained from the high and low estimates of the physiochemical properties, had no significant impact for gasoline and jet fuel. Both of these oil products were relatively nonpersistent (Figure 2-6).

Fuel oil #2 was also relatively nonpersistent; however, some of the compounds in fuel oil #2 were appreciably persistent in the aquatic environment (Figure 2-6). Relative persistence increased from lube oils through Bunker C, and residual asphaltenes were the most persistent fraction of crude oil.

The fraction of material that persists in the water column is negligible when compared to the soil and sediment compartments. The majority of the persistent fraction is distributed evenly between the soil and sediments. The remaining material, up to 99.9%, is lost to the atmosphere via evaporation.

The range of relative persistence (Figure 2-6) is not a measure of uncertainty, but an estimate of the differences in persistence that is expected for an oil or oil product. Oil products are complex mixture of organic chemicals, and the relative persistence of some compounds are either more or less than others. Average bulk persistence for an oil product is estimated at the midpoint between the least persistent fraction and the most persistent fraction.

The range between the more persistent fraction and the less persistent fraction is greatest for crude oil. Crude oil is a mixture of everything from gasoline to asphaltenes. The relative persistence calculations (Figure 2-6) demonstrate that some components of crude oil are nonpersistent (gasoline), and others are highly persistent (asphaltenes). The origin of the crude oil will determine the relative importance of the different fractions; crudes are classified as light, medium, or heavy depending on their composition.

Table 2-2. Physiochemical data used in relative persistence model runs.

Oil Product	Molecular Weight (g/mol)	Solubility (g/mol)	Vapor Pressure (Pa)	Log (K_{OW})
Gasoline				
Low persistence	75	50	5E+04	2.5
High persistence	125	2.0	1000	3.5
Jet Fuel				
Low persistence	125	2.0	1000	3.5
High persistence	200	0.02	10	4.5
Fuel Oil #2				
Low persistence	200	0.02	10	4.5
High persistence	275	2E-04	0.10	5.5
Lube Oils				
Low persistence	275	2E-04	0.10	5.5
High persistence	375	2E-06	0.001	6.5
Bunker C				
Low persistence	375	2E-06	0.001	6.5
High persistence	500	2E-08	1E-05	7.5
Asphaltenes				
Low persistence	500	2E-08	1E-05	7.5
High persistence	600	2E-09	1E-06	8.0

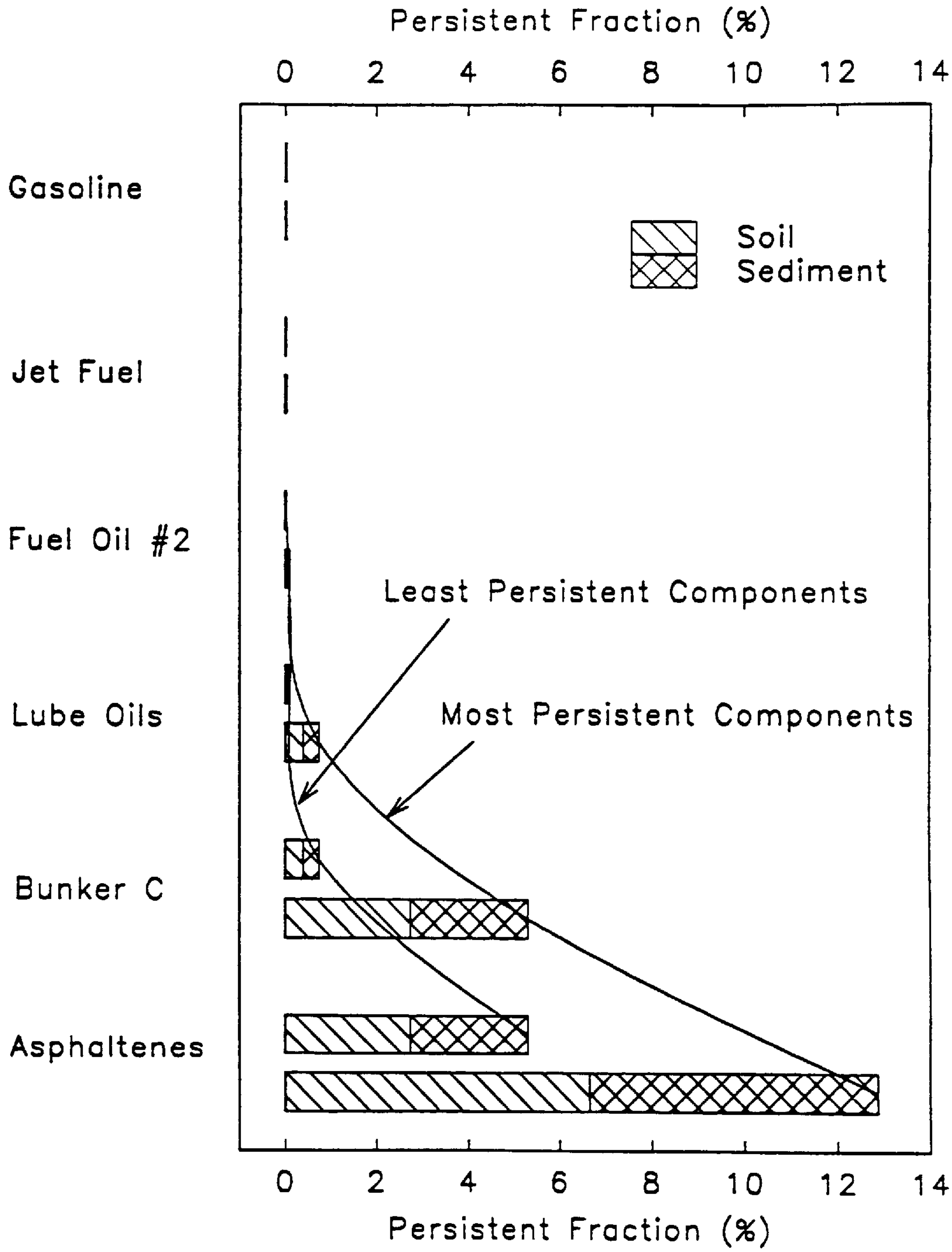

Figure 2-6. Persistent fraction of petroleum products in aquatic environments, expressed as percent of original material remaining in water, sediment, and soil. For each pair, the top bar represents the least persistent components and the bottom bar represents the most persistent components. Solid lines outline the range of persistence for each oil or product.

2.3.3 Numerical Persistence Scale

Relative rankings for each oil product, from least persistent to most persistent, are listed in Table 2-3. Data from Figure 2-6 were used to compare the oil products. A numerical scale was developed by dividing the mid-point of the range of relative persistence estimates for each oil product by the least persistent oil product (gasoline). Gasoline, jet fuel, and fuel oil #2 are relatively nonpersistent. Lube oils are persistent, and fuel oil #6 is highly persistent. Residual asphaltenes are the most persistent oil product considered in this study.

A persistence ranking for a crude oil requires a definition of the composition (i.e., the mass fractions of different classes of compounds). Some components of crude oil are extremely persistent, while most other fractions are nonpersistent. A persistence ranking score is defined for a generic light, medium, and heavy crude by estimating the mass fractions of the individual products. Fractional distillation data from CONCAWE (1983) was used to generate the data in Table 2-4. Crude oil rankings are also presented in Table 2-3.

Table 2-3. Numerical scale for relative persistence of oil and oil products in the aquatic environment.

Oil/Oil Product	Relative Persistence
Gasoline	1
Jet Fuel	2
Fuel Oil #2	8
Lube Oils	55
Light Crude Oil	320
Fuel Oil #6	400
Medium Crude Oil	450
Heavy Crude Oil	590
Residual Asphaltenes	1600

Table 2-4. Estimated mass fraction for three generic crude oils.[1,2,3]

Crude Oil	Gasoline	Jet Fuel	Fuel Oil #2	Lube Oils	Bunker C	Residual Asphaltenes
Light	12.5	21.1	22.2	13.4	15.4	15.4
Medium	12.4	16.6	16.7	9.7	22.3	22.3
Heavy	2.6	8.8	17.2	13.1	29.2	29.2

1 Estimated from fractional distillation data reported by CONCAWE (1983).
2 All fractions are expressed as percentage of total.
3 Residual fraction from CONCAWE (1983) is assumed to consist of equal parts of Bunker C and residual asphaltenes.

2.4 SUMMARY

The primary processes determining the fate of crude oil and oil products after a spill are spreading, evaporation, emulsification, dispersion, dissolution, reaction, and sedimentation. These processes are influenced by the spill characteristics, environmental conditions, and physiochemical properties of the spilled material. Because of the confounding effects of site- and spill-specific variables, physiochemical data will only provide a relative scale as to which oil and oil products will persist in the aquatic environment.

An equilibrium partitioning model provides insight into where the oil and oil products will partition in aquatic environments. The model serves as a mathematical tool that differentiates between oil and oil products, without becoming a site-specific oil spill model. The generic environment used for the model consists of atmosphere, water, soil, suspended matter, sediment, and biota.

Quantifying the physiochemical data associated with the oils and oil products is difficult because refining processes and technologies differ worldwide. For this reason, physiochemical data is considered a continuum, and oil products are represented as broad ranges of compounds characterized by carbon number and boiling points. This approach represents the fractional distillation process, and ignores any post-refining blending. Estimates are made for molecular weight, aqueous solubility, vapor pressure, and octanol/water partition coefficient.

A numerical persistence scale is outlined and crude oil and oil products are ranked based on their persistence in aquatic environments. Persistence is defined as the aggregate fraction remaining in the water, soil, and sediment. Generally, it can be concluded that gasoline, jet fuel, and fuel oil #2 are relatively nonpersistent in the marine environment. Lube oils are slightly persistent, Bunker C (fuel oil #6) and crude oils are persistent, and asphaltenes are highly persistent (Table 2-3).

It should be reemphasized that this analysis has a number of qualifications. First the crude oil and oil products are characterized with a broad range of physiochemical properties. This data has been estimated, and is not from measurements of actual samples. Second, this treatment is not compound specific. It treats an oil or oil product as a homogeneous, hypothetical compound. Third, relative persistence was estimated with an equilibrium model. There is no *a priori* reason to assume an oil spill is in equilibrium. Finally, several important environmental parameters (e.g., wind speed, wave energy, currents, water depth, and habitat) are not considered in this study. The fate of petroleum products in the aquatic environment depends on physiochemical, as well as environmental parameters. A detailed analysis based on spill-specific and site-specific conditions was beyond the scope of this study.

3.0 CHAPTER 3: OIL PRODUCT TOXICITY AND PERSISTENCE: A PERSPECTIVE

3.1 INTRODUCTION

Public outcry after a number of incidents within a period of a year (1989-1990) in the United States resulted in legislation designed to improve response preparedness to oil spills (Oil Pollution Act of 1990). The incidents also gave rise to a renewed interest and utilization of DOI rules regarding the assessment of damages to natural resources. States also began devising their own "formulas" for compensating the public for damages to a marine resource.

How damaging are major spills? Do products actually persist for many years and have toxic effects? This section of the report will provide a perspective regarding the use of the terms toxicity and persistence in predicting injury and developing compensation formulas.

The discussion below evaluates acute toxicity and persistence associated with oil products and crude as related to oil spills in general. Recognizing that this discussion is based in this context is important, since the ultimate impacts of oil are related to exposure conditions, product composition, and type of release. The prediction of biological injury is related then to both the inherent toxicity of the substance and the conditions of exposure. The discussion below views the spill scenario as a single incident and does not examine any cumulative or other risks which would be considered if other exposure methods (e.g., multiple spill incidents, slow releases) were a factor.

3.2 TOXICITY OF OIL

How toxic is oil? This study and State/DOI compensation formulas focus on acute toxicity in evaluating oil spill injuries. We have seen from discussions in this study that toxicity data associated with oil products are highly dependent on the test method used. This does not mean that the tests are not useful or that the science is inaccurate. It only means that test results and use thereof must consider the exposure methods used when the laboratory test was performed. As is evident from this study, all LC50 values are not comparable and careful consideration to methodology is important when interpreting the values.

Concern for the impact of released oil products must be judged based on the amount of oil product needed to cause a given negative effect. As we have seen, some of the approaches to quantifying toxicity attempt to use the most toxic components of the oil product to represent the overall toxicity of the product. This is primarily because toxicologists have not been able to accurately represent the toxicity of complex mixtures. The science of aquatic toxicology typically utilizes the dissolved compound as the exposure concentration on which to base an LC50. With single compound products, it is sensible to compare the toxicity of the product to the dissolved fraction. Since oil products have a sizable non-soluble fraction, describing the products' toxicity based on a small fraction of the product (dissolved or soluble portion) does not provide an accurate representation of the overall product toxicity.

We have seen from the analyses presented in this study that components and dissolved fractions are not necessarily representative of the relative toxicity of oil products themselves (Table 1-43). Oil products have components that can be viewed as relatively toxic. Naphthalenes and phenanthrenes have LC50 values in the low mg/l ranges for many marine invertebrates (Neff, 1985). Pesticides are normally considered the most toxic compounds to aquatic organisms and have LC50 values in the 10-9000 ug/l range (Nimmo, 1985). The amount of oil product needed to cause a lethal effect to invertebrates in the laboratory varies considerably. Median effect levels for 224 crude oil data points on invertebrates, using the LC50 and the LL50 method of representation, are 6.31 and 225 mg/l respectively. Median levels for fish and the same crudes have median LC50/LL50 comparisons of 3.12 to 1365 mg/l respectively. Other comparisons are provided Table 1-40.

Predicting the environmental threat of whole crude based on the most toxic component of the crude can be viewed as a misrepresentation of the overall impact of the product on aquatic organisms. Since spills occur with product (not a single component of the product), it would seem reasonable to compare and rank products based on studies that utilize variable ratios of whole product and water (multiple ratio method). These tests are best represented by the LL50 value. Therefore, answering the question "how much product is needed to cause the effect?" is the ultimate gauge of relative product toxicity. This provides a better perspective regarding the relative risk of oil product present during a spill incident since the LL50 can be related to a weight of product per volume of water.

3.3 PERSISTENCE AND OIL PRODUCTS

After spills, a large fraction of the oil product volatilizes into the atmosphere. In the short term, the importance of this fact in mitigating acute injury is dependent on the specific site and the oil product. For example, a large percentage of kerosenes and diesel fuels will ultimately partition into the atmosphere, thus the injury they can cause while approaching equilibrium will be based on water depths, wind conditions, temperatures and other site specific variables. Once at or near equilibrium, we have seen in Chapter 2 that certain products (gasoline, diesel, kerosene) leave little residue in water columns and a relatively small fraction of the total spilled volume remains or is available to partition to sediment or other receptors.

3.3.1 Persistence: Toxicity Based Concerns

The term persistence has two aspects that need to be considered. Persistence when viewed in terms of toxicity is often thought of as negative. Certain pesticides or chlorinated products (PCBs) that persist can provide long term risks due to their ability to incorporate themselves into organisms, biomagnify in food chains and potentially impact reproductive and other key biochemical systems. The persistence of these products is of concern not only because they do not degrade over time or remove themselves from natural systems, but also because of their instrinsicly toxic characteristics. Therefore, when compounds are persistent, mobile, able to biomagnify, and toxic they are in fact reasons for concern. We can refer to this group of persistent compounds/products as those which should elicit a *toxicity based* concern.

Fortunately, oil products do not share all the characteristics noted to provide the same *toxicity based* concern that pesticides and other selected compounds cause. This is due to the fact that oil products by and large do not biomagnify through food chains since most higher organisms in the food chain (some crustaceans, most fish, all mammals) have enzyme systems capable of metabolizing aromatic compounds within their tissues (Neff, 1985). This is not to say that dissolved polyaromatic hydrocarbons do not bioaccumulate. The ability of organisms to metabolize varies e.g. bivalves have a rather poor PAH metabolizing ability. Studies have shown that these highly lipophilic compounds (PAHs) can accumulate in organisms when an exposure concentration is maintained in a laboratory environment. The significance of this finding in relation to the actual environment is, however, unclear. The mere phenomenon of bioaccumulation is not necessarily an indication that negative impacts are being exerted on the organism. Studies by Neff have also shown that organisms placed in PAH-free water after an exposure are able to release (i.e., depurate) contaminants and thereby regain an uncontaminated state. Finally, aromatic hydrocarbon compounds that may accumulate in organisms for a period of time are not commercially designed, potent chemicals as are pesticides. The overall significance of bioaccumulation from a spill has by no means been fully evaluated nor is there a body of evidence demonstrating cause and effect.

The toxicity based definition of persistence is often the implied meaning when the term is used. As spilled oil weathers, its characteristics change. Compounds which were bioavailable during the early phases of a spill become less available due to either losses to the atmosphere or to aggregation through sedimentation, precipitation or emulsification. All these processes serve to reduce the overall bioavailability through the water column or dissolved fraction pathway.

Based on the above description of the fate of spilled oil, a common industry perspective is that the persistent oil components from a spill (residues, tar balls, mousse etc.) are of low concern since they are not bioavailable. Thus multiplying a toxicity factor by a persistence factor in a compensation table seems illogical and is questioned. The argument is made that if the more persistent components are not bioavailable due to their form and low solubility, they cannot exert a toxic impact or cause biological injury. The problem with this argument is that it assumes that the primary reason for multiplying a persistence factor is the toxicity based concern noted above.

States are using acute toxicity data and relating this endpoint or consideration directly to persistence by multiplying the two factors. This in effect attempts to directly relate two poorly related factors (persistence and acute toxicity). One factor (persistence) implies a long term exposure concern whereby the other (acute toxicity) denotes an impact requiring brief exposure. This, it could be argued, is the fundamental problem with interpreting a States' use of the term persistence in a toxicity-based context. Acute effects can be predicted without a great deal of consideration to persistence. Chronic effects, however, could more appropriately be related to toxicity-based context of persistence. The following discussion notes the second aspect of persistence which needs to be considered in assessing total injury.

3.3.2 Persistence: Habitat Based Concerns

As noted there are at least two perspectives on persistence. The above discussion is referred to as the *toxicity based* persistence argument. The second perspective can be described as the *habitat based* view. It is based on the observation that certain spilled oils or crudes have a tendency to have long term negative impacts on selected habitats. These impacts primarily refer to mechanical disruption caused by oil residues on e.g., ocean sediments, rocky substrates, beaches, intertidal zones, and coral reefs. Impacts can be related to actual oil that comes on shore or weathered residues and solids from offshore incidents. These impacts are referred to as habitat related since they can interfere with the normal physical characteristics of substrates which serve as habitats for a variety of organisms. Residuals may take the form of tar balls and or mousse that have settled in bays or deeper waters thus having a potential impact on the inhabitability of the sediments. They may also take the form of precipitated oils agglomerated with inorganic and organic particles or debris. Residues can also be viewed as potentially ingestible by filter feeding organisms depending on their physical size and form. This physical interference may persist for significant periods of time since the same characteristics of the weathered hydrocarbons which reduce their biological availability also allow them to persist as a potential habitat impediment.

3.4 SUMMARY

With these two perspectives regarding persistence in mind, a better understanding of the appropriate use of the term "persistence" can be developed. After the initial phases of a spill, when most of the active dissolution and volatilization has been accomplished, oil spill residuals from heavier products and crudes become less bioavailable with time. Thus, from the toxicity based persistence perspective, residuals represent a less acute threat over time. When using the toxicity based interpretation of the term persistence, it is not appropriate to utilize a direct proportion for estimating acute injury (i.e., multiplication of two numerical factors representing acute toxicity and persistence). However, the use of the term as a directly proportional factor from a habitat based standpoint is somewhat more defensible since it could be viewed as both a habitat based factor and a substitute for the lack of chronic toxicity considerations in the formulas.

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[Note: Bolded references are those utilized in the Toxicity Database.]

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APPENDIX A-2: ARTICLES UTILIZED IN THE TOXICITY DATABASE

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APPENDIX B: RESULTS OF STATISTICAL COMPARISONS OF OIL PRODUCT AND TESTING METHODOLOGIES

Appendix Table B-1. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.

COMP = Class/group compared

oval Indicates significance

INVERTEBRATES: FREE PRODUCT ABSENT

	BUNKER					CRUDE					DIESEL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration			(0.23)					(<.001)					(<.001)		
0 = None	-	-		0-1		-	-		0-1		-	-		0-1	
1 = 0-1 hours	2	3.85		0-2		8	25.50		0-2		4	4.05		0-2	
2 = 1-12 hours	4	1.70		0-3		12	3.70		0-3		4	0.92		0-3	
3 = 12-24 hours	16	3.00		0-4		117	8.46		0-4		105	3.36		0-4	
4 = >24 hours	6	3.22		0-5		63	4.49		0-5		13	9.50		0-5	
5 = Not reported	-	-		1-2		24	1.93		1-2	(0.02)	3	4.60		1-2	(0.03)
				1-3					1-3	(0.02)				1-3	(0.25)
				1-4					1-4	(<.001)				1-4	(0.08)
				1-5					1-5	(<.001)				1-5	(1.00)
				2-3					2-3	(0.04)				2-3	(0.02)
				2-4					2-4	(0.48)				2-4	(0.004)
				2-5					2-5	(0.27)				2-5	(0.05)
				3-4					3-4	(<.001)				3-4	(<.001)
				3-5					3-5	(<.001)				3-5	(0.29)
				4-5					4-5	(<.001)				4-5	(0.14)
Test Solution Development								(<.001)							
1 = Single ratio	28	3.00		1-2		215	5.70		1-2	(<.001)	120	3.36		1-2	
2 = Multiple ratio	-	-		1-3		4	46.50		1-3	(<.001)	-	-		1-3	(0.04)
3 = Not reported	-	-		2-3		5	19.80		2-3	(0.018)	9	6.20		2-3	
Test Chamber															
1 = Open	21	3.20		1-2	(1.00)	141	7.40		1-2	(<.003)	104	3.28		1-2	(<.001)
2 = Closed	7	2.30		1-3		83	4.49		1-3		25	8.35		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)			(0.06)					(0.007)					(<.001)		
4	2	3.40		4-24		20	4.15		4-24	(0.06)	5	20.00		4-24	(0.001)
24	6	5.05		4-48		36	6.87		4-48	(0.42)	20	4.30		4-48	(0.01)
48	12	3.00		4-96		49	5.53		4-96	(0.04)	25	4.60		4-96	(<.001)
96	6	2.25		4->96		106	7.40		4->96	(0.06)	75	3.11		4->96	(0.02)
>96	2	1.70		24-48		11	1.76		24-48	(0.18)	4	2.05		24-48	(0.39)
				24-96					24-96	(0.99)				24-96	(0.04)
				24->96					24->96	(<.001)				24->96	(0.13)
				48-96					48-96	(0.08)				48-96	(0.003)
				48->96					48->96	(0.01)				48->96	(0.04)
				96->96					96->96	(0.001)				96->96	(0.45)
Life Stage			(0.27)					(<.001)					(<.001)		
0 = Eggs	1	1.00		0-1		3	5.70		0-1	(0.60)	1	0.43		0-1	(0.23)
1 = Larvae	3	1.60		0-2		29	2.00		0-2	(0.88)	5	1.30		0-2	(0.10)
2 = Juvenile	9	1.90		0-3		81	5.30		0-3	(0.52)	31	6.60		0-3	(0.12)
3 = Adult	15	0.90		1-2		111	8.20		1-2	(<.004)	92	3.36		1-2	(<.001)
				1-3					1-3	(<.001)				1-3	(0.05)
				2-3					2-3	(<.002)				2-3	(<.001)
Exposure Method								(<.001)							
ST = Static	26	3.20		ST-SR	(0.12)	196	6.78		ST-SR	(0.10)	116	3.36		ST-SR	(0.21)
SR = Static Renewed	2	1.70		ST-FT		18	2.05		ST-FT	(<.001)	13	4.60		ST-FT	
FT = Flow-through	-	-		SR-FT		10	1.74		SR-FT	(0.40)	-	-		SR-FT	
Test Condition															
FW = Freshwater	3	4.45		FW-SW	(0.06)	30	2.31		FW-SW	(<.001)	9	7.95		FW-SW	(0.015)
SW = Saltwater	25	2.60				194	6.92				120	3.36			
Measured/Stock/Unmeasured								(<.001)					(0.30)		
M = Measured	6	3.22		M-S	(0.52)	135	4.06		M-S	(<.001)	44	2.23		M-S	
S = Stock	22	3.00		M-U		84	8.71		M-U	(<.001)	77	3.50		M-U	
U = Unmeasured	-	-		S-U		5	19.80		S-U	(<.002)	8	4.35		S-U	

Appendix Table B-2. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.

COMP = Class/group compared

oval Indicates significance

INVERTEBRATES: FREE PRODUCT ABSENT	GASOLINE					JET FUEL					LUBE OIL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration															
0 = None	-	-		0-1		-	-		0-1		-	-		0-1	
1 = 0-1 hours	-	-		0-2		1	3.50		0-2		2	2.00		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	-	-		0-4		-	-		0-4		-	-		0-4	
4 = >24 hours	12	20.25		0-5		-	-		0-5		12	1.50		0-5	
5 = Not reported	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				1-4					1-4					1-4	(0.17)
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					3-5	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	12	20.25		1-2		1	3.50		1-2		14	1.58		1-2	
2 = Multiple ratio	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Chamber															
1 = Open	-	-		1-2		1	3.50		1-2		2	2.00		1-2	(0.17)
2 = Closed	12	20.25		1-3		-	-		1-3		12	1.50		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)													(0.30)		
4	4	16.20		4-24		-	-		4-24		4	1.65		4-24	
24	-	-		4-48	(0.67)	-	-		4-48		1	2.00		4-48	
48	8	20.25		4-96		1	3.50		4-96		9	0.92		4-96	
96	-	-		4->96		-	-		4->96		-	-		4->96	
>96	-	-		24-48		-	-		24-48		-	-		24-48	
				24-96					24-96					24-96	
				24->96					24->96					24->96	
				48-96					48-96					48-96	
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage															
0 = Eggs	-	-		0-1		-	-		0-1		-	-		0-1	
1 = Larvae	-	-		0-2		-	-		0-2		-	-		0-2	
2 = Juvenile	12	20.25		0-3		1	3.50		0-3		14	1.58		0-3	
3 = Adult	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				2-3					2-3					2-3	
Exposure Method															
ST = Static	12	20.25		ST-SR		1	3.50		ST-SR		14	1.58		ST-SR	
SR = Static Renewed	-	-		ST-FT		-	-		ST-FT		-	-		ST-FT	
FT = Flow-through	-	-		SR-FT		-	-		SR-FT		-	-		SR-FT	
Test Condition															
FW = Freshwater	6	5.83		FW-SW	(0.045)	1	3.50		FW-SW		6	1.21		FW-SW	(0.90)
SW = Saltwater	6	26.00				-	-				8	1.66			
Measured/Stock/Unmeasured															
M = Measured	12	20.25		M-S		-	-		M-S		12	1.50		M-S	(0.17)
S = Stock	-	-		M-U		1	3.50		M-U		2	2.00		M-U	
U = Unmeasured	-	-		S-U		-	-		S-U		-	-		S-U	

Appendix Table B-3. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.
COMP = Class/group compared
oval Indicates significance

INVERTEBRATES: FREE PRODUCT PRESENT

	BUNKER					CRUDE					DIESEL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration															
0 = None	-	-		0-1		5	250.00		0-1	(0.67)	7	20.00		0-1	(0.036)
1 = 0-1 hours	2	55.85		0-2		17	200.00		0-2		10	3.95		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	-	-		0-4		-	-		0-4		-	-		0-4	
4 = > 24 hours	-	-		0-5		-	-		0-5		-	-		0-5	
5 = Not reported	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				1-4					1-4					1-4	
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					3-5	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	2	55.85		1-2		4	58.50		1-2	(0.01)	4	24.35		1-2	(0.40)
2 = Multiple ratio	-	-		1-3		18	475.00		1-3		13	9.40		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Chamber															
1 = Open	2	55.85		1-2		22	225.00		1-2		17	9.40		1-2	
2 = Closed	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)								(0.67)					(0.19)		
4	-	-		4-24		-	-		4-24		-	-		4-24	
24	1	100.00		4-48		6	118.50		4-48		5	41.00		4-48	
48	1	11.70		4-96		7	63.00		4-96		4	3.75		4-96	
96	-	-		4->96		9	450.00		4->96		8	10.00		4->96	
>96	-	-		24-48	(1.00)	-	-		24-48		-	-		24-48	
				24-96					24-96					24-96	
				24->96					24->96					24->96	
				48-96					48-96					48-96	
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage								(0.11)					(0.24)		
0 = Eggs	-	-		0-1		-	-		0-1		-	-		0-1	
1 = Larvae	-	-		0-2		4	350.00		0-2		2	7.00		0-2	
2 = Juvenile	2	55.85		0-3		5	59.00		0-3		5	41.00		0-3	
3 = Adult	-	-		1-2		13	1000		1-2		10	6.60		1-2	
				1-3					1-3					1-3	
				2-3					2-3					2-3	
Exposure Method													(0.19)		
ST = Static	2	55.85		ST-SR		20	225.00		ST-SR	(0.69)	14	5.90		ST-SR	
SR = Static Renewed	-	-		ST-FT		2	790.00		ST-FT		2	15.0		ST-FT	
FT = Flow-through	-	-		SR-FT		-	-		SR-FT		1	4778		SR-FT	
Test Condition															
FW = Freshwater	-	-		FW-SW		-	-		FW-SW		-	-		FW-SW	
SW = Saltwater	2	55.85				22	225.00				17	9.40			
Measured/Stock/Unmeasured															
M = Measured	-	-		M-S		-	-		M-S		-	-		M-S	
S = Stock	2	55.85		M-U		4	58.50		M-U		4	24.35		M-U	
U = Unmeasured	-	-		S-U		18	475.00		S-U	(0.012)	13	9.40		S-U	(0.40)

Appendix Table B-4. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.

COMP = Class/group compared

oval Indicates significance

	INVERTEBRATES: FREE PRODUCT PRESENT														
	GASOLINE					JET FUEL					LUBE OIL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration															
0 = None	-	-		0-1		-	-		0-1		-	-		0-1	
1 = 0-1 hours	-	-		0-2		-	-		0-2		2	55.50		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	-	-		0-4		-	-		0-4		-	-		0-4	
4 = >24 hours	-	-		0-5		-	-		0-5		-	-		0-5	
5 = Not reported	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				1-4					1-4					1-4	
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					3-5	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	-	-		1-2		-	-		1-2		2	55.50		1-2	
2 = Multiple ratio	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Chamber															
1 = Open	-	-		1-2		-	-		1-2		2	55.50		1-2	
2 = Closed	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)															
4	-	-		4-24		-	-		4-24		-	-		4-24	
24	-	-		4-48		-	-		4-48		1	91.00		4-48	
48	-	-		4-96		-	-		4-96		1	20.00		4-96	
96	-	-		4->96		-	-		4->96		-	-		4->96	
>96	-	-		24-48		-	-		24-48		-	-		24-48	(1.00)
				24-96					24-96					24-96	
				24->96					24->96					24->96	
				48-96					48-96					48-96	
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage															
0 = Eggs	-	-		0-1		-	-		0-1		-	-		0-1	
1 = Larvae	-	-		0-2		-	-		0-2		-	-		0-2	
2 = Juvenile	-	-		0-3		-	-		0-3		2	55.50		0-3	
3 = Adult	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				2-3					2-3					2-3	
Exposure Method															
ST = Static	-	-		ST-SR		-	-		ST-SR		2	55.50		ST-SR	
SR = Static Renewed	-	-		ST-FT		-	-		ST-FT		-	-		ST-FT	
FT = Flow-through	-	-		SR-FT		-	-		SR-FT		-	-		SR-FT	
Test Condition															
FW = Freshwater	-	-		FW-SW		-	-		FW-SW		-	-		FW-SW	
SW = Saltwater	-	-				-	-				2	55.50			
Measured/Stock/Unmeasured															
M = Measured	-	-		M-S		-	-		M-S		-	-		M-S	
S = Stock	-	-		M-U		-	-		M-U		2	55.50		M-U	
U = Unmeasured	-	-		S-U		-	-		S-U		-	-		S-U	

Appendix Table B-5. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.
COMP = Class/group compared
oval Indicates significance

FISH: FREE PRODUCT ABSENT

	BUNKER					CRUDE					DIESEL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration								(0.17)							
0 = None	-	-		0-1		-	-		0-1		-	-		0-1	
1 = 0-1 hours	4	4.20		0-2		11	6.60		0-2		8	6.05		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	9	3.10		0-4		42	2.93		0-4		23	2.29		0-4	
4 = >24 hours	-	-		0-5		-	-		0-5		-	-		0-5	
5 = Not reported	-	-		1-2		1	1.64		1-2		-	-		1-2	
				1-3	(0.44)				1-3					1-3	(0.006)
				1-4					1-4					1-4	
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					3-5	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	13	3.60		1-2		51	3.73		1-2		31	3.50		1-2	
2 = Multiple ratio	-	-		1-3		-	-		1-3	(0.07)	-	-		1-3	
3 = Not reported	-	-		2-3		3	1.90		2-3		-	-		2-3	
Test Chamber															
1 = Open	13	3.60		1-2		54	3.12		1-2		31	3.50		1-2	
2 = Closed	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)			(0.12)					(0.11)					(0.01)		
4	-	-		4-24		-	-		4-24		-	-		4-24	
24	5	3.80		4-48		8	5.80		4-48		9	5.70		4-48	
48	3	2.70		4-96		1	8.70		4-96		2	4.95		4-96	
96	5	1.90		4->96		43	2.92		4->96		20	2.00		4->96	
>96	-	-		24-48		2	1.14		24-48		-	-		24-48	(0.56)
				24-96					24-96					24-96	(0.007)
				24->96					24->96					24->96	
				48-96					48-96					48-96	(0.12)
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage								(0.004)							
0 = Eggs	-	-		0-1		1	2.20		0-1	(0.54)	-	-		0-1	
1 = Larvae	-	-		0-2		2	1.40		0-2	(0.83)	-	-		0-2	
2 = Juvenile	-	-		0-3		15	2.04		0-3	(0.28)	-	-		0-3	
3 = Adult	13	3.60		1-2		36	5.00		1-2	(0.26)	31	3.50		1-2	
				1-3					1-3	(0.05)				1-3	
				2-3					2-3	(<.002)				2-3	
Exposure Method															
ST = Static	13	3.60		ST-SR		54	3.13		ST-SR		31	3.50		ST-SR	
SR = Static Renewed	-	-		ST-FT		-	-		ST-FT		-	-		ST-FT	
FT = Flow-through	-	-		SR-FT		-	-		SR-FT		-	-		SR-FT	
Test Condition															
FW = Freshwater	2	5.85		FW-SW	(0.048)	15	2.68		FW-SW	(0.98)	4	7.30		FW-SW	(0.004)
SW = Saltwater	11	3.10				39	3.73				27	2.90			
Measured/Stock/Unmeasured															
M = Measured	-	-		M-S		24	2.21		M-S	(<.001)	5	2.29		M-S	(0.21)
S = Stock	13	3.60		M-U		30	5.70		M-U		26	3.90		M-U	
U = Unmeasured	-	-		S-U		-	-		S-U		-	-		S-U	

Appendix Table B-6. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.
COMP = Class/group compared
oval Indicates significance

	FISH: FREE PRODUCT ABSENT														
	GASOLINE					JET FUEL					LUBE OIL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration															
0 = None	-	-		0-1		-	-		0-1		-	-		0-1	
1 = 0-1 hours	-	-		0-2		-	-		0-2		4	2.25		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	-	-		0-4		-	-		0-4		-	-		0-4	
4 = >24 hours	-	-		0-5		-	-		0-5		-	-		0-5	
5 = Not reported	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				1-4					1-4					1-4	
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					3-5	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	-	-		1-2		-	-		1-2		4	2.25		1-2	
2 = Multiple ratio	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Chamber															
1 = Open	-	-		1-2		-	-		1-2		4	2.25		1-2	
2 = Closed	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)															
4	-	-		4-24		-	-		4-24		-	-		4-24	
24	-	-		4-48		-	-		4-48		2	2.35		4-48	
48	-	-		4-96		-	-		4-96		-	-		4-96	
96	-	-		4->96		-	-		4->96		2	2.25		4->96	
>96	-	-		24-48		-	-		24-48		-	-		24-48	
				24-96					24-96					24-96	(1.00)
				24->96					24->96					24->96	
				48-96					48-96					48-96	
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage															
0 = Eggs	-	-		0-1		-	-		0-1		-	-		0-1	
1 = Larvae	-	-		0-2		-	-		0-2		-	-		0-2	
2 = Juvenile	-	-		0-3		-	-		0-3		-	-		0-3	
3 = Adult	-	-		1-2		-	-		1-2		4	2.25		1-2	
				1-3					1-3					1-3	
				2-3					2-3					2-3	
Exposure Method															
ST = Static	-	-		ST-SR		-	-		ST-SR		4	2.25		ST-SR	
SR = Static Renewed	-	-		ST-FT		-	-		ST-FT		-	-		ST-FT	
FT = Flow-through	-	-		SR-FT		-	-		SR-FT		-	-		SR-FT	
Test Condition															
FW = Freshwater	-	-		FW-SW		-	-		FW-SW		2	2.60		FW-SW	(0.22)
SW = Saltwater	-	-				-	-				2	2.00			
Measured/Stock/Unmeasured															
M = Measured	-	-		M-S		-	-		M-S		-	-		M-S	
S = Stock	-	-		M-U		-	-		M-U		4	2.25		M-U	
U = Unmeasured	-	-		S-U		-	-		S-U		-	-		S-U	

Appendix Table B-7. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.
COMP = Class/group compared
oval Indicates significance

	FISH: FREE PRODUCT PRESENT														
	BUNKER					CRUDE					DIESEL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration															
0 = None	-	-		0-1		12	757.50		0-1	(0.10)	4	795.00		0-1	(0.02)
1 = 0-1 hours	4	55.70		0-2		34	3200		0-2		16	38.75		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	-	-		0-4		-	-		0-4		-	-		0-4	
4 = >24 hours	-	-		0-5		-	-		0-5		-	-		0-5	
5 = Not reported	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				1-4					1-4					1-4	
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					3-5	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	4	55.70		1-2		8	40.00		1-2	(<0.001)	8	12.70		1-2	(<0.002)
2 = Multiple ratio	-	-		1-3		38	3200		1-3		12	162.50		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Chamber															
1 = Open	4	55.70		1-2		46	1365		1-2		20	45.10		1-2	
2 = Closed	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)								(0.07)					(0.37)		
4	-	-		4-24		-	-		4-24		-	-		4-24	
24	2	175.00		4-48		16	3200		4-48		8	47.60		4-48	
48	-	-		4-96		3	15000		4-96		3	125.00		4-96	
96	2	10.70		4->96		21	1250		4->96		9	33.00		4->96	
>96	-	-		24-48		-	-		24-48		-	-		24-48	
				24-96	(0.24)				24-96					24-96	
				24->96					24->96					24->96	
				48-96					48-96					48-96	
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage								(0.17)							
0 = Eggs	-	-		0-1		4	3200		0-1		-	-		0-1	
1 = Larvae	-	-		0-2		-	-		0-2		-	-		0-2	
2 = Juvenile	-	-		0-3		10	560.00		0-3		-	-		0-3	
3 = Adult	4	55.70		1-2		32	2550		1-2		20	45.10		1-2	
				1-3					1-3					1-3	
				2-3					2-3					2-3	
Exposure Method															
ST = Static	4	55.70		ST-SR		34	3200		ST-SR		16	38.75		ST-SR	
SR = Static Renewed	-	-		ST-FT		-	-		ST-FT	(0.10)	-	-		ST-FT	(0.02)
FT = Flow-through	-	-		SR-FT		12	757.50		SR-FT		4	795.00		SR-FT	
Test Condition															
FW = Freshwater	2	130.70		FW-SW	(0.70)	12	1525		FW-SW	(0.30)	4	12.70		FW-SW	(0.03)
SW = Saltwater	2	55.00				34	1365				16	70.50			
Measured/Stock/Unmeasured								(<0.001)							
M = Measured	-	-		M-S		4	42.00		M-S	(1.00)	-	-		M-S	
S = Stock	4	55.70		M-U		8	40.00		M-U	(<0.002)	8	12.70		M-U	
U = Unmeasured	-	-		S-U		34	3200		S-U	(<0.001)	12	162.50		S-U	(<0.002)

Appendix Table B-8. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.

COMP = Class/group compared

oval Indicates significance

FISH: FREE PRODUCT PRESENT

	GASOLINE					JET FUEL					LUBE OIL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration															
0 = None	-	-		0-1		8	560.00		0-1		-	-		0-1	
1 = 0-1 hours	-	-		0-2		-	-		0-2		3	68.00		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	-	-		0-4		-	-		0-4		-	-		0-4	
4 = >24 hours	-	-		0-5		-	-		0-5		-	-		0-5	
5 = Not reported	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				1-4					1-4					1-4	
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					[illegible]	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	-	-		1-2		-	-		1-2		3	68.00		1-2	
2 = Multiple ratio	-	-		1-3		8	560.00		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Chamber															
1 = Open	-	-		1-2		8	560.00		1-2		3	68.00		1-2	
2 = Closed	-	-		1-3		-	-		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Duration (hours)								(0.38)							
4	-	-		4-24		-	-		4-24		-	-		4-24	
24	-	-		4-48		3	560.00		4-48		2	85.50		4-48	
48	-	-		4-96		2	555.00		4-96		-	-		4-96	
96	-	-		4->96		3	470.00		4->96		1	33.00		4->96	
>96	-	-		24-48		-	-		24-48		-	-		24-48	
				24-96					24-96					24-96	(0.54)
				24->96					24->96					24->96	
				48-96					48-96					48-96	
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage															
0 = Eggs	-	-		0-1		-	-		0-1		-	-		0-1	
1 = Larvae	-	-		0-2		-	-		0-2		-	-		0-2	
2 = Juvenile	-	-		0-3		-	-		0-3		-	-		0-3	
3 = Adult	-	-		1-2		8	560.00		1-2		3	68.00		1-2	
				1-3					1-3					1-3	
				2-3					2-3					2-3	
Exposure Method															
ST = Static	-	-		ST-SR		8	560.00		ST-SR		3	68.00		ST-SR	
SR = Static Renewed	-	-		ST-FT		-	-		ST-FT		-	-		ST-FT	
FT = Flow-through	-	-		SR-FT		-	-		SR-FT		-	-		SR-FT	
Test Condition															
FW = Freshwater	-	-		FW-SW		8	560.00		FW-SW		2	68.00		FW-SW	(1.00)
SW = Saltwater	-	-				-	-				1	68.00			
Measured/Stock/Unmeasured															
M = Measured	-	-		M-S		-	-		M-S		-	-		M-S	
S = Stock	-	-		M-U		-	-		M-U		3	68.00		M-U	
U = Unmeasured	-	-		S-U		8	560.00		S-U		-	-		S-U	

Appendix Table B-9. Statistical comparisons of median effect concentration data by methodological parameter.

KW indicates Kruskal Wallis p-value if appropriate.

COMP = Class/group compared

oval Indicates significance

ALGAE: FREE PRODUCT PRESENT

	JET FUEL					CRUDE					DIESEL				
	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value	N	MEDIAN	KW	COMP	P-value
Agitation Duration															
0 = None	2	210.00		0-1		28	95.00		0-1		15	50.00		0-1	
1 = 0-1 hours	-	-		0-2		-	-		0-2		-	-		0-2	
2 = 1-12 hours	-	-		0-3		-	-		0-3		-	-		0-3	
3 = 12-24 hours	-	-		0-4		-	-		0-4		-	-		0-4	
4 = >24 hours	-	-		0-5		-	-		0-5		-	-		0-5	
5 = Not reported	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				1-4					1-4					1-4	
				1-5					1-5					1-5	
				2-3					2-3					2-3	
				2-4					2-4					2-4	
				2-5					2-5					2-5	
				3-4					3-4					3-4	
				3-5					3-5					3-5	
				4-5					4-5					4-5	
Test Solution Development															
1 = Single ratio	-	-		1-2		-	-		1-2		-	-		1-2	
2 = Multiple ratio	2	210.00		1-3		28	95.00		1-3		15	50.00		1-3	
3 = Not reported	-	-		2-3		-	-		2-3		-	-		2-3	
Test Chamber															
1 = Open	2	210.00		1-2		-	-		1-2		-	-		1-2	
2 = Closed	-	-		1-3		16	1.00		1-3		-	-		1-3	
3 = Not reported	-	-		2-3		12	1500		2-3	(<0.001)	15	50.00		2-3	
Test Duration (hours)															
4	-	-		4-24		-	-		4-24		-	-		4-24	
24	-	-		4-48		-	-		4-48		-	-		4-48	
48	-	-		4-96		-	-		4-96		-	-		4-96	
96	-	-		4->96		-	-		4->96		-	-		4->96	
>96	2	210.00		24-48	(1.00)	28	95.00		24-48		15	50.00		24-48	
				24-96					24-96					24-96	
				24->96					24->96					24->96	
				48-96					48-96					48-96	
				48->96					48->96					48->96	
				96->96					96->96					96->96	
Life Stage (NA for Algae)															
0 = Eggs	-	-		0-1		-	-		0-1		-	-		0-1	
1 = Larvae	-	-		0-2		-	-		0-2		-	-		0-2	
2 = Juvenile	-	-		0-3		-	-		0-3		-	-		0-3	
3 = Adult	-	-		1-2		-	-		1-2		-	-		1-2	
				1-3					1-3					1-3	
				2-3					2-3					2-3	
Exposure Method															
ST = Static	2	55.85		ST-SR		28	95.00		ST-SR		15	50.00		ST-SR	
SR = Static Renewed	-	-		ST-FT		-	-		ST-FT		-	-		ST-FT	
FT = Flow-through	-	-		SR-FT		-	-		SR-FT		-	-		SR-FT	
Test Condition						(12 values not reported)					(15 values not reported)				
FW = Freshwater	2	210.00		FW-SW		-	-		FW-SW		-	-		FW-SW	
SW = Saltwater	-	-				16	1.00				-	-			
Measured/Stock/Unmeasured															
M = Measured	-	-		M-S		-	-		M-S		-	-		M-S	
S = Stock	-	-		M-U		-	-		M-U		-	-		M-U	
U = Unmeasured	2	210.00		S-U		28	95.00		S-U		15	50.00		S-U	

APPENDIX C: DATA CLASSIFIED AS LOW RELIABILITY

Appendix Table C-1. Effect Concentration (mg/l) for Data Records Classified as "Low Reliability".

Oil Product	Invertebrates								Fish							
	Free Product Absent				Free Product Present				Free Product Absent				Free Product Present			
	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max	N	Median	Min	Max
Bunker					**2**	**504.10**	**6.20**	**1002**								
Bunker C (unspecified)(B01)																
Venezuelan Bunker C (B02)																
Bunker C Light (B04)																
Heavy Fuel Oil No. 4 (B05)					2	504.10	6.20	1002								
Crude	**2**	**12.06**	**11.58**	**12.55**	**2**	**275.40**	**0.80**	**550.00**	**11**	**204.00**	**88.00**	**497.00**	**1**	**20000**	**20000**	**20000**
Kuwait (light) Crude (C01)																
Cook Inlet Crude (C02)																
Southern Louisiana Crude (C03)																
Florida Jay Crude (C04)																
Prudhoe Bay Crude (C05)									11	204.00	88.00	497.00				
Venezuelan Crude (C06)					2	275.40	0.80	550.00								
Western Sweet Blend Crude (C07)																
Transmountain Crude (C08)																
Norman Wells Crude (C09)																
Hibernia Crude (C10)																
Amauligak Crude (C11)																
Tarsuit Crude (C12)																
Lago Medio Crude (C13)																
Atkinson Crude (C14)																
Bent Horn Crude (C15)																
Ramashkin Crude (C16)																
Dubai Crude (C18)	2	12.06	11.58	12.55									1	20000	20000	20000
Diesel																
Diesel (D01)																
Fuel Oil No. 2 (D02)																
Fuel Oil No. 2, Furnace Oil (D03)																
Light Diesel Fuel (D04)																
Heavy Diesel Fuel (D05)																
Navy Distillate (D06)																
Marine Diesel (D07)																
Gasoline													**3**	**171.00**	**47.00**	**233.00**
Leaded Gasoline (G01)													1	233.00	233.00	233.00
Low Leaded Gasoline (G03)													2	109.00	47.00	171.00
Jet Fuel					**2**	**86.65**	**0.30**	**173.00**					**20**	**17.50**	**1.90**	**66.00**
Light Fuel Oil No. 1 - (J02)					2	86.65	0.30	173.00								
Jet Fuel - JP9 (J03)													8	2.60	1.90	10.00
Jet Fuel - JP4 (J04)													12	24.50	16.00	66.00
Lube Oil																
Auto Lube (L01)																
Heavy Marine Lube (L02)																
9250 Lube Oil (L03)																

Note: Five (5) additional "low reliability" records are not included in this table. These data were not designated as to whether free product was present or absent.

APPENDIX D: OILTOX DATABASE SYSTEM VERSION 1.0 USERS GUIDE

OILTOX DATABASE SYSTEM: Version 1.0

User's Guide

Table of Contents

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TERMS: "API" MEANS THE AMERICAN PETROLEUM INSTITUTE.

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INTRODUCTION TO THE OILTOX DATABASE

The Oil and Oil Product Toxicity Database (OILTOX) was developed for the American Petroleum Institute(API) by ENTRIX, Inc. as described in the API Report entitled "*A Critical Review of Toxicity Values and an Evaluation of the Persistence of Petroleum Products for Use in Natural Resource Damage Assessments*". The database contains acute toxicity values for a variety of oils and oil product groups as well as major taxonomic groups. Additionally, the database contains a variety of parameters which describe the methodological conditions under which each toxicity value was derived. The oil groups, taxonomic groups, and methodological parameters included in the database are described in the above mentioned report.

The OILTOX software is user-friendly, mouse compatible and runs on IBM compatible microcomputers. Although OILTOX was designed to be simple and straight-forward, use of the software assumes that the user has limited knowledge of database management and computer functions.

The database provided on the attached diskette is the "**Read-Only**" version. The database contains 748 individual data records and allows the user to browse the existing data set as well as produce a variety of data reports. The information comprising each data record in the database is presented on the data entry form in Figure 1. The database structure is presented in Table 1. The oil product and species code lists are provided at the end of this users guide.

System Requirements

You can run OILTOX on the IBM PC, Personal Computer AT, PC/XT, or 100% compatible computers.

OILTOX runs with PC-DOS release 2.0 or greater.

To set-up OILTOX, you will need the program diskette and at least 2 MB of hard disk space and 640K of RAM memory. A color monitor is helpful but not essential in running the program.

API TOXICITY DATABASE ENTRY FORM: 712400

Oil Product: ☐☐☐

B = Bunker C (No. 6)
C = Crude Oil
D = Diesel (No. 2)
G = Gasoline
J = Jet Fuel (No. 1)
K = Kerosene
L = Lube Oil

Study Purpose Endpoint: Primary: ☐☐☐☐☐

ENDPOINTS: (LC50 / LC100 / EC50 / EC100 / NOEC / LOEC)

Persistence Data Reported? (Y=yes/N=no): ☐ If Yes, Qualitative (1) or Quantitative(2)? ☐

Chronic Data Reported? (Y=yes/N=no): ☐

Agitation Duration During Preparation (hrs)?: ☐

(0=0/1=0-1/2=1-12/3=12-24/4=>24/5=not reported)

Test Solution Development: (1=single ratio/2=multiple ratio/3=not reported): ☐

Test Chamber: (1=open/2=closed/3=not reported): ☐

Free Product Present: (Y=present/N=absent/U=unknown): ☐

Test Duration (hours): ☐☐☐

Species Identification Code: ☐☐☐

Age/Life-stage Code: (0=egg/1=larvae/2=juvenile/3=adult): ☐

Study Type (1=lab/2=field(deliberate spill)/3=field(accidental spill): ☐

Exposure Method(ST=static, non-renewed/SR= static, renewed/FT= flow-through): ☐☐

Test Condition (FW=freshwater/SW=saltwater): ☐☐

Effect Concentration (mg/l): Primary: ☐☐☐☐☐☐☐.☐☐

Measured/Unmeasured/Stock (M=measured/U=unmeasured/S=stock): ☐

Reliability Code (L=low/M=medium/H=high): ☐

L = Study does not meet criteria for reliability (low)
M = Study meets some criteria for reliability (medium)
H = Study meets all criteria for reliability (high)

Peer Reviewed? (Y=yes/N=no/U=unknown): ☐

Reference Number: ☐☐☐ Year Published: ☐☐☐☐

Remarks: ______________________________

____

Additional Notes: (Not for Computer Entry):

____

____

Figure 1. Example of the database entry form.

Structure for database : F:\ARAGO\APITOX.DBF
Number of records : 748
Last update : 03-30-93

Field	Field Name	Type	Length	Dec
1	OILPROD	Character	3	
2	PRIMEND	Character	5	
3	PERSIST	Character	1	
4	QUAL	Numeric	1	
5	CHRONIC	Character	1	
6	AGITATE	Numeric	1	
7	TESTSOL	Numeric	1	
8	TESTCHAM	Numeric	1	
9	FREEPROD	Character	1	
10	TESTDUR	Numeric	3	
11	SPECIES	Numeric	3	
12	LIFESTAGE	Numeric	1	
13	STUDYTYPE	Numeric	1	
14	EXMETH	Character	2	
15	TESTCOND	Character	2	
16	EFFCONCP	Numeric	9	2
17	MEASURED	Character	1	
18	RELIABLE	Character	1	
19	PEERREV	Character	1	
20	REFNUMBER	Numeric	3	
21	YRPUB	Numeric	4	
22	REMARKS	Character	240	
** Total **			287	

Table 1. OILTOX Database Structure.

If you are having RAM memory problems, you may want to lower the number of buffers in the Config.Sys file and clear out other memory resident programs.

INSTALLATION

The OILTOX diskette is not copy protected. You should make backup copies of the software for archival purposes. The program disk contains the following files:

OILTOX.EXE
RPW.MEM
APITOX.DBF
APISPP.DBF
APIOIL.DBF
APIREF.DBF
OILPROD.NDX
REFNUM.NDX
SPPCODE.NDX
REFNO.NDX
OILNAME.NDX

To install OILTOX on your computer, copy (using DOS commands) all of the files from the OILTOX program diskette to the directory and subdirectory in which you would like the OILTOX program to reside. For further details on using DOS commands please refer to your DOS manual.

Installation Instructions Example:

Installing from Drive A: to C:\OILTOX subdirectory:

1) Create subdirectory OILTOX to contain program.
   ie. @ DOS prompt (C:\>) type in **MD OILTOX** then press enter

2) Insert the OILTOX program diskette into Drive **A:**

3) Copy all files from diskette to subdirectory OILTOX
   ie. @ DOS prompt (C:\>) type in **Copy A:*.* C:\OILTOX** then press enter.

Running the Program

1) Get into the OILTOX subdirectory
   ie. At the DOS prompt (C:\>) type in **CD C:\OILTOX** then press enter

2) Type in **OILTOX** and press enter to execute the program.
   i.e. At the DOS prompt (C:\OILTOX>) type in **OILTOX** then press enter.

Program Functions

A mouse or keyboard can be used in moving about the OILTOX program. When using the keyboard, you can press the "highlighted" letter of a given choice to select that choice or you can move the cursor to that choice and press the enter key. If using a mouse you can just "click" on a selected choice.

Note: In the following guide, the term "click" refers to both pressing the mouse button on a selected choice and, if using the keyboard, pressing the enter key once the choice has been selected.

There are six major panels (choices) available from the Main Menu. These are:

Password	Browse	Reports	File Maintenance	Utilities	Exit

These choices are described in detail below:

Password

When you start the OILTOX program, you will need to enter a password before you can use any of the modules. When you click on the password panel, you will be prompted to enter a password (up to 8 characters). When you first receive the program, the password assigned is **OILTOX.** You can change the password by entering an X after the password. For example, when you are prompted to enter the password, if you enter APIOILX, you will access a screen from which you can change the password.

Browse Data

When you click on the Browse Data panel, you are provided with one choice:

- BROWSE EXISTING TOXICITY DATA

Browse Existing Toxicity Data

This module allows the user to browse existing data records. **The data records are accessed by Oil Product code in alphabetical order.** Help messages are provided at the bottom of the screen.

The codes for the OIL PRODUCT and SPECIES variables can be accessed through this screen. You can also access the literature reference from which each data record was developed. To access the code lists or the literature reference, place then click the mouse cursor on the "**V**" which is located immediately to the left of each respective variable. The code list or literature reference will appear on the screen. To move up and down each code list, use the up-down arrow keys, the PgDn/PgUp keys, or place the mouse cursor on the arrows located in the popup window and click on the direction in which you would like to move. To Exit the code list, press the ESC button.

You are provided with several panels (options) in the Browse Data Screen.

NEXT: *Moves to the next record in the toxicity database.*
PREV: *Moves to the previous record in the toxicity database.*
+10: *Jumps ahead 10 data records in the toxicity database.*
-10: *Jumps backwards 10 data records in the toxicity database.*
VIEW: *Produces a view screen where each toxicity data record is presented in table form (1 record per line).*

When **VIEW** is selected:

To move between records, use the Up and Down arrow keys to move one record at a time, and PgUp and PgDn to move one screen at a time. Use Ctrl-PgUp and Ctrl-PgDn to move to the beginning or the end of the database. Use HOME to move to the first field of a record or END to move to the last field. To move across a record you can place the mouse cursor on the arrows located in the popup window (horizontal direction) and click on the direction in which you would like to move or drag the cursor in the direction you would like to move. Press ESC to Exit the VIEW screen and return to the Browse screen.

QUIT *Quits the browse module and returns to the main menu.*

Reports

User Specified Data Report

The Reports module allows the user to produce a user-defined report. For instance, you may be interested in reviewing data on diesel fuel toxicity to saltwater invertebrates. When the Report module is selected, a Report Selection Checklist will appear on the screen. By clicking on the appropriate checkboxes, the user can select these fields and subsequent produce a report containing only these data. The reports can either be written to the screen, an ASCII Text file or sent directly to the printer. Click on as many checkboxes as you wish. When you have checked the boxes from which your report will be created, click on the OK panel.

For each checkbox checked, a prompt will be provided to determine the value or range on which that parameter is to be selected. For example, if the "Free Product Presence" checkbox is checked, you will be prompted to enter a "Y" or "N". In either case, the output produced will consist of only those records you selected (e.g. if a "Y" was entered, the report would contain only toxicity data where exposure systems had "Free Product Present"). You may click on as many checkboxes as you wish in developing a report. If no checkboxes are checked, then all data records will be selected. The checkboxes allow a wide variety of subsets of the database to be created. (See "*Utilities*").

In selecting by Oil Product you may select by specific Oil Product code or you may select by group. For example, if you wanted to select Cook Inlet Crude you would enter "C02". If you wanted to select all Crudes you would enter "C".

The codes for the OIL PRODUCT and SPECIES variables can be accessed through this screen. To access the code lists place then click the mouse cursor on the "V" which is located immediately to the left of each respective variable. The code list will appear on the screen. To move up and down each code list, use the up-down arrow keys, the PgDn/PgUp Keys, or place the mouse cursor on the arrows located in the popup window and click on the direction in which you would like to move. To Exit the code list press the ESC button.

Once you have selected to send the output to the screen, the printer or to a file, you will be prompted to select a report output format.

If you choose "Send TOX Values to the Screen", the following data will be written to the screen:

OILP:	Oil Product Code
ENDPT:	Test Endpoint (i.e., LC50, EC50)
CONC(mg/l):	Effect Concentration (mg/l)
SPP:	Species
TESTCOND:	Test Condition
FREEPROD:	Free Product Presence
YEAR:	Year Published
REF #:	Reference Number

Reference Numbers in OILTOX relate to the assigned reference numbers in Appendix A of the API Report entitled "*A Critical Review of Toxicity Values and an Evaluation of the Persistence of Petroleum Products for Use in Natural Resource Damage Assessments*".

If you choose to send the output to a file, you will be prompted to enter a filename. If not otherwise specified, the output file will have a default extension of .PRT and will be written to the default directory.

If you choose to send the report to the printer, the report will be sent directly to the printer.

When the report is completed, a message will be displayed as to the number of data records selected for the report (number of records meeting the selection criteria).

Types of Reports

There are three types of report output which can be produced if you select to sent the output to a file or to the printer. These are:

- ALL FIELDS: 1 RECORD PER PAGE,
- LC50 VALUES, and
- ALL FIELDS: 1 RECORD PER ROW: (COMMA DELIMITED)

All Fields: 1 Record per Page:

If this report format is selected, all of the data fields from each record will be displayed as presented in Figure 2. Only one data record will be displayed per page.

LC50 Values

If this report format is selected, the following information will be displayed, 1 record per line:

Primary Endpoint   Effect Concentration(mg/l)   Species Reference #

An example of this report output type is presented in Figure 3.

All Fields: 1 Record per Row: (Comma Delimited)

If this report format is selected, all of the data fields from each record will be displayed, 1 record per line with each field separated by a comma (,). This type of format can easily be read into a spreadsheet program or other software package. An example printout of this type of report is presented in Figure 4. The order of the variables in the output report are presented in the first line of the report.

API TOXICITY DATA REPORT: PAGE 1

Oil Product: L01

Study Purpose Endpoint: Primary: EC50

Persistence Data Reported: N
Chronic Data Reported: N
Agitation Duration During Preparation (hrs): 4
Test Solution Development: 1
Test Chamber: 2
Free Product Present: N
Test Duration (hrs): 4
Species Identification Code: 262
Age-Life Stage: 2
Study Type: 1
Exposure Method: ST
Test Condition: SW

Effect Concentration (mg/l): Primary: 1.50

Measured/Unmeasured/Stock: M

Reliability Code: H
Peer Reviewed: U
Reference Number: 84
Year Published: 1989

Remarks:
Immobility. Value represents >100% WSF. Measured by fluoresc
ence spectroscopy.

Figure 2. Example output from report module using the "All Fields: 1 Record per Page" option.

TOXICITY ENDPOINT SUMMARY

Primary Endpoint	Effect Conc (mg/l), primary	Spp	Ref#:
EC50	1.50	262	84
LC50	0.44	262	84
EC50	0.30	201	84
LC50	0.38	201	84
EC50	1.50	201	84
EC50	0.08	262	84
EC50	100000.00	303	14
EC50	100000.00	302	14
EC50	1.66	262	84
LC50	1.66	262	84
EC50	0.92	201	84
LC50	2.38	201	84
EC50	2.40	201	84
EC50	1.80	262	84
LC50	91.00	262	1
LC50	20.00	262	1
LC50	2.00	262	1
LC50	2.00	262	1
LC50	2.00	170	1
LC50	2.00	170	1
LC50	68.00	170	1
LC50	2.50	110	1
LC50	2.70	110	1
LC50	33.00	110	1
LC50	103.00	110	1

Figure 3. Example output from report module using the "LC50 Values" option.

```
OILP,ENDP,PERS,CHRO,AGIT,TSOL,TCHA,FREE,TDUR,SPP,LIFES,STYPE,EXMETH,TCOND,EFFCONC,MEAS,RELI,PEER,REFN,YEAR
L01, EC50,N,N,4,1,2,N,  4,262,2,1,ST,SW,      1.50,M,H,U, 84,1989
L01, LC50,N,N,4,1,2,N, 48,262,2,1,ST,SW,      0.44,M,H,U, 84,1989
L01, EC50,N,N,4,1,2,N, 48,201,2,1,ST,FW,      0.30,M,H,U, 84,1989
L01, LC50,N,N,4,1,2,N, 48,201,2,1,ST,FW,      0.38,M,H,U, 84,1989
L01, EC50,N,N,4,1,2,N,  4,201,2,1,ST,FW,      1.50,M,H,U, 84,1989
L01, EC50,N,N,4,1,2,N, 48,262,2,1,ST,SW,      0.08,M,H,U, 84,1989
L01, EC50,N,N,5,2,3,Y,240,303,3,1,ST,FW,100000.00,U,L,U, 14,1975
L01, EC50,N,N,5,2,3,Y,240,302,3,1,ST,FW,100000.00,U,L,U, 14,1975
L02, EC50,N,N,4,1,2,N, 48,262,2,1,ST,SW,      1.66,M,H,U, 84,1989
L02, LC50,N,N,4,1,2,N, 48,262,2,1,ST,SW,      1.66,M,H,U, 84,1989
L02, EC50,N,N,4,1,2,N, 48,201,2,1,ST,FW,      0.92,M,H,U, 84,1989
L02, LC50,N,N,4,1,2,N, 48,201,2,1,ST,FW,      2.38,M,H,U, 84,1989
L02, EC50,N,N,4,1,2,N,  4,201,2,1,ST,FW,      2.40,M,H,U, 84,1989
L02, EC50,N,N,4,1,2,N,  4,262,2,1,ST,SW,      1.80,M,H,U, 84,1989
L03, LC50,Y,N,1,1,1,Y, 24,262,2,1,ST,SW,     91.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,Y, 48,262,2,1,ST,SW,     20.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,N, 24,262,2,1,ST,SW,      2.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,N, 48,262,2,1,ST,SW,      2.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,N, 96,170,3,1,ST,SW,      2.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,N, 24,170,3,1,ST,SW,      2.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,Y, 24,170,3,1,ST,SW,     68.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,N, 96,110,3,1,ST,FW,      2.50,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,N, 24,110,3,1,ST,FW,      2.70,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,Y, 96,110,3,1,ST,FW,     33.00,S,H,U,  1,1975
L03, LC50,Y,N,1,1,1,Y, 24,110,3,1,ST,FW,    103.00,S,H,U,  1,1975
```

Figure 4. Example output from report module using the "All Fields: 1 Record per Row, Comma Delimited" option.

File Maintenance

When you click on the File Maintenance Panel, you are presented with 2 options. These are:

- BACKUP THE DATABASE, and
- RESTORE INDEX FILES

Backing-Up the Database

Choosing this option backs-up the files which comprise the database (.DBF files). The backed-up files are given the same name with an extension of .BDB (Backed-up DataBase). The backed-up database files are saved to the default drive and directory.

Restoring Index Files

The database files and code list files are indexed by selected parameters such as reference number, oil product, etc. These indexes are contained in files with an .NDX extension. If one of these index files is opened and subsequently abnormally exited, the index file may not reflect the current contents of the active database or the files may have been corrupted. If the index files are corrupted, they can be restored with this option. Executing this option deletes all of the .NDX files and creates new ones from the current database. It is a good practice to restore the index files at the start and end of each session of database use. Restoring the index files is a good way to confirm that your .NDX files are currently 100% indexed to the active database.

Utilities

There are 3 options to choose from the Utilities Menu. These are:

- EXPORT ASCII FILE,
- EXPORT LOTUS FORMATTED FILE, and
- CHANGE MOUSE SUPPORT

Export ASCII File

With this option, the entire database can be exported in SDF (System Data Format) format. Each record is a fixed length; the end of a record is marked with a carriage return and a line feed. A .TXT extension is provided to the filename unless another extension is provided. Subsets of the database may be exported in ASCII format using the Reports module. The variable order of the exported database is presented in the database structure (Table 1).

Export Lotus Formatted File

With this option, the entire database can be exported in Lotus 1-2-3 spreadsheet format. Records are copied to Lotus 1-2-3 rows, and fields are copied to Lotus 1-2-3 columns. A .WKS extension is provided to the filename unless another extension is provided. Subsets of the database may be exported in ASCII comma-separated format (spreadsheet compatible) using the Report module. The variable order of the exported database is presented in the database structure (Table 1).

Change Mouse Support

This option allows the user to turn the mouse on and off. If the mouse is turned off, the user must use the keyboard to move about the program.

SPECIES CODE LISTS

Fish: 100 - 199

Freshwater 100-149

101 Chinook salmon/*Oncorhynchus tshawytscha*
102 Coho salmon/*Oncorhynchus kisutch*
103 Pink salmon/*Oncorhynchus gorbuscha*
104 Sockeye salmon/*Oncorhynchus nerka*
105 Arctic char/*Salvelinus alpinus*
106 Dolly Varden/*Salvelinus malma*
107 Arctic grayling/*Thymallus arcticus*
108 Threespine stickleback/*Gasterosteus aculeatus*
109 Slimy sculpin/*Cottus cognatus*
110 Fathead minnow/*Pimephales promelas*
111 Goldfish/*Carassius auratus*
112 Golden shiner/*Notemigonus chrysoleneas*
113 Bluegill sunfish/*Lepomis macrochirus*

Saltwater 150-199

151 Walleye pollock/*Theragra chalcogramma*
152 Atlantic siverside/*Menidia menidia* or *Menidia beryllina*
153 Pink salmon/*Oncorhynchus gorbuscha*
154 Dolly Varden/*Salvelinus malma*
155 Sockeye salmon/*Oncorhynchus nerka*
156 Saffron cod/*Eleginus gracilis*
157 Tube-snouts/*Aulorhynchus flavidus*
158 Shiner perch
159 Sandlance
160 Chum salmon
161 Staghorn sculpin
163 Pipe fish
164 Capelin
165 Starry flounder/*Platichthys stellatus*
166 Pacific herring/*Clupea pallasi*
167 Great sculpin/*Myoxocephalus polyacanthocephalus*
168 Crescent gunner/*Pholis laeta*
169 Cockscomb prickleback/*Anoplarchus purpurescens*
170 Mummichog/*Fundulus heteroclitus* or *Fundulus similus*
171 Sheepshead minnow/*Cyprinodon variegatus*
172 Bleak/*Alburnus alburnus*

Invertebrates: 200 - 300

Freshwater 200-229

201 Water flea/*Daphnia magna*
202 *Asellus aquaticus*
203 Copepod/*Nitocra spinipes*

Saltwater 230-299

233 Arctic krill/*Thysanoessa raschii*
234 Whute shrimp/*Penaeus setiferus*
235 Brown shrimp/*Penaeus aztecus*
236 Nemerteans/*Paranemertes peregrina* (purple ribbon worm) *Lineus vegetus* (brown ribbon worm)
237 Annelids/*Nereis vexillosa* (mussel worm) *Harmothoe imbricata* (scale worm)
238 Hall's colus/*Colus halli*
239 Periwinkles/*Littorina sitkana* (Sitka) *Thais lima* (file)
240 Purple margarite/*Margarites pupillus*
241 Chitons/*Katharina tunicata* (leather) *Tonicellla lineata* (lined) *Mopalia ciliata* (ciliated)
242 White cucumber/*Eupentacta quinqueimita*
243 Six-armed starfish/*Leptasterias hexactis*
244 Green sea urchin/*Strongylocentrotus drobachiensis*
245 Tarspot/*Cucumaria vega*
246 Amphipod/*Orchomene pinguis*
247 Purple shore crab/*Hemigrapsis nudus*
248 Grass shrimp/*Palaemonetes pugio* or *Crangon alaskensis* (ref#115)
249 Rock crab
250 Kelp crab
251 Tanner crab/*Chionoecetes bairdi*
252 Crab/*Paragrapsus quadridentatus*
253 King crab/*Paralithodes camtschatica*
254 Kelp shrimp/*Eualus suckleyi* or *Eualus* spp.
255 Scooter shrimp/*Eualus fabricii*
256 Humpy (humpback) shrimp/*Pandalus goniurus*
257 Coonstripe shrimp/*Pandalus hypsinotus* or *Pandalus danae*
258 Quahog clam/*Mercenaria* sp.
259 Dungeness crab/*Cancer magister dana*
260 Ghost crab/*Ocypode quadrata*
261 Planktonic shrimp/*Lucifer faxoni*
262 Brine shrimp/*Artemia*
263 Shrimp/*Crangon crangon*

264 American oyster/*Crassostrea virginica*
265 Arctic invertebrate/*Onisimus litoralis*
266 Arctic invertebrate/*Boeckosimus edwardsi*
267 Arctic invertebrate/*Anonyx nugax*
268 Arctic invertebrate/*Calanus hyperborreus*
269 Barnacle/*Balanus glandula*
270 Supralittoral isopod/*Lygia exotica*
271 Copepod/*Acartia tonsa*
272 Amphipod/*Elasmopus pectenicrus*
273 Amphipod/*Gammarus oceanicus*
274 Amphipod/*Orchomene pinguis*
275 Isopod/*Idothea wosnesenski*
276 Scallops/*Chlamys* spp.
277 Hermit crabs/*Pagurus hirsutiusculus*
278 Dock shrimp/*Pandalus danae*
279 Pink shrimp/*Pandalus borealis*
280 Polychaetous annelid/*Capitella capitata*
281 Polychaetous annelid/*Cirriformia spirabrancha*
282 Polychaetous annelid/*Ctenodrilus serratus*
283 Polychaetous annelid/*Ophryotrocha puerilis*
284 Polychaetous annelid/*Ophryotrocha* sp.
285 Polychaetous annelid/*Neanthes arenaceodentata*
286 Arctic shallow-water mysid/*Mysis oculata*
287 Mysid/*Acanthomysis pseudomacropsis* or *Mysidopsis almyra*
288 Sea cucumber/*Eupentacta quinquesemita*
289 Sea cucumber/*Cucumaria cf. vega*
290 Littleneck clam/*Protothaco staminea*
291 Mussel/*Mytilus edulis*
292 Limpet/*Notoacmaea* spp.
293 Plate limpet/*Collisella scutum*
294 Chiton/*Ischnochiton stelleri*
295 Chiton/*Katharina tunicata*
296 Snail/*Littorina sitkanna*
297 Snail/*Margarites pupilus*
298 Whelks/*Nucella lima* and *Neptunea lyrata* (ridged)

Plants/Algae: 300 - 399

Freshwater 300-349

301 Green algae/*Selanastrium capricornutum*
302 Green algae/*Euglena gracilis*
303 Green algae/*Scenedesmus quadricauda*

Saltwater 350-399

351 Diatom/*Skeletonema costatum*
352 Diatom/*Chaetoceros septentrionalis*
353 Diatom/*Navicula bahusiensis*
354 Diatom/*Nitschia delicatissima*
355 Diatom/*Cylindrotheca* sp.

360 Green algae/*Dunaliella euchlora*
361 Green algae/*Isochrysis galbana*
362 Green algae/*Monochrysis lutheri*
363 Green algae/*Nannochloris oculata*
364 Green algae/*Chlamydomonas pulsatilla*
365 Green algae/*Chlorella autotrophica*

370 Blue-green algae/*Agemenellum quadruplicatum*

Zooplankton: 400 - 499

Freshwater 400-449
Saltwater 450-499

OIL PRODUCT CODE LIST

Crude Oils

C01 Kuwait (light) crude
C02 Cook Inlet crude
C03 Southern Louisiana crude
C04 Florida Jay crude
C05 Prudhoe Bay crude
C06 Venezuelan crude (incl. BCF-22)
C07 Western sweet blend crude
C08 Transmountain crude
C09 Norman Wells crude
C10 Hibernia crude
C11 Amauligak crude
C12 Tarsuit crude
C13 Lago Medio crude
C14 Atkinson crude
C15 Bent Horn crude
C16 Ramashkin crude
C17 West Texas crude
C18 Dubai crude
C19 Nigerian crude
C20 Pembina crude
C21 Alaskan crude (ARCO, unspecified)

Diesel Fuels

D01 Diesel
D02 Fuel Oil No. 2
D03 Fuel Oil No. 2 - furnace fuel
D04 Light diesel fuel
D05 Heavy diesel fuel
D06 Navy distillate fuel
D07 Marine diesel

Bunker Oil

B01 Bunker "C" (unspecified)
B02 Venezuelan Bunker C
B03 Fuel Oil No. 6
B04 Bunker C light
B05 Heavy Fuel Oil No. 4
B06 Navy Special (rptd to be btwn comm. fuels no. 4 and no. 5)

Jet Fuel

J01 Jet fuel - JP8
J02 Light Fuel Oil No. 1
J03 Jet fuel - JP9
J04 Jet fuel - JP4

Gasolines

G01 Leaded gasoline
G02 Unleaded gasoline
G03 Low leaded gasoline

Lube Oils

L01 Auto lube/lubricating oil - unspec.
L02 Heavy marine lube
L03 9250 lube oil

196pp

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