3. AQUATIC ENDPOINTS

3.1 QUOTIENT METHOD

Also known as the "ratio method," this approach to assessing the relative hazard of several constituents has been used in such fields as environmental health and epidemiology. The quotient is calculated from the ratio of the known or estimated concentration of a chemical in the environment to a concentration of that chemical proven or calculated (by extrapolation from experimental data) to be toxic to certain organisms at a particular test endpoint. The endpoint, known as a toxicological benchmark, may be one of several, among them the USEPA water quality criteria (USEPA 1980a-p), the effective concentration causing a designated effect on 20% of the test organisms, (EC_{20}), mean toxic concentration, (MTC), lowest observed toxic concentration (LOTC), median tolerance limit (TL_m), and the concentration required to kill 50% of the test organisms (LC_{50}).

Since this report compares potential toxic differences between groups of chemicals (RACs), benchmarks common to as many of the RACs as possible were preferred. LC_{50} and TL_m, the two benchmarks most frequently found in aquatic toxicological literature, were selected to represent acute toxicity (Table A-1). Chronic effects are presented as the geometric mean maximum allowable toxicant concentration (GMATC), which is the geometric mean of the highest no-observed-effect concentration and the lowest observed-effect concentration (Table A-2). In contrast, benchmarks used in algal tests can vary between studies; therefore, a variety of test endpoints were selected for this report (Table A-3).

Appendix A does not include all extant data on the responses of freshwater organisms to the test chemicals. For example, for the heavy metals, data were excluded for the sake of brevity, but several representative values are included.

As in the selection of benchmarks, the test species chosen for tabulation were those that appear most frequently in the literature. Invertebrates were usually represented by cladocerans (Daphnia species), with insect data presented when available. The fish species selected are those usually used in toxicity testing, namely, fathead minnows (*Pimephales promelas*), bluegills (*Lepomis macrochirus*), and rainbow trout (*Salmo gairdneri*). Data for algal assays are sparse, so all species appearing in the literature, to our knowledge, were included in Table A-3.

Tables 3.1-1 and 3.1-2 present the highest quotients for each RAC and category of effect for the two indirect liquefaction technologies. The acute toxicity quotients were calculated using the upper 95th percentile concentration (an estimate of the worst acute exposure, assuming stable plant operation). The chronic quotients were calculated using the annual median concentration, and the algal quotients were calculated for both concentrations, since the distinction between acute and chronic effects is not clear for algae. The higher the value of these quotients, the greater the risk of acute effects on organisms in the reference stream.

Quotients are interpreted according to the best judgment of the analyst (Barnthouse et al. 1982). A value of 0.01 (1.0 E-02) or less indicates little apparent environmental significance, 0.01 to 10 suggests possible or potential adverse effects, and greater than 10 describes a chemical of probable environmental concern. The utility of these screening criteria for risk analysis must be confirmed by further experience in risk analysis and by field studies.

Ammonia (alkaline gases - RAC 5) and hydrogen sulfide (acid gases - RAC 4) appear to be the most serious ichthyotoxin in the effluents of both technologies, with quotients for fish acute toxicity greater than 1.0 for both. Cadmium (RAC 34) also appears to be a general problem, with fish quotients greater than 0.1 for acute toxicity in both technologies. Quotients greater than 0.01 for acute or chronic toxicity appeared in both technologies for mercury (RAC 32), lead (RAC 35), and other trace elements (RAC 36). No organic RACs had quotients greater than 0.01 for either technology. Fewer RACs appear to be important for algal toxicity due to both the shortage of algal toxicity data and the relative insensitivity of algae to several tested RACs. Only nickel (RAC 33) and cadmium (RAC 34) had quotients greater than 0.01 for either technology.

Table 3.1-1. Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for Lurgi/Fischer-Tropsch process

RAC	Name	Highest quotient[a] Fish (acute) 95%	Fish (chronic) Median	Algae Median	Algae 95%
1	Carbon monoxide	b	b		
2	Sulfur oxides	b	b		
3	Nitrogen oxides	b	b		
4	Acid gases	2.18 E+00	c		
5	Alkaline gases	3.95 E+00	c	c	
6	Hydrocarbon gases	b	b	b	
7	Formaldehyde	b	b	b	
8	Volatile organochlorines	b	b	b	
9	Volatile carboxylic acids	1.81 E-03	c	c	
10	Volatile O & S heterocyclics	c	c	c	
11	Volatile Nheterocyclics	b	b	b	
12	Benzene	3.61 E-06	c	1.63 E-08	3.64 E-08
13	Aliphatic/alicyclic hydrocarbons	9.1 F-08	c	c	
14	Mono- or diaromatic hydrocarbons	4.55 E-05	7.54 E-05	1.42 E-06	3.17 E-06
15	Polycyclic aromatic hydrocarbons	2.97 E-03	c	1.14 E-06	2.18 E-06
16	Aliphatic amines	b	b	b	b
17	Aromatic amines	b	b	b	b
18	Alkaline N heterocyclics	b	b	b	b
19	Neutral N, O, S heterocyclics	c	c	c	c
20	Carboxylic acids	8.85 E-05	c	c	c
21	Phenols	1.12 E-04	1.76 E-04	1.93 E-05	4.33 E-05
22	Aldehydes and ketones	6.81 E-06	6.47 E-06	c	c
23	Nonheterocyclic organosulfur	b	b	b	b
24	Alcohols	c	c	c	c
25	Nitroaromatics	b	b	b	b
26	Esters	4.74 E-08	1.93 E-06	1.40 E-07	3.15 E-07
27	Amides	b	b	b	b
28	Nitriles	b	b	b	b
29	Tars	b	b	b	b
30	Respirable particles	b	b	b	b
31	Arsenic	1.31 E-03	1.56 E-03	3.35 E-03	7.51 E-03
32	Mercury	7.81 E-03	3.64 E-01	1.05 E-03	2.34 E-03
33	Nickel	4.54 E-04	8.54 E-03	9.31 E-03	2.09 E-02
34	Cadmium	1.91 E-01	5.01 E-02	1.70 E-02	3.81 E-02
35	Lead	3.67 E-03	5.18 E-02	1.97 E-03	4.41 E-03
36	Other trace elements	1.67 E-02	1.52 E-04	c	c

[a]The quotients are calculated using the lowest acute LC_{50} or TLm for fish in each RAC (Table A-1), the lowest chronic response by a fish (Table A-2), and the lowest algal response (Table A-3) with either the median or upper 95th percentile of the predicted ambient contaminant concentration (Table 2.2-3).

[b]No effluent.

[c]No toxicity data.

Table 3.1-2. Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for Koppers-Totzek/Fischer-Tropsch process

RAC	Name	Highest quotient[a] Fish (acute) 95%	Fish (chronic) Median	Algae Median	Algae 95%
1	Carbon monoxide	b	b	b	b
2	Sulfur oxides	b	b	b	b
3	Nitrogen oxides	b	b	b	b
4	Acid gases	1.95 E+00	c	c	c
5	Alkaline gases	1.22 E+00	c	c	c
6	Hydrocarbon gases	b	b	b	b
7	Formaldehyde	b	b	b	b
8	Volatile organochlorines	b	b	b	b
9	Volatile carboxylic acids	1.65 E-02	c	c	c
10	Volatile O & S heterocyclics	b	b	b	b
11	Volatile Nheterocyclics	b	b	b	b
12	Benzene	1.46 E-07	c	6.58 E-10	1.47 E-09
13	Aliphatic/alicyclic hydrocarbons	1.92 E-06	c	c	c
14	Mono- or diaromatic hydrocarbons	6.73 E-07	1.11 E-06	2.09 E-08	4.69 E-08
15	Polycyclic aromatic hydrocarbons	1.22 E-05	c	4.88 E-09	8.99 E-09
16	Aliphatic amines	b	b	b	b
17	Aromatic amines	b	b	b	b
18	Alkaline N heterocyclics	b	b	b	b
19	Neutral N, O, S heterocyclics	b	b	b	b
20	Carboxylic acids	b	b	b	b
21	Phenols	4.05 E-07	6.40 E-07	7.01 E-08	1.57 E-07
22	Aldehydes and ketones	6.23 E-05	6.10 E-05	c	c
23	Nonheterocyclic organosulfur	b	b	b	b
24	Alcohols	c	c	c	c
25	Nitroaromatics	b	b	b	b
26	Esters	4.37 E-07	1.78 E-05	1.29 E-06	2.90 E-06
27	Amides	b	b	b	b
28	Nitriles	b	b	b	b
29	Tars	b	b	b	b
30	Respirable particles	b	b	b	b
31	Arsenic	4.54 E-04	5.4 E-04	1.16 E-03	2.61 E-03
32	Mercury	7.43 E-04	3.46 E-02	9.94 E-05	2.23 E-04
33	Nickel	2.21 E-04	4.16 E-03	4.54 E-03	1.02 E-02
34	Cadmium	1.17 E-01	3.08 E-02	1.05 E-02	2.34 E-02
35	Lead	8.04 E-04	1.13 E-02	4.30 E-04	9.64 E-04
36	Other trace elements	3.98 E-01	3.62 E-03	c	c

[a]The quotients are calculated using the lowest acute LC_{50} or TLm for fish in each RAC (Table A-1), the lowest chronic response by a fish (Table A-2), and the lowest algal response (Table A-3) with either the median or upper 95th percentile of the predicted ambient contaminant concentration (Table 2.2-4).

[b]No effluent.

[c]No toxicity data.

Barnthouse et al. (1982) discussed the uncertainties involved in applying the quotient method to environmental data. One of the major inherent problems is that of comparing results from dissimilar tests. Although an attempt was made in this analysis to avoid such pitfalls by comparing, when possible, the same test species and benchmarks, uncontrolled variables inevitably remain. For example, in tests with certain metals (RACs 33, 34, and 35), water hardness is important in determining the concentrations of these metals that are required to elicit a toxic response (Table 3.1-1), a fact reflected in the USEPA criteria for each. Usually, the data are insufficient to compare quotients from tests using the same organisms in both soft and hard waters. Also, in some instances, the analyst must compare quotients derived from tests using water of unspecified or inconsistent quality.

This exercise with the quotient method, in addition to suggesting which of the assigned RACs pose the greatest potential environmental threat, emphasizes the lack of toxicological research on algae as important components of the ecosystem and on synfuels-related organic compounds in general. Despite obvious weaknesses, the method does provide a useful means of screening data from a variety of sources.

3.2 ANALYSIS OF EXTRAPOLATION ERROR

This method of risk analysis is based on the fact that application of the results of laboratory toxicity tests to field exposures requires a series of extrapolations, each of which is made with some error (Barnthouse et al. 1982). The products of the extrapolation are estimates of the centroid and distribution of the ambient concentration of a chemical at which a particular response will occur. The risk of occurrence of the prescribed response is equal to the probability that the response concentration is less than the ambient concentration, given the probability distribution of each. In this section, we extrapolate from acute toxic concentrations for test species of fish to chronic responses of the reference commercial and game species characteristic of the eastern reference site (Travis et al. 1983). The acute toxicity criterion is the 96-h LC_{50}. The chronic toxicity criterion is the life-cycle maximum allowable toxicant concentration (MATC), an interval bounded by the highest no-observed-effects concentration and the lowest concentration causing a statistically significant effect on growth, survival, or reproduction in a life-cycle toxicity test (Mount and Stephan 1969). The geometric mean of the bounds (GMATC) is used as a point estimate of the MATC, as was done in calculating the national water quality criteria (USEPA 1980a-p).

3.2.1 Methods

The computational methods used for the analysis of extrapolation error (AEE) were described by Suter et al. (1983). Acute toxicity data from the Columbia National Fisheries Research Laboratory (Johnson and Finley 1980) were used for the extrapolation between species. Life-cycle toxicity data (Suter et al. 1983) were used to develop a regression relationship between acute toxicity data and chronic toxicity data. Variances associated with extrapolating acute toxicity between taxa and acute to chronic toxicity were accumulated to provide an estimate of the variability associated with the estimate of chronic toxicity; they were also used in obtaining estimates of risk, given estimates of the distribution of the ambient contaminant concentrations.

All of the emitted RACs for which 96-h LC_{50}'s could be found (Table A-1) have been analyzed by the extrapolation error method. The quotient of the ratio of the ambient concentration of a RAC to its predicted GMATC (PGMATC) is presented as an estimate of the hazard of chronic toxicity. Risk, which is defined as the probability that the ambient contaminant concentration exceeds the GMATC, is also presented. Both the hazard and risk estimates are based on the mean ambient concentrations (Tables 2.2-3 and 2.2-4).

In general, the extrapolation between species was done using the regression relationship between the tested and assessed fish at the same taxonomic level and having in common the next higher level. For example, if the fish are in the same family but different genera, the extrapolation would be made between genera. There were three instances when our hierarchical approach failed because of the limitation in the acute toxicity data for the contaminant. The only acute toxicity data available for hydrogen sulfide (RAC 4) and for fluoranthene (RAC 15) were for bluegill sunfish (Lepomis macrochirus), and the only acute toxicity data available for indan (RAC 13) and for quinoline (RAC 18) were for fathead minnows (Pimephales promelas). Difficulties arose with RAC 15 for estimating the acute toxicity of white bass (Morone chrysops) and with RAC 13 for estimating the acute toxicity of bigmouth and smallmouth buffalo (Ictiobus cyprinellus and I. bulbalus). The problem arose because no fish in the family Percichthyidaea or in the genus Ictiobus were tested at the Columbia National Fisheries Research Laboratory. The genus Ictiobus is in the family Catostomidae, which was tested at the Columbia National Fisheries Research Laboratory, but the Cyprinidae-Catostomidae relationship had insufficient sample size (n = 1). Hence, further statistical relationships were developed comparing bluegill sunfish with all Perciformes other than bluegills (R^2 = 0.91) and fathead minnow with all Cypriniformes other than fathead minnow (R^2 = 0.92).

3.2.2 Results

The species-specific values of the PGMATCs, quotients, and the risks of exceeding the GMATC for the annual median ambient contaminant concentrations are presented in Appendix D. These species-specific values are presented only for those RACs with a hazard greater than or equal to 0.01. They are summarized in Tables 3.2-1 and 3.2-2 for the two technologies. Hydrogen sulfide (RAC 4) and ammonia (RAC 5), with quotients and risks greater than 0.1 for all species and technologies, appear to present the most consistent threat of chronic toxicity to fish. For both technologies, the predicted risks of ammonia and hydrogen sulfide are greater than 0.5 for most or all species. Volatile carboxylic acids (RAC 9) appear to be as important as ammonia and hydrogen sulfide for the Koppers-Totzek process. For the Lurgi process, the quotients and risks for RAC 9 are substantially smaller than those for RACs 4 and 5, but are still high enough to cause concern. The only other RACs with hazard or risk values greater than 0.1 for any combination of species and technology are carboxylic acids (RAC 20), arsenic (RAC 37), mercury (RAC 32), and cadmium (RAC 34).

Table 3.2-1. Ranges of predicted geometric means of maximum allowable toxicant concentrations (PGMATC): ratios of ambient concentrations to PGMATC, and probabilities of exceeding the PGMATC for the Lurgi/Fischer-Tropsch process

RAC		Ratio of ambient concentration to PGMATC	Probability of exceeding the PGMATC[a]
1	No effluent		
2	No effluent		
3	No effluent		
4[b]		0.7580-5.6337	0.4529-0.7859
5[b]		2.7565-6.6493	0.6832-0.8330
6	No effluent		
7	No effluent		
8	No effluent		
9		0.0756-0.3336	0.0945-0.3098
10	No fish toxicity data		
11	No effluent		
12		0.0000-0.0001	0.0000-0.0000
13		0.0000-0.0000	0.0000-0.0000
14		0.0003-0.0007	0.0000-0.0005
15		0.0003-0.0029	0.0000-0.0040
16	No effluent		
17	No effluent		
18	No effluent		
19	No fish toxicity data		
20		0.0002-0.0050	0.0000-0.1130
21		0.0008-0.0075	0.0001-0.0152
22		0.0000-0.0001	0.0000-0.0000
23	No effluent		
24	No fish toxicity data		
25	No effluent		
26		0.0000-0.0000	0.0000-0.0000
27	No effluent		
28	No effluent		
29	No effluent		
30	No effluent		
31[b]		0.0162-0.1161	0.0123-0.1721
32[b]		0.0024-0.0060	0.0023-0.0056
32A[b]		0.0072-0.0187	0.0101-0.0216
33[b]		0.0011-0.0325	0.0008-0.0670
34[b]		0.0011-0.1617	0.0001-0.1816
35[b]		0.0024-0.0183	0.0004-0.0329

[a]Species-specific values are provided in Appendix D.

[b]Ambient concentration includes demineralizer regeneration wastewater.

Table 3.2-2. Ranges of predicted geometric means of maximum allowable toxicant concentratons (PGMATC), ratios of ambient concentrations to PGMATC, and probabilities of exceeding the PGMATC[a] for the Koppers-Totzek/Fischer-Tropsch process

RAC		Ratio of ambient concentration to PGMATC	Probability of exceeding the PGMATC[a]
1	No effluent		
2	No effluent		
3	No effluent		
4[b]		0.6753-5.0189	0.4334-0.7701
5[b]		0.8527-2.0569	0.4701-0.6435
6	No effluent		
7	No effluent		
8	No effluent		
9		0.6911-3.0498	0.4256-0.6930
10	No effluent		
11	No effluent		
12		0.0000-0.0000	0.0000-0.0000
13		0.0001-0.0002	0.0000-0.0000
14		0.0000-0.0000	0.0000-0.0000
15		0.0000-0.0000	0.0000-0.0000
16	No effluent		
17	No effluent		
18	No effluent		
19	No effluent		
20	No effluent		
21		0.0000-0.0000	0.0000-0.0000
22		0.0001-0.0005	0.0000-0.0003
23	No effluent		
24	No fish toxicity data		
25	No effluent		
26		0.0000-0.0000	0.0000-0.0000
27	No effluent		
28	No effluent		
29	No effluent		
30	No effluent		
31[b]		0.0056-0.0403	0.0022-0.0792
32[b]		0.0002-0.0006	0.0000-0.0002
32A[b]		0.0007-0.0018	0.0003-0.0008
33[b]		0.0005-0.0173	0.0003-0.0343
34[b]		0.0007-0.0993	0.0000-0.1246
35[b]		0.0005-0.0040	0.0000-0.0034

[a]Species-specific values are provided in Appendix D.

[b]Ambient concentration includes demineralizer regeneration wastewater.

The differences in the relative rankings between species is attributable to variation in three factors: (1) the magnitudes of the LC_{50}'s of different species that have been tested for a particular chemical, (2) differences in sensitivity that are expressed as biases in the extrapolation between the test species and site species, and (3) the variance associated with the extrapolation.

3.2.3 Toxicity of the Whole Effluent

Table 3.2-3 presents estimates of the acute toxicity of the whole effluent. Only acute toxicity is considered because there is no theory for modeling addition of effects expressed as toxic thresholds such as GMATCs. The acute effects are expressed in a common unit, the 96-h LC_{50} to largemouth bass, which is generated by taxonomic extrapolation from LC_{50} data for a variety of species (Appendix A), using the method of Suter et al. (1983).

The possible modes of joint action of chemicals are synergism, concentration addition, independent action (response addition), and antagonism (Muska and Weber 1977). Concentration addition is generally accepted to be the best general model for describing the combined effects of mixed chemicals on fish (Alabaster and Lloyd 1982; EIFAC 1980; SGOMSEC, in press). In a recent review, Lloyd (in press) stated: "There is no evidence for synergism (i.e., more-than-additive action) between the common pollutants; at toxic concentrations the joint action is additive and at concentrations below those considered 'safe' there is circumstantial evidence for less-than-additive joint action." Furthermore, Parkhurst et al. (1981) found that when ammonia speciation is accounted for, the toxicity of the major components of two synfuels effluents was concentration additive. Therefore, we used the concentration addition model to examine the potential toxicity of the combined RACs.

The analysis was performed by calculating the total toxic units (ΣTU) of the effluent, where a toxic unit is the concentration of a toxicant divided by the threshold LC_{50} (Sprague and Ramsay 1965). We used the upper 95th percentile of the predicted concentration, since the concern in this case is with acute lethality, and we used the 96-h

Table 3.2-3. Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for the Lurgi/Fischer-Tropsch and Koppers-Totzek/Fischer-Tropsch processes

RAC	LC_{50} (mg/L)	Concentration/LC_{50}	
		Lurgi	Koppers-Totzek
1	No toxicity data		
2	No toxicity data		
3	No toxicity data		
4[a]	36.3	5.42 E-01	4.82 E-01
5[a]	444	6.05 E-01	1.87 E-01
6	5,716,048	No effluent	No effluent
7	No toxicity data		
8	52,048	No effluent	No effluent
9	10,511	1.52 E-02	1.39 E-01
10	No toxicity data		
11	No toxicity data		
12	4815	3.97 E-06	1.61 E-07
13	2324	5.48 E-07	1.15 E-05
14	2296	4.56 E-05	6.74 E-07
15	3310	3.59 E-05	1.48 E-07
16	No toxicity data		
17	No toxicity data		
18	6171	No effluent	No effluent
19	No toxicity data		
20	184,876	8.62 E-05	No effluent
21	14,282	6.06 E-05	2.20 E-07
22	160	1.96 E-06	1.79 E-05
23	No toxicity data		
24	No toxicity data		
25	No toxicity data		
26	601	5.76 E-08	5.30 E-07
27	No toxicity data		
28	9437	No effluent	No effluent
29	No toxicity data		
30	No toxicity data		
31[a]	22,236	7.84 E-04	2.72 E-04
32[a]	321	5.84 E-04	5.55 E-05
32A[a]	74.6	2.51 E-03	2.39 E-04
33[a]	4496	4.64 E-04	2.26 E-04
34[a]	1696	1.12 E-04	6.91 E-05
35[a]	20,865	1.06 E-04	2.31 E-05
Total		1.17	0.81

[a]Ambient concentration includes demineralizer regeneration wastewater.

LC_{50} as a reasonable approximation of the threshold LC_{50} (Ruesink and Smith 1975). The ΣTU of 1.17 for Lurgi gasification suggests a high likelihood of acute toxic effects from its effluent. This is almost entirely due to RAC 4 (acid gases - hydrogen sulfide) and RAC 5 (alkaline gases - ammonia). The ΣTU of 0.81 for Koppers-Totzek gasification is less than unity, but Alabaster et al. (1972) found that only "coarse fish" were present when the ΣTU based on the upper 95th percentile concentration and on rainbow trout 48-h LC_{50}'s was above 0.6. Therefore, the total toxicity of this effluent, which is primarily due to RAC 4, RAC 5, and RAC 9 (volatile carboxylic acids), also seems worthy of concern.

3.3 ECOSYSTEM UNCERTAINTY ANALYSIS

3.3.1 Explanation of Method

Ecosystem uncertainty analysis (EUA) estimates the risk associated with both direct and indirect effects of toxicants. It considers data on a variety of test organisms rather than emphasizing a single taxonomic group. By integrating effects across trophic levels, EUA considers components of environmental risk that are not included in other methods.

The method uses the Standard Water Column Model (SWACOM) (O'Neill and Giddings 1979; O'Neill et al. 1982). SWACOM is an adaptation of an earlier model, CLEAN (Park et al. 1974), and considers ten phytoplankton, five zooplankton, three forage fish, and a game fish population. The model simulates the annual cycle of a lake and incorporates temperature, light, and nutrient responses. Changes can be made to tailor SWACOM for toxicological assessments in a variety of aquatic ecosystems. The model is designed to simulate a generalized water column and sacrifices site specificity to emphasize complex interactions and indirect effects.

Available toxicity data are primarily in the form of mortalities. Therefore, assumptions about the mode of action of the toxicant are required to determine changes in model parameters. We have assumed that organisms respond to all chemicals according to a general stress syndrome; that is, they increase their respiration rates, decrease their photosynthetic and feeding rates, and become more susceptible to predation. This assumption permits us to define percent changes in model parameters that cause the same mortality as measured in the laboratory. This extrapolation of laboratory data involves considerable uncertainty. In our analysis, the uncertainties are preserved by associating each parameter change with a probability distribution. In calculating risk, parameter values are selected from the distributions and a simulation is performed with SWACOM. The process is repeated 500 times. The risk associated with an undesirable effect, such as a significant reduction in game fish, is estimated by the frequency of simulations that showed this effect. Further details of the method are given in Appendix E and by O'Neill et al. (1982).

The data used for the EUA are shown in Table 3.3-1. Estimates of risk can be made for only ten RACs. These RACs were the only chemical groups for which adequate data exist.

3.3.2 Results of Ecosystem Uncertainty Analysis

Results of the EUA for the direct liquefaction technologies are shown in Figs. 3.3.1 to 3.3.3. Deterministic results are shown on Table 3.3-2. None of the technologies produces measureable amounts of quinoline (RAC 18), so this risk assessment unit was not considered in the analysis. Environmental concentrations of benzene (RAC 12), naphthalene (RAC 14), and phenol (RAC 21) were very low and did not result in significant risks; therefore, results for these three chemicals are not shown on the graphs.

Two endpoints were considered: a quadrupling of the peak biomass of noxious blue-green algae and a 25% decrease in game fish biomass. These endpoints were chosen as indicative of minimal effects that could be quantified in the field. Risk estimates were calculated for these endpoints across a range of environmental concentrations that encompasses the 5th to 95th percentile exposures. The range of exposures for each technology is shown at the bottom of the figures.

Table 3.3-1. Values[a] of LC_{50}/EC_{50} (mg/L) used to calculate effects matrix for SWACOM

Trophic level	Model species	Ammonia	Benzene	Naphthalene	Quinoline	Phenol	Arsenic	Nickel	Cadmium	Lead	Mercury
Algae	1-3	420.0	525.0	33.0	25.0	258.0	2.32	0.50	0.16	0.50	0.01
	4-7	420.0	525.0	33.0	25.0	20.0	2.32	0.50	0.06	0.50	0.01
	8-10	420.0	525.0	33.0	117.0	95.0	2.32	0.50	0.06	0.50	0.01
Zooplankton	11	8.0	450.0	8.6	57.2	300.0	4.47	9.67	0.5	40.8	0.78
	12	8.0	380.0	8.6	28.5	36.4	5.28	0.85	0.0099	0.45	0.005
	13	8.0	300.0	6.5	48.2	58.1	1.35	1.93	0.14	27.4	0.53
	14	8.0	233.8	4.5	39.3	157.0	2.49	4.91	0.25	14.0	0.27
	15	8.0	17.6	2.5	30.3	14.0	0.51	0.15	0.0035	0.67	0.01
Forage fish	16	1.1	33.0	6.6	1.5	36.0	15.6	4.87	0.63	4.61	0.15
	17	8.2	22.0	78.3	1.5	16.4	41.8	5.27	1.94	23.8	0.24
	18	23.7	34.0	150.0	1.5	34.9	26.0	4.45	1.63	31.5	0.50
Game fish	19	0.41	5.3	2.3	11.0	9.0	13.3	0.05	0.002	1.17	0.25

[a]Values taken from following Water Quality Criteria documents: ammonia - Hohreiter (1980); benzene - USEPA (1980c); naphthalene - USEPA (1980e); quinoline - O'Neill et al. (1982); phenol - USEPA (1980g); arsenic - USEPA (1980l); nickel - USEPA (1980n); cadmium - USEPA (1980o); lead - USEPA (1980p); and mercury - USEPA (1980m).

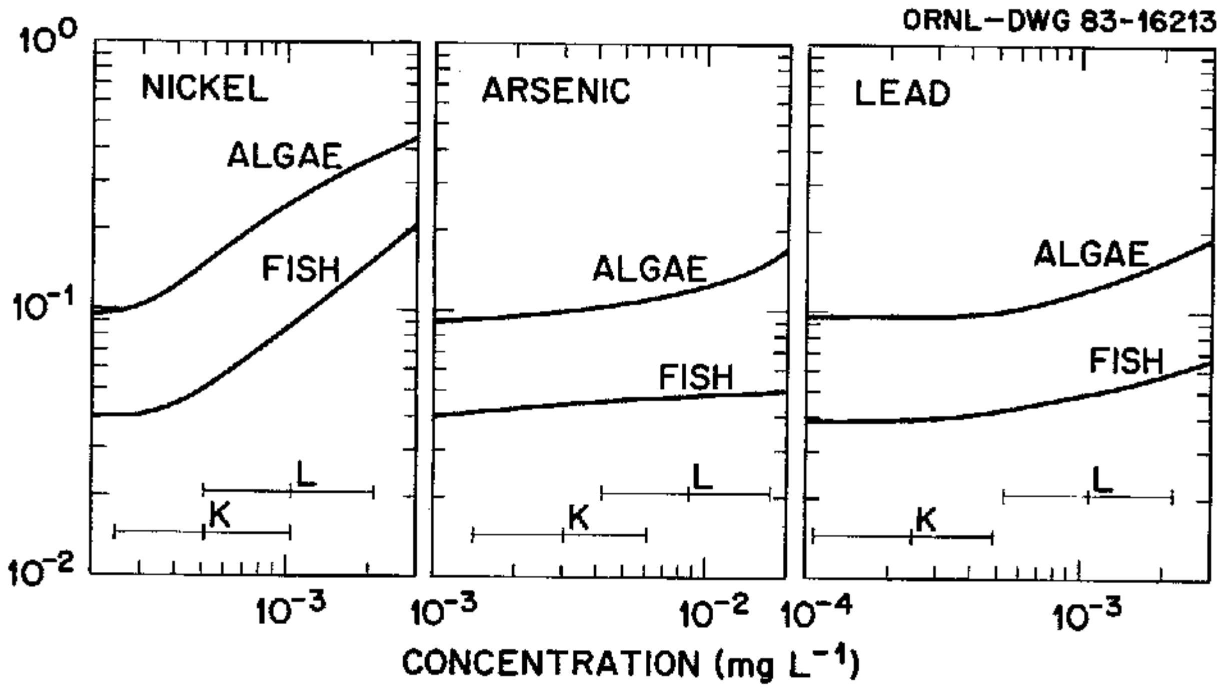

Fig. 3.3.1. Risk estimates for three heavy metals over a range of environmental concentrations. The 5th percentile, mean, and 95th percentile concentrations associated with the Lurgi/Fischer-Tropsch (L) and Koppers-Totzek/Fischer-Tropsch (K) processes are shown at the bottom of each graph. The plotted values are the probability of a quadrupling of the blue-green algal bloom and a 25% reduction in game fish biomass.

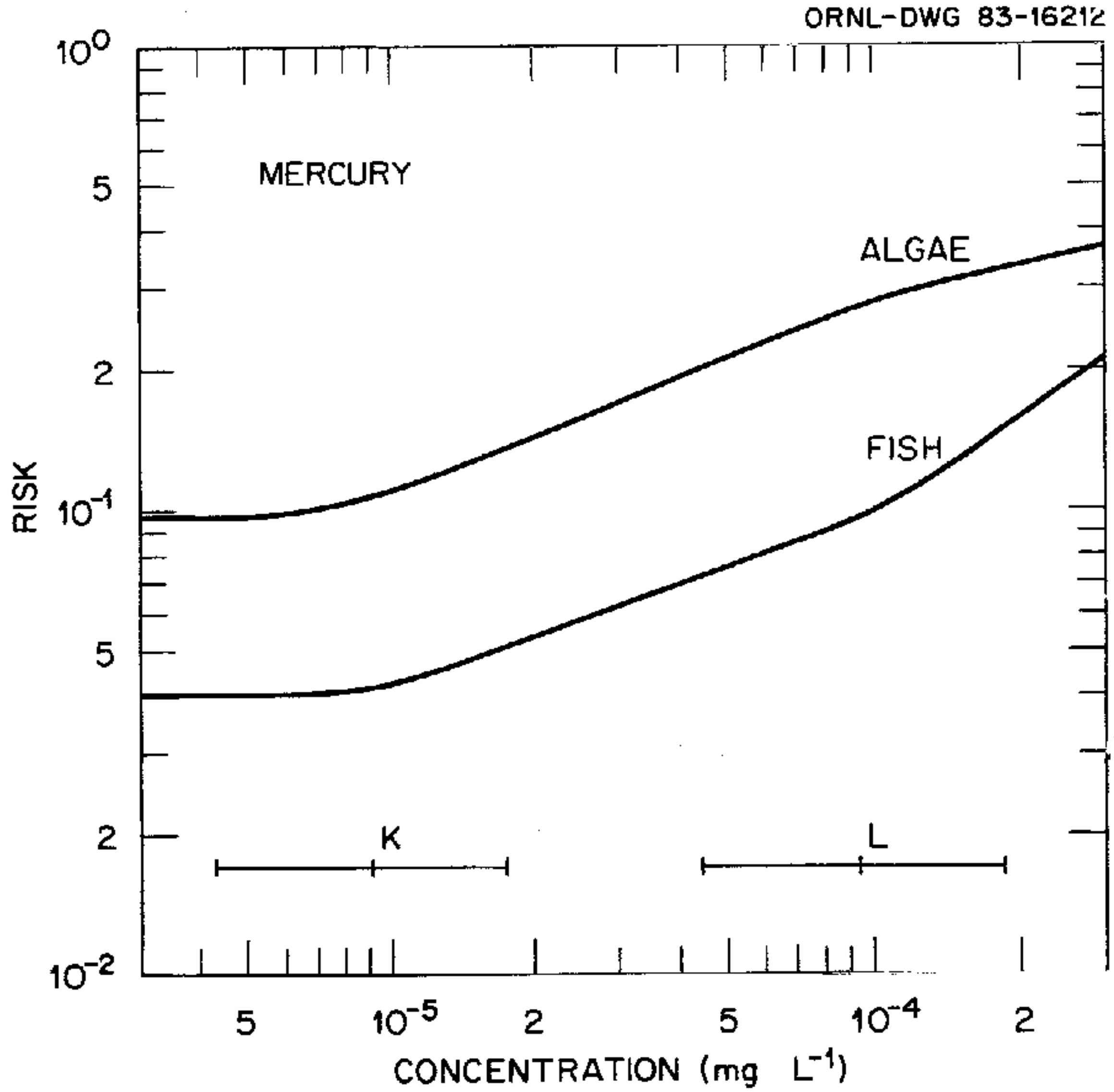

Fig. 3.3.2. Risk estimates for mercury over a range of environmental concentrations. The 5th, mean, and 95th percentile concentrations associated with the Lurgi/Fischer-Tropsch (L) and Koppers-Totzek/Fischer-Tropsch (K) processes are shown at the bottom of the graph. The plotted values are the probability of a quadrupling of the blue-green algal bloom and a 25% reduction in game fish biomass.

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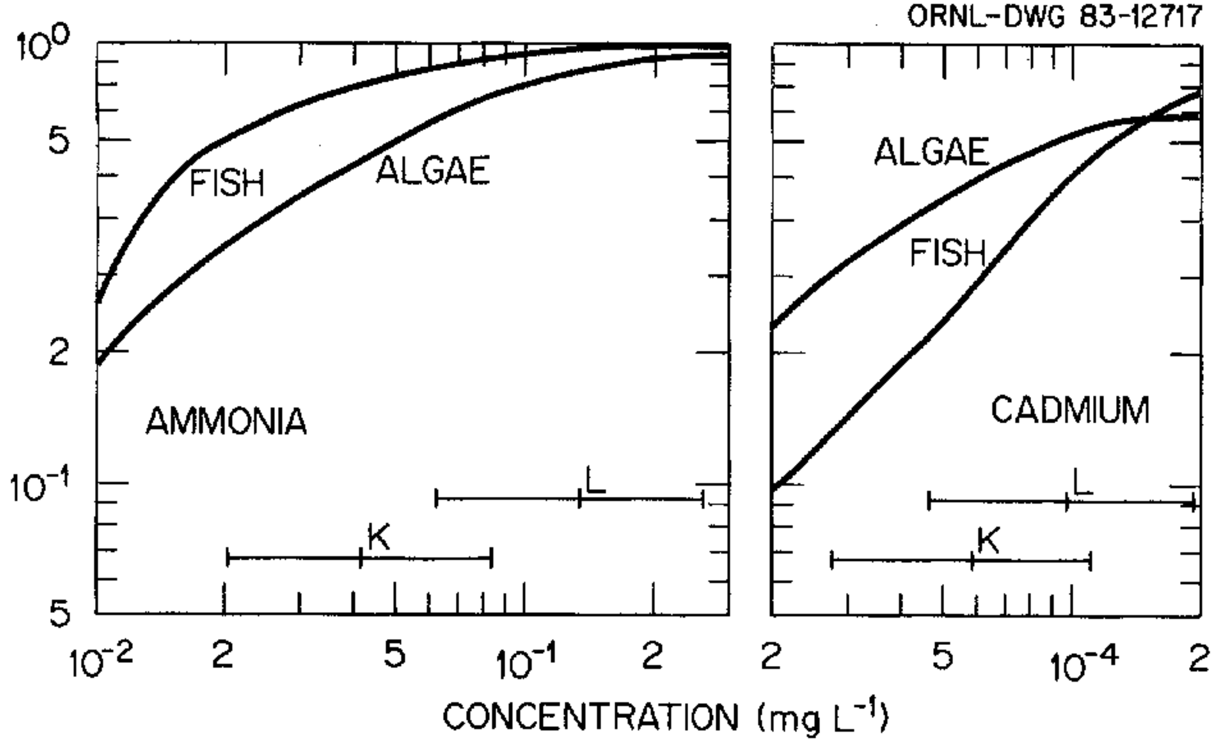

Fig. 3.3.3. Risk estimates for ammonia and cadmium over a range of environmental concentrations. The 5th, mean, and 95th percentile concentrations associated with the Lurgi/Fischer-Tropsch (L) and Koppers-Totzek/Fischer-Tropsch (K) processes are shown at the bottom of each graph. The plotted values are the probability of a quadrupling of the blue-green algal bloom and a 25% reduction in game fish biomass.

Table 3.3-2. Deterministic results of EUA (values are percent increases in maximum algal bloom and percent decrease in game fish biomass at the mean environmental concentration for each of the indirect liquefaction technologies)

	Endpoint	Lurgi/ Fischer-Tropsch	Koppers-Totzek/ Fischer-Tropsch
Ammonia	Algae	+306	+15
	Fish	-61	-32
Benzene	Algae	a	a
	Fish	a	a
Naphthalene	Algae	a	a
	Fish	a	a
Phenol	Algae	a	a
	Fish	a	a
Arsenic	Algae	+16	+6
	Fish	-1	-1
Mercury	Algae	+102	+7
	Fish	-6	-1
Nickel	Algae	+89	+32
	Fish	-5	-3
Cadmium	Algae	+368	+297
	Fish	-21	-15
Lead	Algae	+15	+3
	Fish	-2	a

[a]Percent change is less than 1%.

The lines on the graph do not pass through the origin because there is a risk of an increase in algae (0.086) or a decrease in fish biomass (0.038) even as the environmental concentrations of the toxicants approach zero. This reflects residual uncertainty in simulating ecosystem effects. For example, there is always some probability of a small decrease in fish biomass due to natural variability.

Results for the four heavy metals show a similar pattern. In all of these cases, there is an upturn in the risk curves, showing significant risks at the higher concentrations generated by one or both of the technologies. The increased risk of an effect to game fish populations seems intuitively reasonable. However, the increasing risk of a blue-green algal bloom with increasing concentration is counterintuitive. Even though each of the chemicals is toxic to the algae, the reduction in sensitive grazing organisms more than compensates for the direct effect on phytoplankton. This is an example of the indirect effects that EUA is capable of showing.

Results for ammonia and cadmium show considerably higher risk values across the full range of environmental concentrations. The high values occur for both endpoints and both technologies. The results indicate that these two RACs should be of primary concern in evaluating the environmental hazards of indirect coal liquefaction.

All of the graphs illustrate the complexity of the ecosystem responses simulated by EUA. The relationship between concentration of toxicant and risk is not simply linear or exponential. The complexity of these responses results from the nonlinear interactions considered in the analysis.

3.3.3 Comparison of Risks Across RACs

The importance of cadmium and ammonia is further emphasized in Fig. 3.3.4. The graph shows the maximum risk associated with each of the nine RACs. The maximum risk is defined as the risk associated (1) with the upper 95th percentile concentration for whichever technology showed the highest concentrations and (2) with either algal blooms or a reduction in game fish biomass, whichever showed the higher risk. Thus, the maximum risk attempts to separate RACs that never show a significant risk from those that are significant in at least one of the relevant calculations.

The figure shows that there is a very reasonable probability that cadmium and ammonia could significantly affect the aquatic ecosystem. In addition, the graph indicates that the other heavy metals (RACs 31-35) could also cause problems, although these probabilities are associated only with the highest concentrations produced by the Lurgi/Fischer-Tropsch process.

3.3.4 Comparison of Risks Between Technologies

Figure 3.3.5 compares risks across the nine RACs for the two technologies. The risk values are those associated with the upper 95th percentile concentrations. For each RAC, moving in a clockwise direction, results are given first for the risk of algal blooms and then for the risk of a reduction in game fish.

Because of consistently lower environmental concentrations, the Koppers-Totzek technology shows slightly lower risks. However, because of the large risks associated with ammonia (RAC 5) and cadmium (RAC 34) and the smaller, but not insignificant, risks that appear for the other heavy metals (RAC 31-35), neither technology can be considered to be free of environmental risk.

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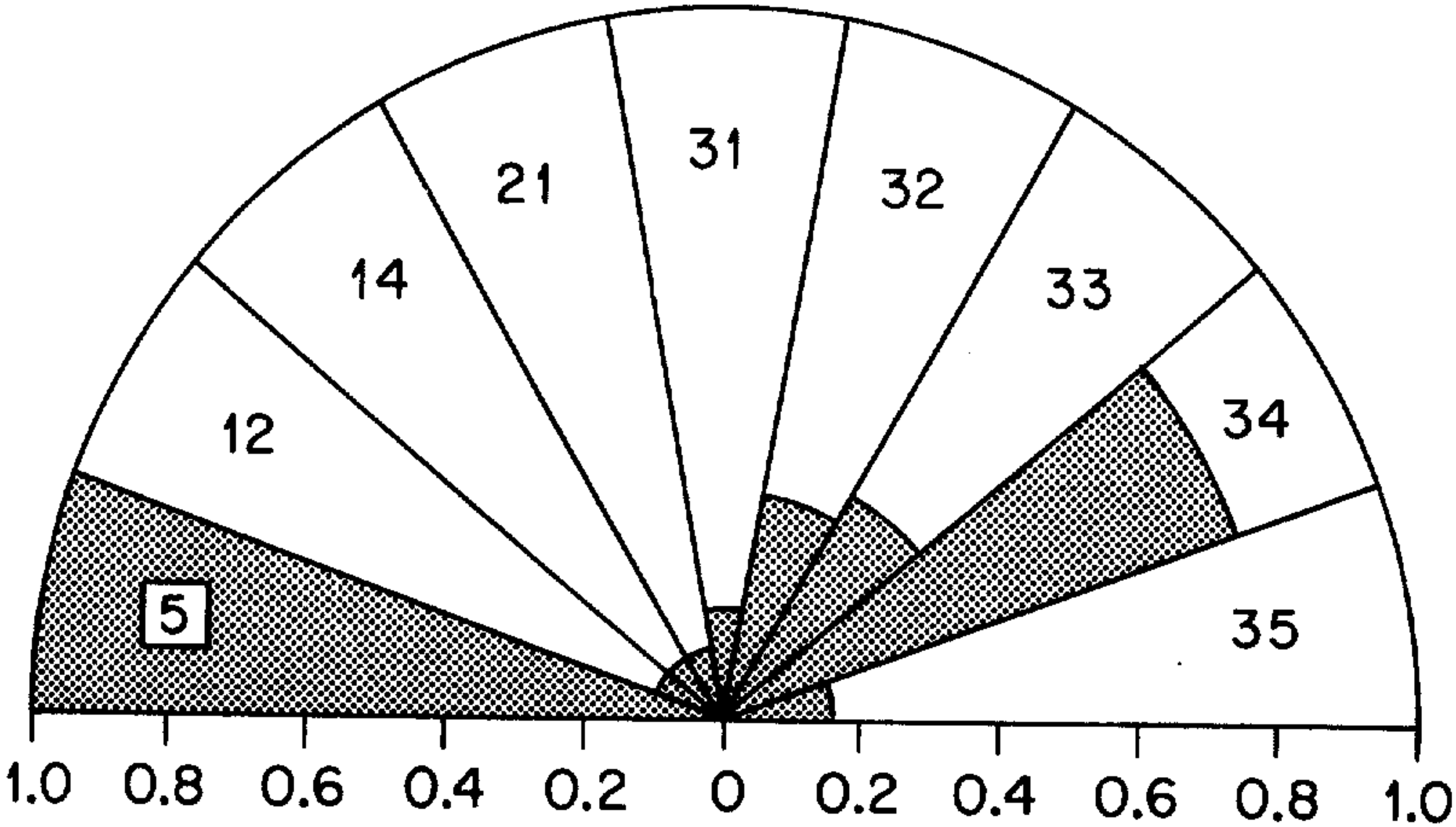

Fig. 3.3.4. Maximum risk estimates for nine RACs (indicated by numbers). The risk values are associated with algal blooms or reductions in fish biomass, whichever was larger, at the 95th percentile concentration of the technology with the higher concentration.

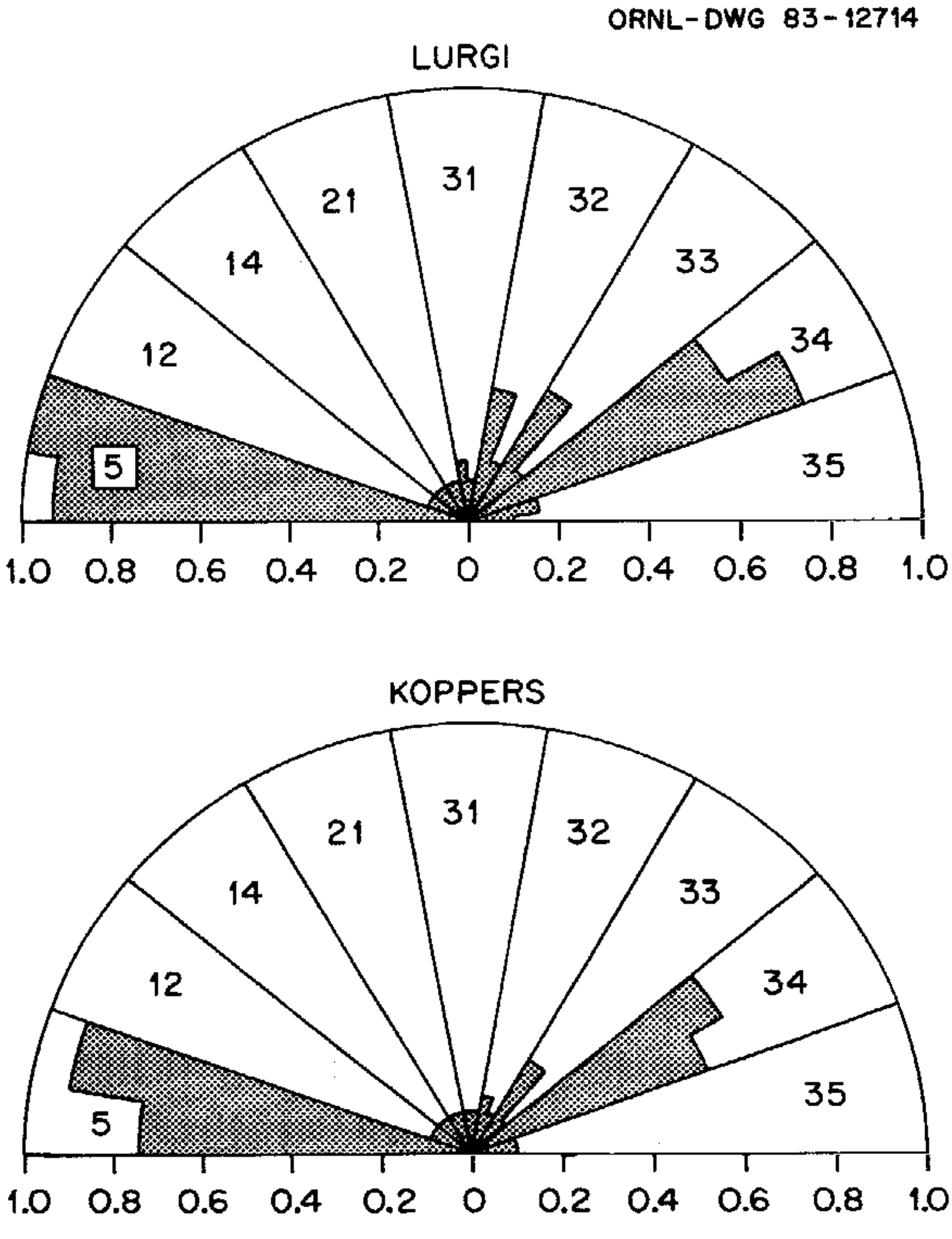

Figure 3.3.5. Comparison of risks between technologies. Risks at the 95th percentile concentration are shown first for the algae and then for game fish, for each of nine RACs (indicated by numbers).