Performing Ecological Risk Assessment of Chemicals using an Ecosystem Model

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Abstract

In order to apply ecological models to ecological risk assessment, it is important to understand the strength and limitation of the model and to determine the domain of the model applicability in ecological risk assessment. The study presented here used the Lake Suwa version of Comprehensive Aquatic Systems Model (CASM_SUWA) to demonstrate risk estimation of 12 different chemicals and examined the pattern of sensitivity of model populations to toxicants in ecological context. The results in this study emphasized that the characteristic ecological features such as predator-prey and competitive interactions, not accounted for in laboratory single-species toxicity test, are important determinant in evaluating the impact of toxicants on the aquatic ecosystems. The results of risk estimation also demonstrated that the model including characteristic ecological features in ecological risk assessment of chemicals could provide additional qualitative information for the management of chemicals in aquatic ecosystems.

1. Introduction

The direct utilization of the results of single-species toxicity tests conducted in laboratory in drawing conclusions regarding chemical effects on aquatic ecosystems composed of complex ecological interactions is questionable. Additionally, conducting field tests or mesocosm tests to assess the impact of chemicals on ecosystems require skilled labor and high cost. One possible solution involves the use of models as a means of translating laboratory data into ecosystem response. Ecological models, which can be defined as a simplified representation of an ecosystem, might be the only option and a cost-effective tool for assessing chemical effects on natural systems under circumstances where field experiments cannot be conducted. With the increasing awareness of the importance of cost-effective and efficient ways of assessing ecological impact of chemicals, a number of ecological models have been developed and reviewed for the potential use in ecological risk assessment (Jorgensen *et al*., 1995).

Previously, the Lake Suwa version of the Comprehensive Aquatic Systems Model (CASM_SUWA) was developed using field data from Lake Suwa. CASM_SUWA can reproduce complex seasonal biomass behavior that reasonably follows the observed pattern for the Lake Suwa ecosystem (Naito *et al*., 1999). Although the model produces a reasonable representation of the real ecosystem, we should not expect it to duplicate all the responses of the real ecosystem. However, since CASM was designed to simulate the effects of chemicals on an ecosystem level including predator-prey interactions, it is reasonable to assume that CASM_SUWA is capable of illustrating the general patterns of chemical effects in an ecological context. In order to apply an ecological model to ecological risk assessment, it is important to understand the strength and limitations of the model and to determine domain of the model applicability in ecological risk assessment processes. In the study presented here, we used CASM_SUWA to demonstrate the risk estimation of 12 different chemicals and examined the pattern of sensitivity of model populations to toxicants in an ecological context.

2. CASM_SUWA description

Since the detailed description of the CASM model used in this study has been reported found elsewhere (DeAngelis *et al*., 1989), only a brief description of the model is presented here.

The Lake Suwa adaptation of CASM was developed by modifying the food-web structure and environmental conditions of the original version of CASM to represent the characteristics of the Lake Suwa ecosystem. CASM is an expansion of SWACOM (Bartell *et al*., 1992), and has also been adapted for estimating the ecological risk for aquatic ecosystems in Quebec (Bartell *et al*., in press). CASM is a bioenergetic ecosystem effects model that simulates the daily production dynamics of populations, including predator-prey interactions, through time in relation to daily changes in light intensity, water temperature, and nutrient availability. CASM_SUWA consists of five

Table 1 List of species used in CASM_SUWA

Population	Species name
Phytoplankton	
1	*Cyclotella sp.*
2	*Melosira*
3	*Astrionella spp.*
4	*Microcystis*
5	*Micractinium pusillum*
Zooplankton	
1	*Bosmina longirostris*
2	*Filinia longiseta*
3	*Keratella quadrata*
Benthic insect	
1	Chronomidae
2	*Tubifex tubifex*
Benthic invertebrate	
1	*Macrobrachium longipes*
Omnivorous fish	
1	*Hypomesus transpacificus*
2	*Carassius carassius*
3	*Cyprinus carpio*
Piscivorous fish	
1	*Parasilurus asotus*

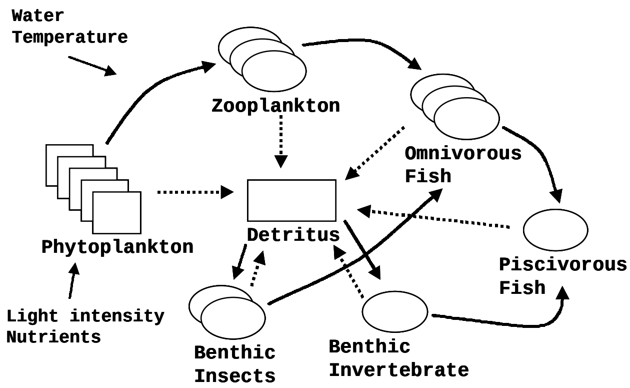

Figure 1. Depiction of CASM_SUWA food web The arrows represent the flow of energy and biomass. Each box or circle represents one model population or nonliving component.

phytoplankton populations, three zooplankton populations, two benthic insect populations, a single benthic invertebrate population, three omnivorous fish populations, and a single piscivorous fish population. The model species considered in CASM_SUWA are listed in Table 1 and the food web structure of CASM_SUWA is shown in Figure 1. Each population is described uniquely by physiological parameters that control growth in relation to daily changes in light intensity, water temperature, available nutrients and respiration, feeding and mortality.

CASM incorporates a toxic-effects submodel that is used to extrapolate the potential effects of chemicals on the biomass production in an aquatic ecosystem from single-species toxicity data(O'Neill, 1982). The effect of a toxicant on each model population is calculated using effect factors by estimating the change in the physiological rates for the expected water concentration of the toxicant. The description of this method can be found in Bartell (1990) and Hanratty and Stay (1994).

Considering the uncertainty associated with the extrapolation of laboratory results to the field, as well as incomplete toxicity data, CASM_SUWA estimates the potential risk of chemicals on the annual production of each population biomass. The uncertainties are represented in the risk estimation by defining distribution of the effect factors. Repeated simulations with all effect factors chosen independently from their respective distributions by the Monte Carlo method are performed to estimate the potential risk of chemicals on the annual total production for each population biomass. Then, the risks are represented in the form of the probability of a specified magnitude of increase or decrease in the biomass, by comparing the simulated annual production values under a toxic-stress condition with the simulated annual production from a reference simulation with no toxic stress.

Table 2. List of chemicals used to evaluate the model

No.	Name of Chemicals	Use
1	Cadmium	Metal
2	Di(2-ethylhexyl)phthalate (DEHP)	Plasticizer
3	Phenol	
4	Linear alkylbenzene sulfonate (LAS)	Anionic surfactant
5	Pentachlorophenol (PCP)	Herbicide
6	Molinate	Herbicide
7	Simetryn	Herbicide
8	Thiobencarb	Herbicide
9	Simazine	Herbicide
10	Fenitrothion (MEP)	Insecticide
11	DDT	Insecticide
12	Diazinon	Insecticide

Table 3. Assignment of toxic values (mg/l) to model species used to analyze patterns of sensitivity

Model Species	Chemical					
	Cadmium	DEHP	Phenol	LAS	PCP	Molinate
Phytoplankton						
1	0.16 (EC50-48h)	0.32 (EC50-96h)	300 (EC37-240h)	20 (EC50-48h)	0.18 (EC50-96h)	6.6 (EC50-96h)
2	0.16 (EC50-48h)	0.32 (EC50-96h)	300 (EC37-240h)	20 (EC50-48h)	0.18 (EC50-96h)	6.6 (EC50-96h)
3	0.16 (EC50-48h)	0.32 (EC50-96h)	300 (EC37-240h)	20 (EC50-48h)	0.18 (EC50-96h)	6.6 (EC50-96h)
4	0.16 (EC50-48h)	0.32 (EC50-96h)	300 (EC37-240h)	10 (EC50-72h)	0.18 (EC50-96h)	34 (LC50-120h)
5	0.16 (EC50-48h)	0.32 (EC50-96h)	300 (EC37-240h)	50 (EC50-48h)	0.18 (EC50-96h)	0.22 (LC50-96h)
Zooplankton						
1	0.05 (LC50-48h)	11 (LC50-48h)	15 (LC50-48h)	2.7 (LC50-48h)	0.67 (LC50-96h)	2.4 (LC50-48)
2	1.3 (LC50-48)	11 (LC50-48h)	15 (LC50-48h)	2.7 (LC50-48h)	2.16 (LC50-24h)	2.4 (LC50-48)
3	1.3 (LC50-48)	11 (LC50-48h)	15 (LC50-48h)	2.7 (LC50-48h)	2.16 (LC50-24h)	2.4 (LC50-48)
Benthic Insect						
1	10 (LC50-48h)	0.18 (LC50-96h)	500 (LC50-48h)	3 (LC50-48h)	1.95 (LC50-24h)	40 (LC50-48h)
2	6.4 (LC50-48h)	0.18 (LC50-96h)	500 (LC50-48h)	1.7(LC50-48h)	1.95 (LC50-24h)	40 (LC50-48h)
Benthic Invertebrate						
1	0.05 (LC50-48)	0.37 (LC50-96h)	94 (LC50-24h)	3 (LC50-48h)	0.88 (LC50-96h)	1 (LC50-48h)
Omnivorous Fish						
1	0.006 (LC50-96h)	0.33 (LC50-96h)	46 (LC50-48h)	4.7 (LC50-48h)	0.2 (LC50-96h)	14 (LC50-96h)
2	0.006 (LC50-96h)	6.18 (LC50-96h)	46 (LC50-48h)	4.4 (LC50-96h)	0.14 (LC50-96h)	34 (LC50-48h)
3	0.006 (LC50-96h)	6.18 (LC50-96h)	46 (LC50-48h)	4.4 (LC50-96h)	0.09 (LC50-96h)	34 (LC50-48h)
Piscivorous Fish						
1	0.006 (LC50-96h)	0.69 (LC50-96h)	46 (LC50-48h)	4.4 (LC50-96h)	0.2 (LC50-96h)	34 (LC50-48h)

	Chemical					
	Simetryn	Thiobencarb	Simazine	MEP	DDT	Diazinon
Phytoplankton						
1	0.18 (EC50-48h)	0.39 (EC50-96h)	0.8 (EC50-144h)	3.5 (EC50-96h)	0.21 (EC50-48h)	0.1 (EC50-48h)
2	0.18 (EC50-48h)	0.39 (EC50-96h)	0.8 (EC50-144h)	3.5 (EC50-96h)	0.21 (EC50-48h)	0.1 (EC50-48h)
3	0.18 (EC50-48h)	0.39 (EC50-96h)	0.8 (EC50-144h)	3.5 (EC50-96h)	0.21 (EC50-48h)	0.1 (EC50-48h)
4	0.18 (EC50-48h)	0.39 (EC50-96h)	0.5 (EC50-144h)	1.1 (EC50-96h)	0.25 (EC50-48h)	0.1 (EC50-48h)
5	0.18 (EC50-48h)	0.39 (EC50-96h)	1.24 (EC50-96h)	3.4(EC50-96h)	0.20 (EC50-48h)	1 (EC50-48h)
Zooplankton						
1	27 (LC50-24h)	0.21 (EC50-48h)	1 (EC50-48h)	0.056 (LC50-48h)	0.0004 (LC50-48h)	0.002 (LC50-96h)
2	27 (LC50-24h)	65 (LC50-24h)	1 (EC50-48h)	58 (LC50-24h)	0.0027 (LC50-48h)	29 (LC50-24h)
3	27 (LC50-24h)	65 (LC50-24h)	1 (EC50-48h)	58 (LC50-24h)	0.0027 (LC50-48h)	29 (LC50-24h)
Benthic Insect						
1	22 (LC50-48)	12 (LC50-48h)	40 (LC50-48h)	0.06 (LC50-48h)	0.0047 (LC50-24h)	0.025 (LC50-96h)
2	22 (LC50-48)	12 (LC50-48h)	40 (LC50-48h)	1.7 (LC50-96h)	0.0047 (LC50-24h)	0.025 (LC50-96h)
Benthic Invertebrate						
1	40 (LC50-72h)	20 (LC50-96h)	100 (LC50-48h)	0.003 (LC50-48h)	0.0042 (LC50-48h)	40 (LC50-72h)
Omnivorous Fish						
1	41 (LC50-48h)	10 (LC50-96h)	100 (LC50-96h)	21 (LC50-48h)	0.03 (LC50-96h)	0.12 (LC50-96h)
2	25 (LC50-48h)	14 (LC50-48)	100 (LC50-96h)	30 (LC50-48h)	0.04 (LC50-96h)	3.1 (LC50-48h)
3	25 (LC50-48h)	14 (LC50-48)	40 (LC50-48h)	30 (LC50-48h)	0.008 (LC50-96h)	3.1 (LC50-48h)
Piscivorous Fish						
1	28 (LC50-72h)	70 (LC50-48h)	80 (LC50-48h)	54 (LC50-96h)	0.001 (LC50-96h)	3.1 (LC50-96h)

3. Description of chemical toxicity data

To explore a variety of sensitivity patterns of the ecological risks of chemicals, 12 chemicals were selected for analysis (Table 2). Cadmium, di-ethylhexyl phthalate, phenol, linear alkylbenzene sulfate, pentachlorophenol, Molinate, Symetryn, Thiobencarb, Simazine, Fenitrothion, DDT, and Diazinon. The selection of chemicals was based on differences in species sensitivities and the availability of toxicity data.

Toxicity data for each chemical used in CASM_SUWA, which are summarized in Table 3, were collected from published literature (e.g., Verschueren, 1996) and a database on the Internet (e.g. EPA, 1999). The test organisms are not completely relevant to the species considered in the model. Thus, the assignments of toxicity values to the model species were based on ecological functions and trophic levels of the test organisms similar to those of model species.

As shown in Table 3, the differences in the susceptibility of each chemical among the species are considerable. For the ratio of highest LC50/lowest LC50, a value of more than 100 was observed for 8 of the 12 chemicals. Some general characteristics of chemical sensitivities among the assigned model populations are as follows. Fish populations are relatively sensitive to cadmium, and phytoplankton populations seem very sensitive to herbicides such as Symetryn, Thiobencarb and Simazine. Insecticides such as Fenitrothion (MEP), DDT, and Diazinon seem to strongly affect the growth of crustaceans and benthic insect populations.

4. Result

Table 4 Estimates of risk of model population in relation to chemical exposure of 1/100 of *Hypomesus* (Omni. fish 1) toxicity value

Population	Percent change in biomass																	
	Cadmium			DEHP			Phenol			LAS			PCP			Molinate		
	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50
Phytoplankton	0	0	0	0	0	0	0.57	0	0	0	0	0	0	0	0	0.89	0	0
Zooplankton	0	0	0	0	0	0	1	0	0	0.99	0	0	0	0	0	1	0	0
Benthic insects	1	0	0	0	1	0.97	1	0	0	0	1	1	1	0	0	0	0.01	0
Benthic invertebrate	0	0	0	0	0.51	0	0	0	0	0	0.83	0.17	0	0	0	0	1	1
Omn. fish* 1	0	0	0	0	0.5	0	0	0	0	0	0.4	0	0	0	0	0	0	0
Omn. fish 2 & 3	0	0	0	0	0.8	0.28	0	0	0	0	0.93	0.43	0	0.35	0	0	0	0
Pisc. fish**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Population	Percent change in biomass																	
	Simetryn			Thiobencarb			Simazine			MEP			DDT			Diazinon		
	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50
Phytoplankton	0	1	1	0.97	0.02	0.01	0.46	0.5	0.45	1	0	0	1	0	0	1	0	0
Zooplankton	0	1	1	0.12	0.87	0.86	0	1	1	0	1	1	0	1	1	0.1	0.88	0.86
Benthic insects	0	1	1	0	0.9	0.57	0	1	1	0	1	1	0	1	1	0	1	1
Benthic invertebrate	0	0.92	0.1	0	0.31	0	0	0.99	0.22	0	1	1	0	1	1	0	0	0
Omn. fish 1	0	1	1	0.07	0.89	0.86	0	1	1	0	1	1	0	1	1	0.1	0.9	0.87
Omn. fish 2 & 3	0	1	0.75	0	0.7	0	0	1	0.95	0	1	1	0	1	1	0	1	0.93
Pisc. fish	0	0.27	0	0	0	0	0	0.49	0	0	0.08	0	0	1	0.93	0	0	0

* Omnivorous fish

** Piscivorous fish

Table 5 Estimates of risk of model population in relation to chemical exposure of 1/1000 of *Hypomesus* (Omni. fish 1) toxicity value

Population	Percent change in biomass																	
	Cadmium			DEHP			Phenol			LAS			PCP			Molinate		
	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50
Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zooplankton	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0.47	0	0
Benthic Insects	0	0	0	0	0.05	0	0	0	0	0	0.16	0	0.16	0	0	0	0	0
Benthic Invertebrate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.78	0.08
Omn. Fish 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Omn. Fish 2 & 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pisc. fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Population	Percent change in biomass																	
	Simetryn			Thiobencarb			Simazine			MEP			DDT			Diazinon		
	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50	+10	-25	-50
Phytoplankton	0	1	0.98	0	0	0	0.99	0	0	1	0	0	0.9	0	0	0.5	0	0
Zooplankton	0	1	1	0.99	0	0	1	0	0	0.29	0.69	0.66	1	0	0	1	0	0
Benthic Insects	0	0.99	0.15	0	0	0	0	0.56	0.09	0	1	1	0	0.85	0.2	0	0.75	0.08
Benthic Invertebrate	0	0	0	0	0	0	0	0	0	0	1	1	0	0.16	0	0	0	0
Omn. Fish 1	0	1	1	0.26	0	0	0.45	0.14	0.04	0.25	0.71	0.66	0.9	0	0	0.5	0	0
Omn. Fish 2 & 3	0	1	0	0	0	0	0	0.21	0	0	1	0.88	0	0.05	0	0	0	0
Pisc. fish	0	0.33	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0

The results of risk estimation, based on 200 Monte Carlo iterations, are summarized in Table 4 and 5. The values in both tables show the probabilities of a 10 % increase, 25 % decrease and 50 % decrease in the biomass for each group or species in the model. The risks are estimated with the concentrations of chemicals set at 1/100 (Table 5) and 1/1000 (Table 6) of the *hypomesus* (omnivorous fish 1) toxic value. For illustrative purposes, the concentrations of chemicals in water were assumed to be constant. To simplify the presentation, the biomass of phytoplankton, zooplankton, benthic insects, and omnivorous fish 2 and 3 were summed over the individual populations. The results of risk estimates for each chemical and the sensitivity ranking are described below

Cadmium – The assignment of cadmium toxicity data on model population implied an intuitive expectation of risk. Since fish populations are the most sensitive to cadmium, the exposure concentrations of 1/100 and 1/1000 of the fish toxicity value translated into the least risks to the model populations. The probability of an increase in benthic insect population was explained by the decrease of fish predatory pressure, which resulted from the direct toxic effect of cadmium.

DEHP – The pattern of risk estimates among the model populations for DEHP showed that benthic insects, which are the most sensitive to DEHP, exhibited a high risk of reduction in biomass, and omnivorous fish 2 and 3 showed a higher risk of reduction in biomass, although omnivorous fish 2 and 3 are less sensitive to DEHP. This pattern of risk can be explained by the reduction of their prey populations, benthic insects, which resulted from the direct toxic effects of DEHP on benthic insect populations.

Phenol – Interestingly, upon phenol exposure of 1/100 of the *hypomesus* toxic value, zooplankton populations, which are sensitive to the toxicant, interestingly, appeared to increase. The explanation of this pattern of behavior is that all species at the same trophic level are not identically sensitive to predatory pressure in the predator-prey relationship, and therefore a positive change does not necessarily mean that the biomass of all populations increases, but only that some populations might increase by a large percentage. In this case, zooplankton population 1 seemed to increase by a large percentage (not shown).

LAS – At the LAS exposure of 1/100 of the *hypomesus* toxicity value, benthic insect, benthic invertebrate, and omnivorous fish populations showed higher risks of reduction in biomass. Interestingly, a probability of an increase in the zooplankton biomass appeared, although the sensitivity of zooplankton populations to LAS is relatively high. This pattern of behavior, caused by the differential sensitivity of predatory pressure in the predator-prey relationship, led to a large percentage of increase of zooplankton population 1 (not shown).

PCP – The risk estimates of PCP appeared to be expected intuitively from the assignments of toxicity data to model populations. Omnivorous fish 2 and 3 populations exhibited the probability of reductions, whereas benthic insect populations appeared to increase. In other words, the resulting decrease in the omnivorous fish populations permitted the benthic insect population to increase.

Molinate – Benthic invertebrate population, which is sensitive to Molinate, showed a higher risk of biomass reduction. The zooplankton population seems to increase in biomass in spite of the high sensitivity to Molinate. This pattern of increase in the zooplankton biomass can also be explained by a large percentage of increase in zooplankton population 1 resulting from predatory pressure differences in the predator-prey relationship (not shown).

Symetryn – The pattern of risks in relation to Symetryn exposure is rather interesting. All the trophic levels exhibited high risks of reduction in biomass. At the Symetryn exposure of 1/1000 of the *hypomesus* toxicity value, the probability of a 50 % reduction in the *hypomesus* biomass was 1.0. This pattern of risk estimates indicated that the direct toxic effects on the phytoplankton populations caused a decreased food supply for zooplankton, which, in turn, decreased the food supply of populations in higher trophic levels.

Thiobencarb – At the Thiobencarb exposure of 1/100 of the *hypomesus* toxic value, the probability of the increase of the phytoplankton population was high, whereas all the trophic levels except phytoplankton and piscivorous fish exhibited high probabilities of reduction in their biomass. At the Thiobencarb exposure of 1/1000 of the *hypomesus* toxic value, there was no probability of reduction at any trophic levels. The probability of increase in zooplankton and *hypomesus* populations, however, appeared to increase. The explanation of this pattern of behavior can be that the increase of a certain zooplankton population produced a large food supply for *hypomesus,* which, in turn, leading to an increase in the *hypomesus* biomass.

Simazine – At the Simazine exposure of 1/100 of the *hypomesus* toxic value, higher risks of reductions in biomass were observed in zooplankton, benthos, and fish populations. At the Simazine exposure of 1/1000 of the *hypomesus* toxic value, phytoplankton and zooplankton populations showed a probability of increase in their biomass, although both populations are sensitive to the toxicant. The *hypomesus* population exhibited a widely distributed risk estimate. This pattern of risk estimates is mainly due to the differences in predatory pressure in the predator-prey relationship and to competition within the same trophic level that led to the widely distributed food supply for *hypomesus* population.

MEP – At the MEP exposure of 1/100 of the *hypomesus* toxic value, all the populations, except the phytoplankton population, showed a higher risk of reduction in biomass. At the MEP exposure of 1/1000 of the *hypomesus* toxic value, a high risk of reduction in the benthic insect population, which is sensitive to MEP, produced an indirect decrease in omnivorous fish 2 and 3 population biomasses. Widely distributed annual productions of the zooplankton population biomass resulted in the widely distributed pattern of risk estimates in the *hypomesus* population.

DDT – At the DDT exposure of 1/100 of the *hypomesus* toxic value, the pattern of risk estimates seemed to be intuitively predictable based on the assignments of toxicity data to

Table 6 Ranking of species in order of sensitivity from most sensitive (1) to least sensitive (15) for laboratory test data and risk estimates of the model

Model	Cadmium		DEHP		Phenol		LAS		PCP		Molinate	
Species	Data	Model[1]	Data	Model[1]	Data	Model[1]	Data	Model[1]	Data	Model[1]	Data	Model[1]
Phyto1	3	-	2	-	4	-	7	-	3	-	4	-
Phyto2	3	-	2	5	4	-	7	-	3	-	4	-
Phyto3	3	-	2	-	4	-	7	-	3	2	4	-
Phyto4	3	-	2	-	4	1	6	4	3	-	8	1
Phyto5	3	-	2	-	4	-	8	-	3	-	1	1
Zoop1	2	-	5	-	1	-	2	-	7	-	3	-
Zoop2	4	-	5	-	1	2	2	7	6	-	3	2
Zoop3	4	-	5	-	1	3	2	-	6	-	3	3
Ben_ins1	6	-	1	1	3	-	3	1	5	-	7	-
Ben_ins2	5	-	1	1	3	-	1	1	5	-	7	4
Ben_inv1	2	-	4	3	8	-	3	5	8	-	2	1
Omnf1	1	-	3	4	2	-	4	6	4	-	5	-
Omnf2	1	-	6	2	2	-	5	3	2	3	6	-
Omnf3	1	-	6	2	2	-	5	2	1	1	6	-
Pisf1	1	-	6	-	2	-	5	-	4	-	6	-

Model	Simetryn		Thiobencarb		Simazine		MEP		DDT		Diazinon	
Species	Data	Model[2]	Data	Model[1]	Data	Model[3]	Data	Model[2]	Data	Model[3]	Data	Model[4]
Phyto1	1	4	4	1	3	-	7	-	11	-	3	-
Phyto2	1	2	4	-	3	-	7	-	11	-	3	-
Phyto3	1	6	4	7	3	-	7	-	11	-	3	-
Phyto4	1	3	3	1	2	1	4	1	10	1	3	1
Phyto5	1	1	1	2	4	-	6	-	9	-	5	-
Zoop1	2	1	2	8	1	-	2	4	1	-	1	3
Zoop2	2	5	8	3	1	1	9	-	4	-	8	-
Zoop3	2	1	8	9	1	1	9	-	4	-	8	-
Ben_ins1	3	1	5	5	5	3	3	1	3	5	2	1
Ben_ins2	3	-	5	4	5	2	5	1	3	2	2	1
Ben_inv1	7	-	9	12	7	-	1	1	5	3	9	-
Omnf1	5	1	7	6	8	6	8	5	6	-	4	4
Omnf2	4	-	6	11	8	5	10	3	7	-	6	2
Omnf3	4	-	6	10	5	4	10	2	8	4	6	2
Pisf1	6	-	10	-	6	-	11	-	2	6	7	-

[1] Rank of sensitivity was based on the magnitude of probability of 25 % decrease in biomass at chemical exposure of 1/100 of *hypomesus* toxicity value

[2] Rank of sensitivity was based on the magnitude of probability of 50 % decrease in biomass at chemical exposure of 1/1000 of *hypomesus* toxicity value

[3] Rank of sensitivity was based on the magnitude of probability of 25 % decrease in biomass at chemical exposure of 1/1000 of *hypomesus* toxicity value

[4] Rank of sensitivity was based on the magnitude of probability of 50 % decrease in biomass at chemical exposure of 1/100 of *hypomesus* toxicity value

model populations. Phytoplankton populations, which are less sensitive to the toxicant, appeared to increase in biomass, whereas sensitive populations such as zooplankton, benthic insects, and benthic invertebrate exhibited higher risks of reduction in biomass. At the DDT exposure of 1/1000 of the *hypomesus* toxic value, zooplankton and *hyomesus* population biomass appeared to increase. The probability of increase in the zooplankton biomass is due to a large percentage of increase in zooplankton populations 1 and 3 (not shown in the table) and the probability of increase in the *hypomesus* biomass resulted from the increase of the total zooplankton biomass.

Diazinon – At the Diazinon exposure of 1/100 of the *hypomesus* toxicity value, zooplankton and benthic insects exhibited higher risks of reduction in biomass. This led to the decreased food supply for omnivorous fish populations, which, in turn, led to the decrease in the omnivorous fish population biomass. At the Diazinon exposure of 1/1000 of the *hypomesus* toxicity value, the *hypomesus* population biomass seemed to increase as zooplankton population biomass increased.

Table 6 shows the ranking of species in order of sensitivity from most sensitive (1) to least sensitive (15) for laboratory test data and risk estimates of the model species. The relative order of sensitivity of the toxicity data assigned to the model population is based on the magnitude of EC or LC values. The relative order of sensitivity of the modeled populations is based on the magnitude of risk in relation to the specific endpoint. The results in Table 6 indicate that the relative order of sensitivity does not always correspond to the relative order of sensitivity of the risks estimated by the model. In the case of Symetryn, phytoplankton populations were assigned with the most sensitive toxicity data, however, the simulated result indicated that *hypomesus* was one of the most sensitive species in the modeled ecosystem.

The results in this study emphasize that predator-prey and competitive interactions, not accounted for in laboratory toxicity tests, are important determinants in evaluating the impact of a toxicant on the aquatic ecosystem.

5. Conclusion

In this study, we used CASM_SUWA to demonstrate the risk estimation of 12 different chemicals and examined the pattern of sensitivity of model populations to toxicants in an ecological context. The results indicated that CASM_SUWA estimated the risks of direct toxic effects on each population and of the indirect ecological effects that propagate through the food web in the model ecosystem. The inclusion of ecological interaction in ecological risk assessment of chemicals using the ecosystem model provides additional qualitative information for determining regulatory standard concentrations of chemicals for an aquatic ecosystems and for developing new test methodology.

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7. References

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