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ORIGINAL RESEARCH

Acute toxicity and risk assessment of three commercial detergents using the polychaete *Capitella* sp. C from Chetumal Bay, Quintana Roo, Mexico

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Abstract The acute toxicity of three formulations of commercial detergent (ROMA®, FOCA® and BLANCA NIEVES®) was evaluated using the polychaete *Capitella* sp. C in static bioassays over a 48-h exposure period. The probit method was used to determine the median lethal concentration (LC_{50}) of each formulation as a whole as well as the LC_{50} of the active ingredient, linear alkylbenzene sulfonate (LAS), using 95 % confidence intervals. The formulations and LAS showed LC_{50} values of between 70.79 and 147.91 ppm and 15.48 and 22.38 ppm, respectively, at 48 h. FOCA® was the most toxic detergent, followed by BLANCA NIEVES® and finally ROMA®. The variation in the toxicity of the three detergents could have been caused both by differences in the relative concentrations of the anionic surfactant LAS contained in each formulation and the presence of other ingredients (enzymes, sodium silicate, sodium tripolyphosphate, bleachers and perfumes) which can also increase formulation toxicity. Correlation analysis revealed that percent mortality of *Capitella* sp. C increased with increase in the concentrations of the detergent over the 48-h exposure period. The risk quotient was greater than one for all three evaluated detergents, indicating that there is a high risk that they adversely affect the aquatic biota, particularly sediment-dwelling organisms such as the test species.

Keywords Polychaeta · *Capitella* · Bioassays · Acute toxicity · Detergents

Introduction

The contamination of aquatic ecosystems is increasing at an alarming rate as a consequence of the discharge of untreated sewage of urban and industrial origin into coastal zones, rivers, streams and lakes. Among the contaminants found in these sewage effluents are organic pollutants such as detergents, which can cause toxicity problems for the aquatic biota found in the receiving water bodies (Uc-Peraza and Delgado-Blas 2012). Furthermore, the phosphorus component of detergents contributes to eutrophication which results in an increase in the cell numbers of some algal species leading to decreased species diversity (Tkachenko and Kutsyn 2002; Markina and Aizdaicher 2007).

Detergents and surfactants are among the extensively used chemicals at home as well as in industry (Azizullah et al. 2011). Currently, the world production of detergent amounts to 10 millions of tons per years (IMRG 2012), and the worldwide total annual production of surfactants is estimated to exceed 15 million tons

To the memory of Jonatán Delgado Martínez, poet, composer, musician and rock drummer.

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(Van Bogaert et al. 2007; Henkel et al. 2012, 2014). As a result, large quantities of detergents and their components enter the environment (Warne and Schifko 1999; Liwarska-Bizukojc et al. 2005). McAvoy et al. (1993) estimated that 5 % of all linear alkylbenzene sulfonate (LAS) produced in the United States reach the aquatic environment. In Mexico, 463,965 tons of detergents are manufactured annually (Sobrino-Figueroa 2013) most of which eventually find their way into freshwater and marine ecosystems (Cserháti et al. 2002).

The toxic effect of a detergent depends on its mode of action, the toxicity of the active ingredient (surfactant) in relation to its chemical and physical structure and the response of the test organism (Ofojekwu et al. 1999). LAS is the most common anionic surfactant used in the formulation of domestic and industrial detergents, and is considered an important potential pollutant (Ainsworth 1992). However, despite the fact that several studies have been undertaken to determine the toxicity of LAS in aquatic organisms, little is known about the toxic effects of detergent as a whole (Markina and Aizdaicher 2007).

The detergents we use in everyday life are complex mixtures of various compounds. A typical detergent consists of surfactants, builders, anti-redeposition agents, zeolite, alkaline agents, corrosion inhibitors, processing aids, colorants, fragrances, oxygen bleach, suds control agents, opacifiers, bleaching agents, enzymes and other minor constituents (Bajpai and Tyagi 2007). These components can interact either antagonistically, additively or synergistically to increase or diminish the toxicity of the detergent in the aquatic environment (Warne and Schifko 1999). Thus, evaluating the individual effects of surfactants or other ingredients does not reflect either the actual or net influence of a detergent on the aquatic environment, it is thus necessary to estimate the biological effects of detergent formulations as a whole (Markina and Aizdaicher 2007; Azizullah et al. 2011).

Polychaetes are generally the most abundant taxon in benthic communities and are commonly utilized as indicator species of environmental conditions in marine ecosystems (Dean 2008). *Capitella capitata* (Fabricius 1780), a species of Capitellidae Grube, 1862, is an opportunistic polychaete that has often been used as an indicator of organic pollution in marine sediments (Reish 1959; Bellan 1967; Pearson and Rosenberg 1978). It has also been extensively employed as a test organism in toxicological bioassays (Reish and LeMay 1991). The *C. capitata* species complex includes at least 50 cryptic siblings that differ mainly in their enzyme and general protein patterns, ecophysiological characteristics and reproduction modes (Méndez et al. 2000). The feeding characteristics of the adults and juveniles mean that they play an important role in the recycling and elimination of toxic substances associated with sediments. Ecotoxicological studies performed with metals (Reish 1988; Reish and LeMay 1991; Méndez and Green-Ruiz 2005, 2006) and other pollutants (Méndez 2005, Méndez et al. 2008, 2013) have registered diverse adverse effects on this species complex.

The introduction of toxic chemical substances, such as detergents, to the aquatic environment could thus negatively impact on the population dynamics of this species in their natural ecosystems. However, in Mexico, ecotoxicological studies of commercial detergent formulations are limited. The aim of this study was to determine the mean lethal concentration (LC_{50}) of three commercial detergents and their ecological risk in sediments, using the polychaete *Capitella* sp. C as the test species. We hope that the information gained will add to the available knowledge about toxicity levels of these detergents in aquatic environments in Mexico. Such knowledge is crucial for the development and implementation of policies associated with the protection of aquatic life in Chetumal Bay, Quintana Roo, Mexico.

Materials and methods

Worms

Adult *Capitella* sp. C individuals were collected from Chetumal Bay, Quintana Roo, Mexico (18°30′47.89″N, 88°16′30.87″W) in a zone free from wastewater discharges. The worms were collected with a PVC corer (0.018 m^2). Deep cores 20 cm deep were taken and then sieved using a 0.5-mm open mesh. The polychaetes were transported to the laboratory in vials containing water from the sampling site. In addition, sediment from the site was collected and transported in sealed polyethylene bags, with the purpose of using it during the adaptation period of the test organisms as well as in the bioassays. In the laboratory, undamaged organisms, 20–25 mm long were selected (polychaetes that were fragmented, pale in color or with reduced motility were discarded). Specimens were identified as *Capitella* sp. C with the aid of a stereoscopic microscope and an optical microscope using the keys given by Garza-García (2009). Individual *Capitella* sp. C were then placed in 3 L, constantly aired aquariums, together with water and sediment from the sampling site and maintained at room temperature (25 ± 1 °C) in a natural light–dark cycle for 2 days prior to the bioassays to allow them to adapt to the conditions (APHA et al. 1992). No food was provided either during acclimation or over the ecotoxicological test period.

Chemicals

Three commercial detergents labeled as biodegradable were evaluated, all of which are among the most commonly used domestic detergents in Mexico: ROMA®, FOCA® and BLANCA NIEVES®. In all cases, the active ingredient was the anionic surfactant LAS. Their usage and other ingredients that make up the detergents are listed in Table 1. It is important to note that neither the LAS concentrations nor those of the other components are stated on the product container: this datum is confidential and inaccessible to the consumer. Nevertheless, the proportions of some of the main constituents of detergents are generally: surfactant 15 %, poly-phosphate + silicate 30 %, sodium perborate 20 %, fluorescent pigment 0.1 %, sodium sulfate 20 % and enzymes 0.5 % (Sobrino-Figueroa 2013).

A stock solution was prepared for each detergent at 0.3 % (3 g) in 1 L of distilled water. This was then used to obtain serial dilutions (uniformly in a 0.5 logarithmic scale) as follows: 15.62, 31.25, 62.5, 125, 250 ppm (test concentrations). The LAS concentration was then calculated for each dilution of each detergent using the analysis method established by the Official Mexican Guideline NMX-AA-039-SCFI-2001 (Secretaria de Económica 2001).

Sediment

The sediment used for the ecotoxicological tests was previously analyzed (very fine sand with 0.81 % organic matter) and sieved with a 0.5-mm mesh to extract any organisms possibly present in the sample. The sediment samples were then refrigerated at 4 °C for 48 h before testing to avoid potential oxidation–reduction reactions and to eliminate any other undesired organisms.

Toxicity tests

Bioassays were of the static type without renewal of the test solution and for each assay a control (without detergent, 0 ppm) and five concentrations were used, each with three replicates. Tank dimensions were 10 × 15 × 22 cm. A total of 100 g of previously treated sediment were placed in each tank (replicate). Saline water was then added and 10 *Capitella* sp. C individuals were randomly selected from a total of 180 organisms for each bioassay chamber and placed in each tank. After waiting 45 min to allow the organisms to bury into the sediment (5 mm thick), the toxic solution was added to give a total volume of 2 L per replicate.

For each bioassay chamber, mortality readings were performed at 1, 2, 4, 8, 18, 24, 36 and 48 h of exposure. Dead organisms were immediately removed after examination. Individuals were considered dead when they fulfilled the following criteria: pale color; swollen and showing no movement on the surface of the sediment (APHA et al. 1992; Uc-Peraza and Delgado-Blas 2012); unresponsive to physical stimulation. Tests were rejected if the survival rate of the control group was 90 % or less. The following physico-chemical parameters were measured before and after the bioassays: temperature, pH, salinity and dissolved oxygen.

Table 1 Summary of the use and ingredients of the LAS-containing commercial detergents tested

Detergents	Detergent use	Ingredients
ROMA®	Multi-propose	Phosphates, sodium silicate, anti-redeposition agents, bleachers and perfume
FOCA®	Laundry	Proteolytic enzyme, phosphates, sodium silicate, anti-redeposition agents, bleachers and perfume
BLANCA NIEVES®	Multi-propose	Sodium silicate, carbonate, sulfate, sodium tripolyphosphate, anti-redeposition agents and perfume

Statistical analysis

The LC_{50} was calculated using the probit method (APHA et al. 1992). The results were then graphed as regression curves with probit units against the logarithm base 10 of detergent concentration using the software SigmaPlot 12.0, with 95 % confidence intervals. The values obtained from the acute toxicity tests were then subjected to a descriptive analysis to assess the general behavior of the data. A one-way analysis of variance (ANOVA, alpha = 0.05) was then performed to analyze differences in percent mortality of *Capitella* sp. C at 48 h among the concentrations of the detergents tested and among replicates. Pearsońs product–moment correlation analyses were then done to assess the relationship between detergent concentration and percent mortality.

Characterization of ecological risk

According to USEPA guidelines, ecological risk assessment (ERA) is defined as a process that evaluates the likelihood of adverse ecological effects on ecosystems exposed to one or more stressors (US EPA 1998; Gao et al. 2013). Risk assessment is thus, essentially, a simple comparison of predicted environmental concentration (PEC) with predicted no-effect concentration (PNEC), normally expressed as the "risk quotient" (RQ = PEC/PNEC) (Jensen et al. 2001), which is then used to determine ecological risk (Cristale et al. 2013; Gao et al. 2013). The principle is that when the risk quotient is greater than or equal to one there is a stronger likelihood of an impact. In contrast, a risk quotient of less than one indicates that the likelihood of an effect is low, and thus of less concern (Lam and Gray 2001). In this study, we examined the ERA by taking the PEC to be equivalent to the LAS value in sediments of 5.3 ppm (Sánchez-Peinado 2007). The PNEC was then calculated using the following equation: $PNEC = LC_{50}/AF$, where LC_{50} is the value obtained from the acute toxicity tests and AF is the assessment factor (100). For data interpretation, an RQ value ≥ 1 indicates a potentially high risk, and an RQ value <1 a nonsignificant (low) risk.

Results

The average values of the physico-chemical parameters of the water used in the bioassays showed little variation (Table 2). However, salinity was the only parameter that remained constant at 10 ‰.

The LC_{50} values at 48 h for the three detergents tested ranged from 70.79 to 147.91 ppm (Figs. 1, 2, 3), giving the following acute toxicity sequence: FOCA® > BLANCA NIEVES® > ROMA®. Table 3 shows the LC_{50} for the active ingredient (LAS) in each detergent, with their corresponding 95 % confidence intervals. These ranged from 15.48 and 22.38 ppm. It can be appreciated that FOCA® produced the lowest LC_{50} values, both for the formulation as a whole and the active ingredient.

The percentage mortality of *Capitella* sp. C exposed to different concentrations of the three formulations of commercial detergents at 48 h is presented in Table 4. It can be seen that no mortality was registered throughout the bioassays in any of the controls used (0 ppm). However, 3–27 % mortality was recorded for the most dilute detergent concentrations: 15.62 and 31.25 ppm, and between 20 and 57 % mortality was registered for 62.5 and 125 ppm. The solutions with the highest detergent concentration (250 ppm) produced the highest mortality percentages for all three formulations tested as follows: ROMA (70 %), BLANCA NIEVES® (87 %) and FOCA®(93 %). The ANOVA detected significant differences ($p < 0.05$) in percent mortality among the concentrations of each detergent. However, there were no significant differences ($p > 0.05$) between replicates or formulations. The correlation coefficient between detergent concentration and percent

Table 2 Means and standard errors for the physico-chemical parameters measured in the bioassays

Detergents	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Salinity (‰)
ROMA®	24.97 ± 0.04	4.81 ± 0.05	8.15 ± 0.04	10
FOCA®	25.00 ± 0.07	3.98 ± 0.11	7.54 ± 0.06	10
BLANCA NIEVES®	25.02 ± 0.02	3.56 ± 0.09	7.88 ± 0.09	10

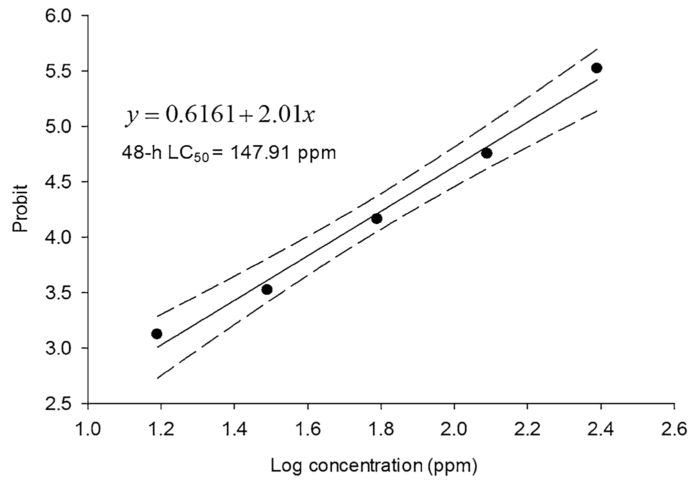

Fig. 1 Probit for the percent mortality of *Capitella sp.* C exposed to varying concentrations of ROMA® for 48 h under laboratory conditions

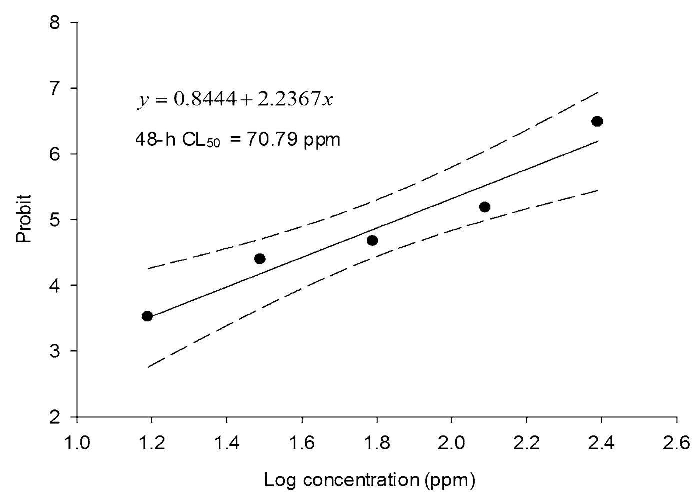

Fig. 2 Probit for the percent mortality of *Capitella sp.* C exposed to varying concentrations of FOCA® for 48 h under laboratory conditions

mortality was statistically significant ($p < 0.05$) in all cases. This means that percent mortality of *Capitella* sp. C increased with increase in the concentrations of the detergents tested over the assay period.

The RQ values calculated for the three commercial detergents were greater than one in all cases (Table 5). The highest RQ value was 7.48 (FOCA®) and the lowest 3.58 (ROMA®) with an average of 5.37. There is thus a high risk that these detergents will cause damage to aquatic ecosystems, particularly sediments.

Discussion

The three commercial detergents tested contain different toxic chemical compounds that may adversely affect aquatic ecosystems. It is known that detergents can be toxic to aquatic invertebrates, fish and plants (Warne 1995). Ecotoxicological studies with fish (Okoli-Anunobi et al. 2002; Omotoso and Fagbenro 2005; Sobrino-Figueroa 2013), algae (Aizdaicher and Markina 2006; Markina and Aizdaicher 2007; Azizullah et al. 2012), crustaceans and bacteria (Pedrazzani et al. 2012) have shown that these organisms are affected morphologically, physiologically and biochemically when exposed to detergents. It has been documented that the use of household washing detergents and softeners can be toxic for aquatic organisms in concentrations from 0.07 up

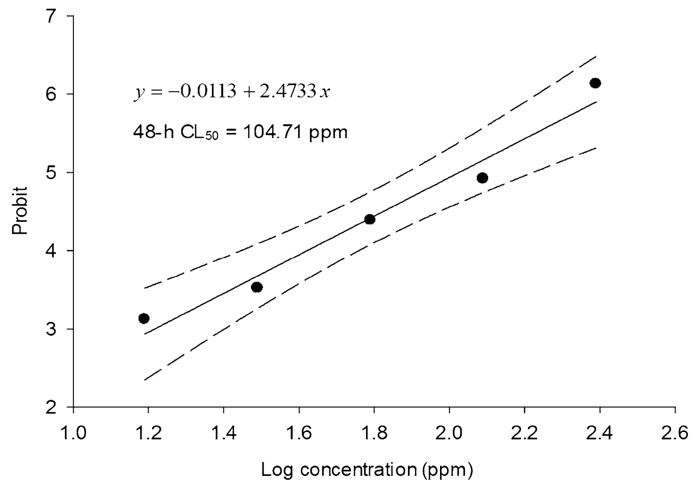

Fig. 3 Probit for the percent mortality of *Capitella sp.* C exposed to varying concentrations of BLANCA NIEVES® for 48 h under laboratory conditions

Table 3 LAS equivalent LC_{50} values at 48 h of *Capitella* sp. C. exposed to varying concentrations of ROMA®, FOCA® and BLANCA NIEVES® for 48 h under laboratory conditions

Detergents	LC_{50} (ppm)	Confidence intervals (95 %)
ROMA®	22.38	±13.42
FOCA®	15.48	±10.32
BLANCA NIEVES®	19.05	±12.55

Table 4 Percent mortality of *Capitella* sp. C. exposed to varying concentrations of ROMA®, FOCA® and BLANCA NIEVES® for 48 h under laboratory conditions

Concentration (ppm)	Mortality (%)		
	ROMA®	FOCA®	BLANCA NIEVES®
250	70	93	87
125	40	57	47
62.5	20	37	27
31.25	7	27	7
15.62	3	7	3
Control	0	0	0

Table 5 Ecological risk to the sediment of the detergents tested

Detergents	PNEC	RQ	Risk level
ROMA®	1.47	3.58	High
FOCA®	0.70	7.48	High
BLANCA NIEVES®	1.04	5.06	High

to 35.4 ppm (Ankley and Burkhard 1992; Pettersson et al. 2000). According to the literature, aquatic organisms are negatively affected by the presence of active ingredients in detergents, such as anionic and non-ionic surfactants, at concentrations ranging from 0.0025 to 300 ppm, and 0.3 to 200 ppm, respectively (Liwarska-Bizukojc et al. 2005). This may be more or less severe depending on the organism tested. In this study, the three detergents evaluated gave LC_{50} values of 70.79–147.91 ppm (formulation as a whole) and

15.48–22.38 ppm (active ingredient only) against *Capitella* sp. C after 48 h exposure, and the percent mortalities registered for the different concentrations of the detergents ranged from 3 to 93 %.

FOCA®, with LC_{50} values of 70.79 (whole formulation) and 15.48 ppm (active ingredient), was the most toxic detergent tested and also produced the highest percent mortality (93 %). These results are similar to those reported by Uc-Peraza and Delgado-Blas (2012) who examined the acute toxicity of these same commercial brands of detergents against other polychaete species. It is known that the toxicity of the detergents is due to the action the surfactants (Markina and Aizdaicher 2007) together with the other ingredients contained in the formulation (Sobrino-Figueroa 2013). It has been demonstrated that surfactants present in detergents can negatively affect living cells in different ways by damaging cell membranes (Mikolajczyk and Diehn 1978; Chawla et al. 1987), attaching to proteins, and affecting cell physiological and biochemical processes (Markina and Aizdaicher 2007; Azizullah et al. 2012). At low concentrations, detergents produce changes in cell membrane permeability, thus altering the function of the respiratory system in aquatic species (Sobrino-Figueroa 2013). In particular, anionic surfactants can solubilize and denature proteins and alter enzyme activity by binding or disrupting enzyme structure (Argese et al. 1994). In polychaetes, the anionic surfactant LAS can cause morphological damages (Conti 1987). Regarding other ingredients, it is known that enzymes (protease and lipase), sodium silicate, perfumes and bleachers (sodium perborate) can contribute to an increase in detergent toxicity for a wide range of aquatic organisms (Warne 1995; Warne and Schifko 1999; Markina and Aizdaicher 2007; Pedrazzani et al. 2012; Sobrino-Figueroa 2013).

BLANCA NIEVES® was less toxic to *Capitella sp*. C than FOCA®, possibly because this formulation does not contain enzymes and bleachers. However, it does contain other ingredients such as sodium silicate and perfumes, which may have contributed to the (lower) toxicity of the detergent. Furthermore, it cannot be ruled out that the other ingredients in the formulation, such as carbonates, sulfates, sodium and anti-redeposition agents may have contributed to its toxicity. Finally, ROMA® was found to be the least toxic of the three detergents tested.

When evaluating detergent toxicity, studies have often focused on surfactants as these are considered to be among the most toxic compounds contained in these materials, and also represent a high percentage, 15–40 %, of the total number of ingredients in the formulations (Scheibel 2004). Warne and Schifko (1999) found that surfactants contributed between 10.4 and 98.8 % of the toxicity of detergents they analyzed with a mean contribution of 40.7 %. Thus, the low toxicity of ROMA® might be due to the low concentrations of surfactant it contains, as well as the absence of other toxic ingredients (enzymes and sodium tripolyphosphate). In conclusion, the variations in toxicity between the detergents tested could be caused both by the concentration of the anionic surfactant LAS in the formulation and the presence of other ingredients (enzymes, sodium silicate, sodium tripolyphosphate, bleachers and perfumes).

The LAS LC_{50} values reported by this study with *Capitella sp*. C are similar to those registered by Uc-Peraza and Delgado-Blas (2012). These authors reported LAS toxicity (LC_{50}) values of between 12.88 and 14.12 ppm against *Laeonereis culveri* at 48 h. Similar values were also reported by Conti (1987) who determined the toxicity of two anionic surfactants: sodium dodecyl sulfate (SDS) and LAS in another polychaete species, *Arenicola marina* (SDS: LC_{50} 15.2 ppm; LAS: LC_{50} 12.5 ppm, at 48 h). This shows that *Capitella sp*. C is less sensitive to anionic surfactants than *A. marina* and *L. culveri* in acute toxicity tests.

Comparing our results with those for other groups of aquatic organisms, we can observe that *Capitella* sp. C is more resistant to detergents than crustaceans and fish. For example, Warne (1995) examined the toxicity of 24 detergents to the cladoceran *Ceriodaphnia* cf. *dubia* and found that toxicity levels (measured as EC_{50} at 48 h, immobilization) varied between 1.6 and 70.3 ppm. In another study, Pettersson et al. (2000) evaluated the toxicity of 26 commercial detergents using *Daphnia magna* as the test organism, reporting values between 4 and 85 ppm (EC_{50} at 48 h) for 25 of them. In fish, Okoli-Anunobi et al. (2002) calculated the acute toxicity of a commercial detergent to *Oreochromis niloticus* finding an LC_{50} of 9.77 ppm at 96 h. Omotoso and Fagbenro (2005) determined the toxicity of three commercial detergents with this same species registering LC_{50} values of between 12.04 and 41.88 ppm at 96 h. However, if we look at studies performed with mollusk species as test organisms, it can be observed that *Capitella* sp. C is more sensitive. For example, Iannacone and Alvariño (2002) undertook an ecotoxicological evaluation of three commercial detergents against different species of mollusks and reported LC_{50} values of 201.07 ppm (*Melanoides tuberculata*), 82.93 ppm (*Physa venustula*) and 71.41 ppm (*Heleobia cumingii*) at 48 h. The differences in sensitivity between polychaetes and mollusks may be explained by the way in which the detergent acts on the organism. In polychaetes

(*Arenicola marina*), anionic detergents (LAS) cause severe damage mainly at the level of the epidermis and in the region of the gills (Conti 1987). This is because, in the majority of cases, the soft bodies of the polychaetes are exposed to the environment and thus come into direct contact with pollutants. In contrast, the hard resistant shells of mollusks afford some protection from contaminants making them more tolerant. It is important to mention that the comparisons made here are based on a limited number of experiments, and the response of different species within taxa may vary with their biochemistry and physiology, the age of the test organisms, the detergent evaluated and the conditions under which the bioassays are conducted. More toxicity tests performed under similar conditions with a wide variety of aquatic species are thus needed.

Our results of the correlation analysis show that *Capitella* sp. C percent mortality increased significantly ($p < 0.05$) with increase in the concentrations of the detergents during the 48-h exposure period, coinciding with the results of Uc-Peraza and Delgado-Blas (2012). This observation also agrees with Okwuosa and Omoregie (1995) and Ogundele et al. (2005) who determined the acute toxicity of anionic surfactants in fish. In another study, Aizdaicher and Markina (2006) evaluated the toxicity of two detergents and one anionic surfactant to an algal species (*Plagioselmis prolonga*) and also observed that the effects on the test organisms increased with increasing concentrations of these substances.

The risk quotient value of the three LAS-containing detergents indicates that they are high-risk substances likely to cause damage to aquatic biota, particularly sediment-dwelling organisms such as *Capitella* sp. C. This is because the motility and feeding characteristics of these organisms make them more vulnerable to the impact of detergents. It has been demonstrated that 20–30 % of surfactants entering the sea environment easily accumulate in sediments and can affect bottom-dwelling biota (Marín et al. 1991; Marin et al. 1994; Markina and Aizdaicher 2007). The effects are particularly acute in those zones where there are outfalls of raw sewage or sewage effluent, as is the case at several sites within the urban shoreline zone at Chetumal, Quintana Roo, where clandestine discharges of soapy water have been detected. Surfactants and other ingredients contained in detergents are common components of the domestic and municipal residual output which eventually reaches the natural environment causing diverse toxic effects to the aquatic organisms present (Ankley and Burkhard 1992; Pettersson et al. 2000, Azizullah et al. 2011). Warne and Schifko (1999) mention that surfactants and sodium silicates are the main contributors to detergent toxicity, and were components of the three detergents evaluated in this study. Surfactants are used as cleaning agents while sodium silicates act as water softeners (Table 1). Specifically, the toxic effects of the anionic surfactant LAS have been examined in several experiments with different groups of aquatic organisms providing evidence of its toxicity (Marín et al. 1991; Bao-Quey and Dar-Yi 1994; Jorgensen and Christoffersen 2000; Rosety et al. 2001; Hampel et al. 2001; Christoffersen et al. 2003; Stefanoni and Abessa 2008; Coelho and Rocha 2010). However, it has been determined that the ecological risk of LAS to aquatic organisms is low (Fendinger et al. 1994; Van de Plassche et al. 1999; Versteeg et al. 1999; Temara et al. 2002). Despite this, both this study and that undertaken by Uc-Peraza and Delgado-Blas (2012) show that when the effects of the surfactant and the other ingredients contained in detergents are considered as a whole, there is a high risk that the aquatic biota will be adversely affected. Commercial detergents are complex mixtures of different compounds which can interact either antagonistically, additively or synergistically, thus modifying their toxicity to the aquatic environment (Warne and Schifko 1999). The observed effects can thus be considered as the net impact of the detergent as a whole (Azizullah et al. 2011). Studies undertaken using different aquatic organisms (Aizdaicher and Markina 2006; Sobrino-Figueroa 2013) have demonstrated that detergent formulations taken as a whole may be more toxic than the active ingredients they contain, with significant ecological consequences for shore ecosystems both at high (10 ppm) and low (0.1–1 ppm) concentrations (Aizdaicher and Markina 2006). Nevertheless, given that the results obtained in this study with *Capitella* sp. C cannot be generalized with other taxa, we recommend that ecotoxicological bioassays at sub-lethal doses to test for chronic toxicity are performed, both with polychaetes and other groups of aquatic organisms representative of the aquatic biota in Chetumal Bay, Quintana Roo, Mexico.

Conclusions

Three formulations of commercial detergents tested showed LC_{50} values (48 h exposure) for *Capitella* sp. C between 70.79–147.91 ppm and 15.48–22.38 ppm corresponding to the formulation and the active ingredient, respectively. The percentage of mortality among the concentrations of the three detergents was 3–93 %. FOCA® was the most toxic detergent of all. The variation in the toxicity of the three detergents could have been caused both by differences in the relative concentrations of LAS contained in each formulation and the presence of other ingredients (enzymes, sodium silicate, sodium tripolyphosphate, bleachers and perfumes) which can also increase formulation toxicity. Finally, the ecological risk assessment for the three detergents indicates that there is a high risk to the aquatic biota, especially sediment-dwelling organisms such as the test species.

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