An Australian Government Initiative

Australian & New Zealand GUIDELINES FOR FRESH & MARINE WATER QUALITY

Toxicant default guideline values for aquatic ecosystem protection

Imazapic in fresh and marine waters

Technical brief

October 2026

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Summary

The default guideline values (DGV) and associated information in this technical brief should be used in accordance with the detailed guidance provided in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality website (www.waterquality.gov.au/anz-guidelines).

Imazapic (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid, CAS No. 104098-48-8, BCPC 2018) is a selective imidazolinone herbicide. Other imidazolinone herbicides include imazaquin, imazapyr, and imazethapyr. Imazapic is toxic to some plant species because it inhibits the enzyme acetohydroxy acid synthase (AHAS), resulting in a lack of amino acids and ultimately leads to the death of grasses and broad-leaved weeds. Imazapic use in Australia is limited to selected cereals (barley and wheat), grasses (sugarcane), and legumes (chickpeas and peanuts), with non-agricultural uses (APVMA, 2020) permitted for lawn/turf applications and sports fields (APVMA, 2020). Imazapic is not registered for use in New Zealand (ACVM 2021).

Previously, no Australian and New Zealand DGV existed for imazapic in fresh or marine environments (ANZECC and ARMCANZ 2000). The recent availability of more data on imazapic toxicity to freshwater and marine species has enabled the calculation of DGVs.

Available data did not indicate a difference in the sensitivity of phototrophs and other organism types therefore toxicity data for all species were used to derive the DGVs for imazapic. The lowest reported chronic toxicity value to freshwater species is 2.58 µg/L (freshwater macrophyte, 14-day NOEL), and to marine species is 45 µg/L (marine microalga, 5-day EC50); while the lowest reported acute toxicity value to freshwater species is > 100,000 µg/L (freshwater arthropod and fish, 48–96-hour EC/LC50) and to marine species is 97,700 µg/L (marine arthropod, 96-hour NOEL and LC50).

Low reliability DGVs for imazapic in fresh and marine waters were derived based on chronic ‘no and negligible effect’ toxicity data for 13 phototrophic and heterotrophic species from 8 phyla and 9 classes, with a poor fit of the species sensitivity distribution (SSD) to the toxicity data. It should be noted that the DGVs derived here are expressed in terms of the active ingredient (imazapic) rather than commercial formulations. The DGVs for 99%, 95%, 90% and 80% species protection are 0.43 µg/L, 2.1 µg/L, 5.3 µg/L and 20 µg/L, respectively. The 95% species protection level for imazapic of 2.1 µg/L is recommended in the assessment of slightly to moderately disturbed ecosystems.

1. Introduction

Imazapic ($C_{14}H_{17}N_3O_3$, CAS no. 104098-48-8, Figure 1) is the active ingredient in a variety of commercial herbicide formulations. Imazapic is often mixed with other herbicides, including diquat and glyphosate (National Centre for Biotechnology Information, 2014), and additives such as surfactants to increase its efficacy. Physicochemical properties of imazapic that may affect its environmental impact and toxicity are presented in Table 1.

Figure 1. Structure of imazapic

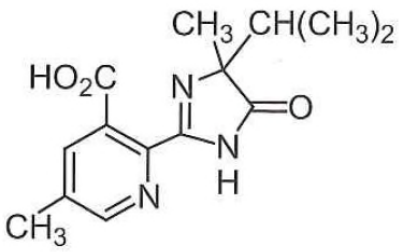


Table 1. Summary of selected physicochemical properties of imazapic

Physicochemical property	Value
Molecular weight	275.3 g/mol[1]
Dissociation constants	pKa1 = 2.0, pKa2 = 3.6, pKa3 = 11.1[1]
Aqueous solubility	2,150 mg/L @ temperature 25 °C[1] 2,230 mg/L @ temperature 20 °C[2]
Logarithm of the octanol-water partition coefficient (log K_{ow})	0.393 @ pH 4, 5, 6 and temperature 25 °C[1] 2.47 @ pH 7 and temperature 20 °C[2]
Logarithm of the organic carbon water partition coefficient (log K_{oc})	2.14[2]
Logarithm of the bioconcentration factor (log BCF)	3[3] or low[2]
Half-life in water ($t_{1/2}$)	< 8 hours[1, 4]
Half-life in soils ($t_{1/2}$)	31–410 days depending on soil and climatic conditions[1] Typical: 120 days; In field: 232 days[2]

[1] BCPC (2012). [2] Pesticide Properties Database (University of Hertfordshire 2013). [3] National Centre for Biotechnology Information (2014). [4] Tu et al. (2001).

Imazapic is a selective herbicide that belongs to the imidazolinone group of herbicides, which also includes imazaquin, imazapyr and imazethapyr. Imazapic is only registered for application to 5 crops in Australia (APVMA, 2020): barley and wheat (cereals), sugar cane (grass), chickpea and peanut (legumes) (APVMA, 2020). The only registered non-agricultural use of imazapic is for pasture and fallow (APVMA, 2020). Imazapic is not registered for use in New Zealand (AVCM, 2021).

Imazapic binds weakly to soil particles and has little adsorption to suspended soils; however, it has high aqueous solubility (Table 1) suggesting that imazapic is moderately mobile. It is readily metabolised by soil microorganisms, with some capacity to leach to groundwater and end up in surface waters (Tu et al. 2001).

Imazapic is persistent in soils with half-life ranging from 31 to 410 days depending on the soil type and climatic conditions (BCPC 2012; Tu et al. 2001) (Table 1). However, it is rapidly degraded by sunlight in the aquatic environment with aqueous hydrolysis ($t_{1/2}$) occurring at approximately 7.2 hours (University of Hertfordshire 2013).

2. Aquatic toxicology

2.1. Mechanisms of toxicity

Imazapic is mainly absorbed through the roots and shoots of plants and is transported to the vascular tissues where it exerts its toxicity (Tu et al. 2001). Imazapic acts by inhibiting the AHAS enzyme that is responsible for catalysing the formation of 3 branched-chain aliphatic amino acids (leucine, valine and isoleucine) within target plants (Tu et al. 2001). Plants die slowly through inhibition of protein synthesis and cell growth due to limitation of the amino acids available to the plant (Tu et al. 2001).

2.2. Relative toxicity

Acute and chronic toxicity data for 10 freshwater and 8 marine species passed the screening and quality assessment processes. The freshwater species comprised 6 phototrophs and 4 heterotrophs, while the marine species comprised 5 phototrophs and 3 heterotrophs. For freshwater species, the phototrophs comprised 3 green algae, 1 diatom, 1 macrophyte and 1 blue-green alga, while the heterotrophs comprised 3 fish and 1 arthropod. For marine species, the phototrophs comprised 2 green algae, 1 diatom, 1 plankton and 1 golden alga, while the heterotrophs comprised a fish, a mollusc, and an arthropod. Despite the ecotoxicity data for imazapic being sparse, some comparisons of relative toxicity to organisms can be made.

There is no clear difference in the toxicity of major taxonomic groups (Appendix D). For freshwater species, the phototrophs were much more sensitive (2.58 – >1,100 µg/L; no observed effect concentration (NOEC) equivalents) than the heterotrophs (96,000–100,000 µg/L; range of endpoints). However, for marine species, the sensitivity of heterotrophs (97,700–99,200 µg/L; NOEC equivalents) fell within the range of phototroph toxicity data (45–790,000 µg/L; NOEC equivalents). The similar sensitivities of marine photo- and heterotrophic species may be an artefact of the small sample size for marine species.

There appeared to be differences in the sensitivity of the types of phototrophic species, with various endpoint values ranging from: >52.3 (USEPA 2015) to 20,800 µg/L (Negri et al. 2020) for green algae; 363,000 µg/L (no effect concentration, NEC) to 790,000 µg/L (50% effect concentration, EC50) (Negri et al. 2020, Thomas et al. 2020) for a cryptophyte; 474 (NEC) to 4,320 µg/L (EC50) (Negri et al. 2020) for a golden alga; >45 µg/L to >46.4 µg/L (EC50; USEPA 2015) for diatoms; 3 values of >165,000 µg/L (Negri et al. 2020) for a marine dinoflagellate species; 2.58 (no observed effect level, NOEL) to 4.23 µg/L (EC50 value) (USEPA 2015) for a macrophyte; and an EC50 value of >67.4 µg/L for a blue-green alga (USEPA 2015).

In contrast to the phototrophic data, there appeared to be similarities in the sensitivity of the types of heterotrophic species. Fish and arthropods both had toxicity values that ranged from 96,000 (chronic

NOEL) to >100,000 µg/L (acute LC/EC50) (USEPA 2015). The marine mollusc had acute NOEL and LC50 values of 99,200 and >99,200 µg/L, respectively (USEPA 2015). There were no chronic toxicity data for marine heterotrophic species.

3. Factors affecting toxicity

No factors have been reported as modifying the toxicity of imazapic. As with many organic chemicals it might be expected that dissolved and particulate organic matter, and suspended solids would affect its bioavailability and toxicity. However, any such effect would be relatively minor given the relatively low log K_{oc} value of imazapic (Table 1).

4. Default guideline value derivation

The DGVs were derived in accordance with the method described in Warne et al. (2018) and using Burrlioz 2.0 software.

4.1. Toxicity data used in derivation

To obtain toxicity data for imazapic to fresh and marine organisms, an extensive search of the scientific literature was conducted. In addition, the following databases were searched: ECOTOX Knowledgebase (USEPA 2015), the Australasian Ecotoxicology Database (Warne et al. 1998) and the ANZECC and ARMCANZ (2000) toxicant database (Sunderam et al. 2000) were searched. There are now sufficient imazapic toxicity data available to enable calculation of DGVs in fresh and marine waters (Appendix A and B). The DGVs were calculated using pooled toxicity data for fresh and marine organisms because there were no differences in the sensitivity of fresh and marine organisms to imazapic (Appendix D). By pooling the data the number of values in the SSD was increased thus improving the statistical rigour of the SSD. The fit of the SSD to the pooled data was better than for either the fresh or marine data separately. All the toxicity data used to calculate the DGVs were determined from experiments using technical or higher grades of imazapic or with a minimum purity of 80% active ingredient (Warne et al. 2018).

Normally, species classified only to the level of genus (e.g. *Tetraselmis* sp.) are not used in the DGV derivation process, as species specificity is required. The use of such data in DGV derivations is usually avoided as the ambiguity at the genus level could result in more than one toxicity value being assigned to a single species. However, visual identification and classification of species within a genus, particularly for microalgae, can be difficult for some genera due to their lack of characteristic morphological features (Kessler and Huss 1992). Nonetheless, when there are no other data for species belonging to the same genus (i.e. there is no chance of duplicating a species) and/or when there are limited amounts of toxicity data available, then such data could be included in the derivation of DGVs (Warne et al. 2018). In deriving the DGVs for imazapic in fresh and marine waters, data for *Tetraselmis* sp. was included as no other toxicity data for this genus were used.

In total, there were freshwater toxicity data for 10 species (6 phyla and 6 classes) and marine toxicity data for 8 species (7 phyla and 7 classes), that passed the screening and quality assessment processes. The represented phyla were Arthropoda, Bacillariophyta, Chlorophyta, Chordata, Cryptophyta, Cyanobacteria, Haptophyta, Miozoa, Mollusca and Tracheophyta. The represented classes were Actinopterygii (which accounts for approximately 99% of fish), Bacillariophyceae (diatoms; a major grouping of algae), Bivalvia (a grouping of molluscs), Branchiopoda (a grouping of crustaceans), Chlorodendrophyceae (a grouping of marine phytoplankton), Chlorophyceae (a major grouping of green algae), Coccolithophyceae (a grouping of marine phytoplankton), Cryptophyceae (a class of cryptomonads), Cyanophyceae (a class of cyanobacteria), Dinophyceae (a class of dinoflagellates), Liliopsida (monocots), Malacostraca (a larger grouping of crustaceans) and Mediophyceae (an algae grouping).

Based on current understanding of imazapic's mode of action, phototrophic species are expected to be more sensitive than non-phototrophic species as imazapic inhibits the AHAS enzyme responsible for synthesising branched-chain amino acids required for plant growth. The mode of action of imazapic indicates that the distribution of toxicity data should be bimodal. However, as the dataset was small and there was no difference in the sensitivity of phototrophs and heterotrophs (Appendix D), the DGVs were calculated using ecotoxicity data for all organisms.

At the time of the literature search, there were a limited number of published studies reporting the toxicity of imazapic to aquatic organisms and these contained minimal data that were suitable for use. The freshwater and marine data (presented in Appendix A and Appendix B) were extracted from ECOTOX knowledgebase (USEPA 2015), Stone (2016), Stone et al. (2019 and 2021), Negri et al. (2020) or Thomas et al. 2020. The data extracted from ECOTOX were derived from reports from commercial laboratories for the purpose of product registration. The USEPA (2015) follows strict quality assurance and quality check procedures within their organisation to ensure only high-quality ecotoxicology data are reported and used. It was therefore assumed that the toxicity data in the unpublished Office of the Pesticide Program studies were also either high or acceptable quality, so they were used in the derivation of DGVs for imazapic.

There were chronic 'no and negligible effect' (i.e. 10% effect concentration (EC10), no observed effect level (NOEL) and no effect concentration (NEC)) concentration data for 9 fresh and marine species. However, due to the extremely poor fit of the SSD to the toxicity data (Appendix C), the dataset was expanded to include chronic estimated negligible effect (i.e. chronic EC50 toxicity data that had been converted to estimates of chronic NOEC by dividing by 5) data. There were chronic no effect, negligible effect and chronic estimated negligible data values available for 13 species (phototrophic and heterotrophic) belonging to 8 phyla and 9 classes, which met the minimum data requirements (i.e. at least 5 species belonging to at least 4 phyla) for a SSD to derive DGVs (Warne et al. 2018). The methods of Warne et al. (2018) state that 'greater than, >' toxicity values can be used provided that: 1) there are no available normal (not '>' or '<') values for the same combination of species, measure and endpoint; and 2) they are used in the following manner, e.g. > 50 µg/L would be changed to 50 µg/L in all subsequent calculations. The reasons such data are acceptable for use is that they provide an environmental protective estimate of the toxicity. A summary of the toxicity data (one value per species) used to calculate the DGVs for imazapic in freshwater and marine environments is provided in Table 2. Further details of the water quality parameters for each single species value used to calculate the DGVs

are presented in Appendix A and Appendix B. Details of the data quality assessment and the data that passed the quality assessment are provided as supporting information.

Table 2. Summary of the single chronic toxicity values for each phototrophic and heterotrophic species that was used to derive the DGVs for imazapic in fresh and marine waters.

Media	Taxonomic group	Species	Life stage	Duration (days)	Toxicity measure (endpoint)	Toxicity value (µg/L)	Final toxicity values (µg/L)
Fresh	Blue-green alga (Cyanobacteria)	*Anabaena flos-aquae*	Not stated	5	Chronic EC50 (Biomass yield, growth rate, AUC[c])	67.4	13.5[d]
	Diatom (Bacillariophyta)	*Navicula pelliculosa*	Not stated	5	Chronic EC50 (Biomass yield, growth rate, AUC[c])	>46.4	9.3[d]
	Green alga (Chlorophyta)	*Monoraphidium arcuatum*[a]	Exponential growth phase	3	Chronic EC10 (Cell density)	>1,100	1,100
		Pediastrum duplex meyen[a]	Exponential growth phase	3	Chronic EC10 (Cell density)	>1,100	1,100
		Selenastrum capricornutum[b]	Not stated	5	Chronic EC50 (Biomass yield, growth rate, AUC[c])	52.3	10.5[d]
	Macrophyte (Tracheophyta)	*Lemna gibba*	Not stated	14	Chronic NOEL (Frond number, frond size, dry weight)	2.58	2.58
	Cladoceran (Arthropoda)	*Daphnia magna*	Life cycle	21	Chronic NOEL (Length, dry weight)	96,000	96,000
	Fish (Chordata)	*Pimephales promelas*	Early life stage	32	Chronic NOEL (Mortality)	96,000	96,000
Marine	Diatom (Bacillariophyta)	*Skeletonema costatum*[a]	Not stated	5	Chronic EC50 (Biomass yield, growth rate, AUC[c])	45	9[d]
	Green alga (Chlorophyta)	*Tetraselmis* sp.	Exponential growth phase	3	Chronic EC10 (Growth rate)	>20,800	20,800
	Golden alga (Haptophyta)	*Tisochrysis lutea*	Exponential growth phase	3	Chronic NEC (Growth rate)	474	474
	Cryptomonad (Cryptophyta)	*Rhodomonas salina*[a]	Exponential growth phase	3	Chronic NEC (Growth rate)	363,000	363,000
	Plankton (Dinoflagellate)	*Cladocopium goreaui*	Exponential growth phase	14	Chronic NEC (Growth rate)	>165,000	165,000

[a] Species that originated from or whose geographic distributions include Australia and/or New Zealand

[b] This species has more recently been called *Raphidocelis subcapitata* and *Pseudokirchneriella subcapitata*.

[c] AUC = area under the growth curve.

[d] Chronic EC50 values that were converted to chronic NOEC values by dividing by 5 (Warne et al. 2018).

To identify species that were regionally relevant to Australia and New Zealand ecosystems, a search of the following resources was conducted: Algaebase (Guiry and Guiry 2017), Atlas of Living Australia (ALA 2017), Catalogue of Life (Roskov et al. 2017), Integrated Taxonomic Information System (ITIS 2017) and the World Register of Marine Species (WoRMS 2017). The dataset used in the guideline derivation process for imazapic in Table 2 includes toxicity data for 2 freshwater and 2 marine species that either originated from or are distributed within Australia and/or New Zealand.

4.2. Species sensitivity distribution

The cumulative frequency (species sensitivity) distribution (SSD) of the 8 fresh and 5 marine species that was used to derive the DGVs is presented in Figure 2.

The SSD was plotted using the Burrlioz 2.0 software. The model was judged to provide a poor fit to the data (Figure 2).

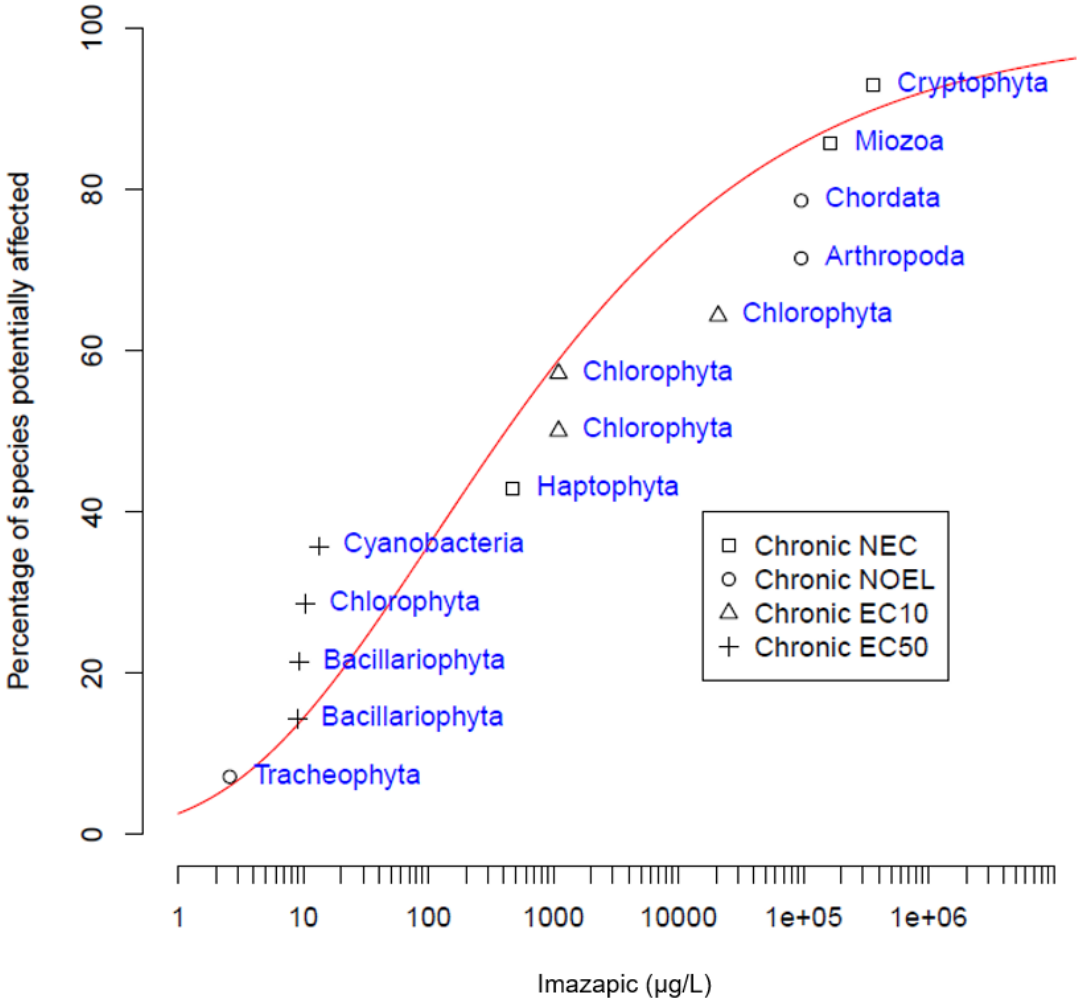


Figure 2. Species sensitivity distribution of imazapic in fresh and marine waters

4.3. Default guideline values

The DGVs for imazapic in fresh and marine water are provided in Table 3. As with all the other pesticides, the DGVs for imazapic are expressed in terms of the concentration of the active ingredient. Although some of the toxicity data used to derive the DGVs may have incorporated toxicity due to imazapic metabolites, this has not been quantified and, therefore, only imazapic (and not any of its metabolites) should be measured for comparison with the DGVs.

Measured log BCF values for imazapic are low (Table 1) and below the threshold at which secondary poisoning must be considered (i.e. threshold log BCF = 4, Warne et al. 2018). Therefore, the DGVs for imazapic do not need to account for secondary poisoning.

Table 3. DGVs (µg/L) for imazapic for the protection of freshwater and marine ecosystems.

Level of species protection (%)	DGV for imazapic (µg/L) [a]
99	0.43
95	2.10
90	5.30
80	20.00

[a] DGVs were derived using the Burrlioz 2.0 (2016) software.

4.4. Reliability classification

The imazapic DGVs have a low reliability classification (Warne et al. 2018) based on the outcomes for the following 3 criteria:

- sample size – 13 (good)
- type of toxicity data – chronic freshwater and marine data
- SSD model fit – poor (inverse Weibull).

Glossary and abbreviations

Acute toxicity	An adverse effect that occurs as the result of a short-term exposure to a chemical relative to the organism's life span. Refer to Warne et al. (2018) for examples of acute exposures.
ANZECC	Australian and New Zealand Environment and Conservation Council.
ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand.
Bimodal	When the distribution of the sensitivity of species to a toxicant has 2 modes. This typically occurs with chemicals with specific modes of action. For example, herbicides are designed to affect plants at low concentrations, but most animals are only affected at high concentrations.
CAS no.	Chemical Abstracts Service number. Each chemical has a unique identifying number that is allocated to it by the American Chemical Society.
Chronic toxicity	An adverse effect that occurs as the result of exposure to a chemical for a substantial portion of the organism's life span or an adverse sub-lethal effect on a sensitive early life stage. Refer to Warne et al. (2018) for examples of chronic exposures.
Default guideline value (Default GV)	A guideline value recommended for generic application in the absence of a more specific guideline value (e.g. site-specific), in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality.
ECx	The concentration of a chemical in water that is estimated to produce x% effect on a sub-lethal endpoint. The magnitude of x can vary from 1 to 100, however values between 5 and 50 are more typical. The ECx is usually expressed as a time-dependent value (e.g. 24-hour or 96-hour ECx).
EC50 (Median effective concentration)	The concentration of a chemical in water that is estimated to produce a 50% effect on a sub-lethal endpoint. The EC50 is usually expressed as a time-dependent value (e.g. 24-hour or 96-hour EC50).
Endpoint	A measurable biological effect including, but not limited to, lethality, immobility, growth inhibition, immunological responses, organ effects, developmental and reproductive effects, behavioural effects, biochemical changes, genotoxicity, etc.
Guideline value (GV)	A measurable quantity (e.g. concentration) or condition of an indicator for a specific environmental value below which (or above which, in the case of stressors such as pH, dissolved oxygen and many biodiversity responses) there is considered a low risk of unacceptable effects occurring to that environmental value. Guideline values for more than one indicator should be used simultaneously in a 'multiple lines of evidence' approach.
ICx	The concentration of a chemical in water that is estimated to produce x% inhibition of a sub-lethal endpoint (usually growth in phototrophic test organisms). The magnitude of x can vary from 1 to 100; however, values

	between 5 and 50 are more typical. The ICx is usually expressed as a time-dependent value (e.g. 24-hour or 72-hour ICx).
LC50 (Median lethal concentration)	The concentration of a chemical in water that is estimated to kill 50% of the test organisms. The LC50 is usually expressed as a time-dependent value (e.g. 24-hour or 96-hour LC50).
LOEC (Lowest observed effect concentration)	The lowest concentration of a chemical used in a toxicity test that has a statistically significant ($p \leq 0.05$) adverse effect on the exposed population of test organisms compared to the controls. All higher concentrations should also cause statistically significant effects.
LOEL (Lowest observed effect level)	Synonymous with LOEC.
Mode of action	The means by which a chemical exerts its toxic effects. For example, triazine herbicides inhibit the photosystem II component of a plant's photosynthesis biochemical reaction.
NEC (no effect concentration)	The highest concentration that does not have an effect – this is determined differently from a NOEC.
NOEC (No observed effect concentration)	The highest concentration of a toxicant used in a toxicity test that does not have a statistically significant ($p > 0.05$) effect compared to the controls. The statistical significance is measured at the 95% confidence level.
NOEL (No observed effect level)	Synonymous with NOEC.
Phototrophs	Organisms that photosynthesize as their main means of obtaining energy e.g. plants and algae.
PSII	Photosystem II of the photosynthetic biochemical pathway.
Site-specific	Relating to something that is confined to, or valid for, a particular place. Site-specific trigger values are relevant to the location or conditions that are the focus of a given assessment.
Species	A group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not produce viable offspring if bred with members of another group.
SSD	Species sensitivity distribution. A method that plots the cumulative frequency of species sensitivity and fits the best possible statistical distribution to the data. From the distribution the concentration that should theoretically protect a selected percentage of species can be determined.
Toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism.

Toxicity test	The means by which the toxicity of a chemical or other test material is determined. A toxicity test is used to measure the degree of response produced by exposure to a concentration of chemical.
USEPA	United States Environmental Protection Agency

Appendix A: Summary details of the freshwater toxicity data used to derive DGVs for imazapic

Phyla/Division	Class	Species	Life stage	Exposure duration (days)	Test type	Toxicity measure (test endpoint)	Test medium	Temp. (°C)	pH	Concentration (µg/L)	Reference
Arthropoda	Branchiopoda	Cladoceran (*Daphnia magna*)	Life cycle	21	Chronic	NOEL (length, dry weight)	Surface or ground, reconstituted or dechlorinated tap water	20 ± 1	Not stated	96,000	USEPA (2015b)
										96,000	**VALUE USED IN SSD**
Bacillariophyta	Bacillariophyceae	Diatom (*Navicula pelliculosa*)	Not stated	5	Chronic	Chronic EC50 (biomass yield, growth rate, AUC[3])	ASTM Type I water	24 ± 2	7.5 ± 0.1	46.4	USEPA (2015b)
										9.3[@]	**VALUE USED IN SSD**
Chlorophyta	Chlorophyceae	Microalga (*Monoraphidium arcuatum*)	Exponential growth phase	3	Chronic	EC10 (cell density)	0.45 µm filtered synthetic soft water	27 ± 2	7.5 ± 2	>1,100[1]	Stone (2016)
										1,100	**VALUE USED IN SSD**
Chlorophyta	Chlorophyceae	Microalga (*Pediastrum duplex meyen*)	Exponential growth phase	3	Chronic	EC10 (cell density)	0.45 µm filtered synthetic soft water	27 ± 2	7.5 ± 2	>1,100[1]	Stone (2016)
										1,100	**VALUE USED IN SSD**
Chlorophyta	Chlorophyceae	Microalgae (*Selenastrum capricornutum*[2])	Not stated	5	Chronic	Chronic EC50 (biomass yield, growth rate, AUC[3])	ASTM Type I water	24 ± 2	7.5 ± 0.1	52.3	USEPA (2015b)
										10.5[@]	**VALUE USED IN SSD**
Chordata	Actinopterygii	Fathead minnow (*Pimephales promelas*)	Early life stage	32	Chronic	NOEL (mortality)	Dilution water	25 ± 2.0	Not stated	96,000	USEPA (2015b)
										96,000	**VALUE USED IN SSD**
Cyanobacteria	Cyanophyceae	Blue-green microalgae (*Anabaena flos-aquae*)	Not stated	5	Chronic	Chronic EC50 (biomass	ASTM Type I water	25 ± 2	7.5 ± 0.1	67.4	USEPA (2015b)

						yield, growth rate, AUC[3])					
										13.5[@]	**VALUE USED IN SSD**
Tracheophyta	Liliopsida	Macrophyte (*Lemna gibba*)	Not stated	14	Chronic	NOEL (frond number, frond size, dry weight)	M-Hoagland's or 20X-AAP nutrient media/ASTM Type I water	25 ± 2	(4.8-5.2 for M-Hoadland's / 7.5 ± 0.1 for 20X-AAP)	2.58	USEPA (2015)
										2.58	**VALUE USED IN SSD**

[1] In calculating the VALUE USED IN SSD, < or > values were treated as absolute values (e.g. > 320 µg/L became 320 µg/L). [2] This species has more recently been called *Raphidocelis subcapitata* and *Pseudokirchneriella subcapitata*. [3] AUC = area under the growth curve. [@] Values were chronic EC50 values that were converted to chronic NOEC values by dividing by 5 (Warne et al. 2018).

Appendix B: Summary details of the marine toxicity data used to derive DGVs for imazapic

Phyla/Division	Class	Species	Life stage	Exposure duration (days)	Test type	Toxicity measure (test endpoint)	Test medium	Salinity (‰)	Temp. (°C)	pH	Concentration (µg/L)	Reference
Bacillariophyta	Mediophyceae	Diatom (*Skeletonema costatum*)	Not stated	5	Chronic	EC50 (Biomass yield, growth rate, AUC[1])	Synthetic salt water or filtered natural salt water	30 ± 5	20 ± 2	8.0 ± 0.1	>45[2]	USEPA (2015b)
											9[@]	**VALUE USED IN SSD**
Chlorophyta	Chlorodendrophyceae	Green alga *(Tetraselmis* sp.*)*	Exponential growth phase	3	Chronic	EC10 (Growth rate)	EDTA-free Guillard's f/2 medium	33 ± 1.5	27 - 29	8.1 - 8.2	>20,800[2]	Negri et al. (2020)
											20,800	**VALUE USED IN SSD**
Cryptophyta	Cryptophyceae	Cryptomonad *(Rhodomonas salina)*	Exponential growth phase	3	Chronic	NEC (Growth rate)	EDTA-free Guillard's f/2 medium	34.2 ± 0.6	26.0 ± 0.6	8.5 ± 0.4	363,000	Negri et al. (2020), Thomas et al. (2020)
											363,000	**VALUE USED IN SSD**
Miozoa	Dinophyceae	Dinoflagellate (*Cladocopium goreaui*)	Exponential growth phase	14	Chronic	NEC (Growth rate)	IMK nutrient media	32.5 ± 0.7	27 ± 0.6	7.8 ± 0.5	>165,000[2]	Negri et al. (2020)
											165,000	**VALUE USED IN SSD**
Haptophyta	Coccolithophyceae	Golden alga (*Tisochrysis lutea*)	Exponential growth phase	3	Chronic	NEC (Growth rate)	EDTA-free Guillard's f/2 medium	33 ± 1.5	27 - 29	7.9 - 8.3	474	Negri et al. (2020)
											474	**VALUE USED IN SSD**

[1] AUC = area under the growth curve. [2] In calculating the VALUE USED IN SSD, < or > values were treated as absolute values (e.g. > 320 µg/L became 320 µg/L). [@] Values were chronic EC50 values that were converted to chronic NOEC values by dividing by 5 (Warne et al. 2018).

Appendix C: Justification for the data used in the DGV derivation

Reliable DGVs could not be calculated when only using the chronic 'no and negligible effect' toxicity data (i.e. EC10/NOEL/NEC) available for 9 freshwater and marine species (Table 4) due to the poor fit of the SSD to the toxicity data (Figure 3). To increase reliability of the resultant DGVs, the chronic 'no and negligible effect' toxicity data were combined with chronic estimated negligible effect data (i.e. chronic EC50 toxicity data that had been converted to estimates of chronic NOEC by dividing by 5). This increased the dataset to 13 species (belonging to 8 phyla and 9 classes). While the fit of the SSD to the toxicity data remained poor (Figure 2), it was markedly better than that produced when only using the chronic 'no and negligible effect' toxicity data for 9 species (Figure 3). The expanded dataset of chronic and chronic estimated data for 13 species was therefore deemed the most appropriate for use to derive DGVs for imazapic in fresh and marine waters.

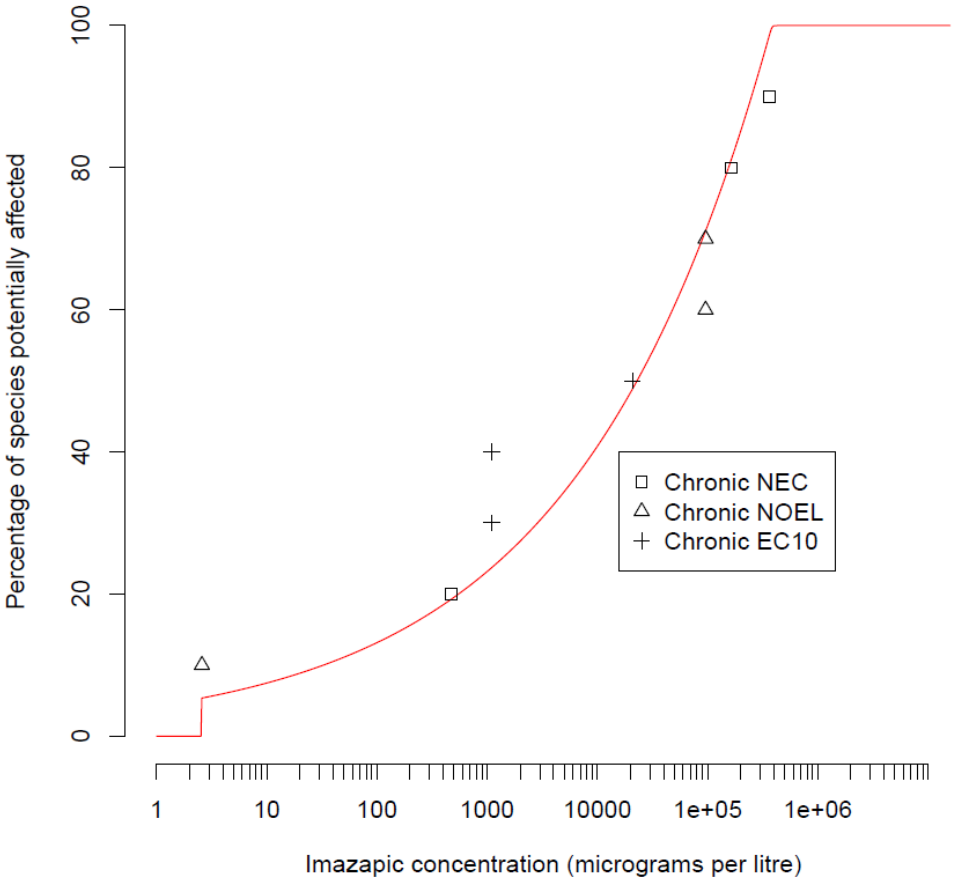


Figure 3. SSD of imazapic in fresh and marine waters – using only chronic EC10, NOEL and NEC data

Table 4. DGVs (µg/L) for imazapic for the protection of freshwater and marine ecosystems

Level of protection (%)	PC value for imazapic (µg/L) [a]
99	0
95	0
90	33
80	550

Appendix D: Modality assessment for imazapic toxicity to aquatic species

A modality assessment was undertaken for imazapic according to the 'weight of evidence' approach specified in Warne et al. (2018).

1) Is there a specific mode of action that could result in taxa-specific sensitivity?

Imazapic acts by inhibiting the acetohydroxy acid synthase (AHAS), an enzyme responsible for catalysing the formation of 3 branched-chain aliphatic amino acids (leucine, valine and isoleucine) within target plants (Tu et al. 2001). Plants die slowly through inhibition of protein synthesis and cell growth due to the limited amino acids available to the plant (Tu et al. 2001).

2) Does the dataset suggest bimodality?

Modality was assessed using a dataset that combined all freshwater and marine data that passed the screening and quality assessment schemes (n = 18). All data that were not chronic 'no effect' or 'negligible effect' values (e.g. EC10, NOEC, NEC) were first converted to this type of data using the methods recommended by Warne et al. (2018). Box and whisker plots for the freshwater and marine data suggested considerable overlap in the data, but with an indication that marine data may be slightly less sensitive (Figure 4). Nevertheless, the pooled dataset was retained for the modality assessment.

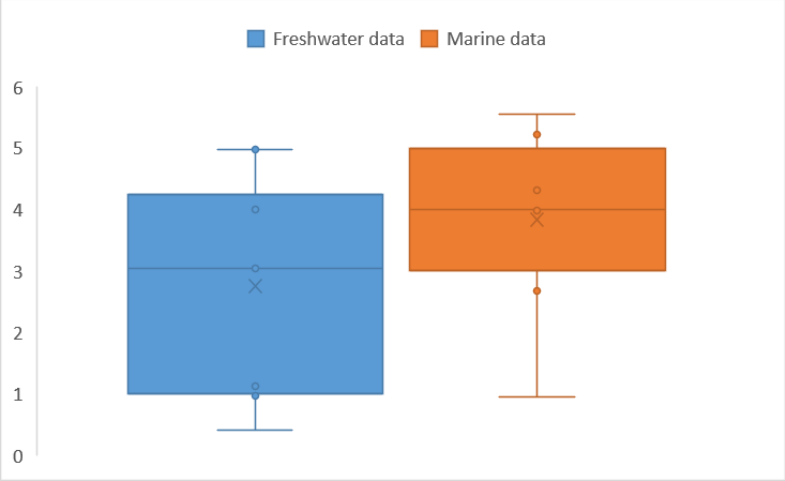


Figure 4. Box plot of the log-transformed ecotoxicity data for freshwater and marine species exposed to imazapic

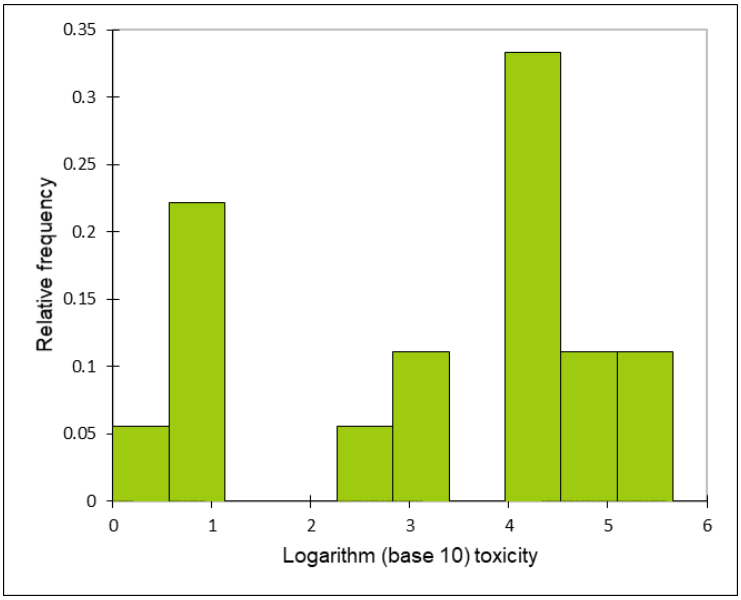


Figure 5. Histogram of the log-transformed ecotoxicity data for fresh and marine species exposed to imazapic

Calculation of the bimodality coefficient (BC) yielded a value of 0.496, which, being below the indicative threshold BC for bimodality of 0.55, suggested the dataset did not exhibit bimodality. A frequency histogram of the dataset (Figure 5) gave some indication that the dataset may not be unimodal.

3) Do data show taxa-specific sensitivity (i.e. through distinct groupings of different taxa types)?

The relative sensitivity of phototrophs and heterotrophs to imazapic was compared using box and whisker plots (Figure 6) and a species sensitivity distribution (Figure 7). These visual analyses indicate that there is not a complete separation in the sensitivity of phototrophs and heterotrophs to imazapic.

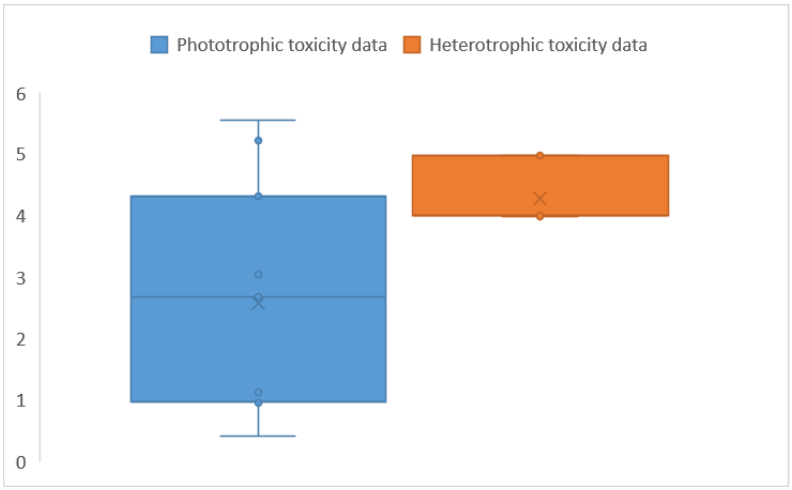


Figure 6. Box and whisker plots of available ecotoxicity data for the different types of fresh and marine organisms exposed to imazapic

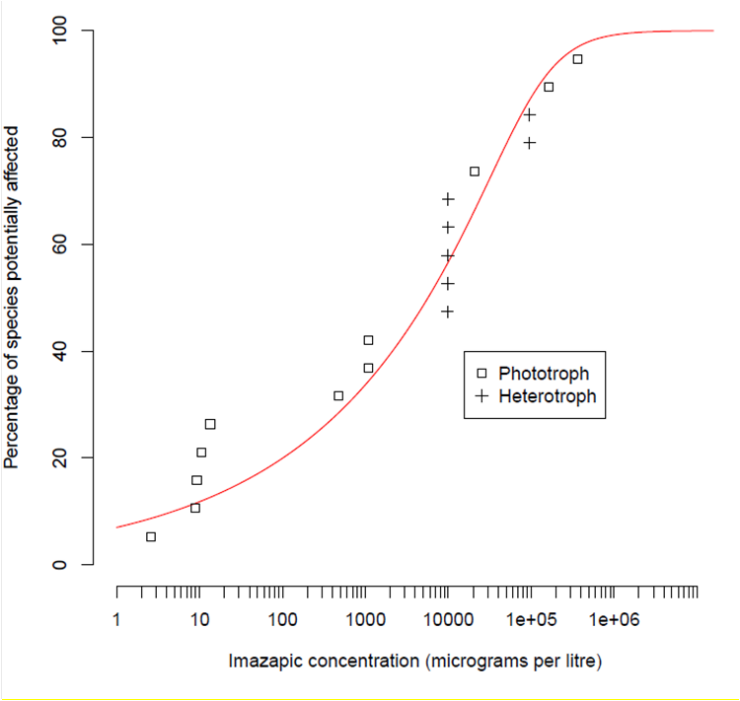


Figure 7. SSD generated by Burrlioz 2.0, using available ecotoxicity data for the different types of fresh and marine organisms exposed to imazapic

4) Is it likely that indications of bi- or multi-modality or distinct clustering of taxa groups are **not** due to artefacts of data selection, small sample size, test procedures, or other reasons unrelated to a specific mode of action?

Given that there are data for 11 phototrophs and 7 heterotrophs it is likely that the distributions are representative, although a bias cannot be ruled out.

The only line of evidence that supports a bi- or multi-modal distribution is based on the mode of action of imazapic. Other lines of evidence suggest the data are unimodal. Overall, this evidence suggests the sensitivity of imazapic is likely to be unimodal. Therefore, ecotoxicity data for all species were used to derive DGVs for imazapic as per Warne et al. (2018).

References

ACVM (2021) Agricultural Compounds and Veterinary Medicines (ACVM) register. Minister for Primary Industries, New Zealand. Accessed: 18 January 2021.

ALA (2017) *Atlas of Living Australia*. Developed by the National Research Infrastructure for Australia (NCRIS) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Available from: https://www.ala.org.au/, Accessed: May 2017.

ANZECC and ARMCANZ (2000) *Australian and New Zealand guidelines for fresh and marine water quality/aquatic ecosystems*, Rationale and background information (Chapter 8). Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australian Capital Territory, Australia, 678pp.

APVMA (Australian Pharmaceutical and Veterinary Medicine Authority) (2020) Public Chemical Registration Information System Search (PubCRIS). Available from: https://portal.apvma.gov.au/pubcris. Accessed: March 2020.

BCPC (2012) *The pesticide manual*. Sixteenth Edition. MacBean C (Ed), British Crop Production Council, Alton, United Kingdom, 1026–1028pp.

BCPC (2018) *Compendium of pesticide common names*. British Crop Protection Council. Available at http://www.bcpcpesticidecompendium.org/. Accessed on 26 March 2024.

Burrlioz 2.0 (2016) Statistical software package to generate trigger values for local conditions within Australia. CSIRO (http://www.csiro.au). [Online] Available from: https://research.csiro.au/software/burrlioz/.

Guiry MD and Guiry GM (2017) *AlgaeBase*. World-wide electronic publication, National University of Ireland, Galway. Available from: http://www.algaebase.org. Accessed: May 2017.

ITIS (2017) Integrated Taxonomic Information System. Available from: https://www.itis.gov/, Accessed: May 2017.

Kessler E and Huss VAR (1992) 'Comparative physiology and biochemistry and taxonomic assignment of the Chlorella (Chlorophyceae) strains of the culture collection of the University of Texas at Austin', *Journal of Phycology*, 28, 550–553.

National Center for Biotechnology Information (2014) PubChem Compound Database; Imazapic CID=91770, Available from: https://pubchem.ncbi.nlm.nih.gov/compound/91770, Accessed 21 November, 2015.

Negri AP, Templeman S, Flores F, van Dam J, Thomas M, McKenzie M, Stapp L, Kaserzon S, Mann RM, Smith R, Warne MStJ and Mueller J (2020) *Ecotoxicology of pesticides on the Great Barrier Reef for guideline development and risk assessments*. Final report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns, 120 pp. Available from: https://nesptropical.edu.au/wp-content/uploads/2020/04/NESP-TWQ-Project-3.1.5-Final-Report.pdf. [Accessed 3 October 2020]

Roskov Y, Abucay L, Orrell T, Nicolson D, Bailly N, Kirk PM, Bourgoin T, DeWalt RE, Decock W, De Wever A, Nieukerken E, Zarucchi J, Penev L, eds. (2017) Species 2000 & ITIS Catalogue of Life, 30th April 2017. Digital resource available from: www.catalogueoflife.org/col. Species 2000: Naturalis, Leiden, the Netherlands. ISSN 2405-8858. Accessed: May 2017.

Stone S (2016) *Development and application of a multispecies microalgal toxicity test to assess the toxicity of herbicides in Northern Queensland catchments*. University of Wollongong, Australia.

Stone S, Adams MS, Stauber JL, Warne MStJ, and Jolley D. 2021. 'Toxicity of herbicide mixtures to tropical freshwater microalgae using a multispecies test', *Environmental Toxicology and Chemistry,* 40(2), 473 – 486. DOI: 10.1016/j.envpol.2019.03.058.

Stone S, Adams MS, Stauber JL, Warne MStJ, and Jolley D. 2019. 'Application of a multispecies toxicity test with freshwater tropical microalgae to assess the toxicity of herbicides in Northern Queensland catchments', *Environmental Pollution,* 250, 97 – 106. DOI: 10.1002/etc.4932.

Sunderam RIM, Warne MStJ, Chapman JC, Pablo F, Hawkins J, Rose RM and Patra RW (2000) The ANZECC and ARMCANZ Water Quality Guideline Database for Toxicants. Supplied as part of a CD-ROM in the ANZECC and ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality.

Thomas MC, Flores F, Kaserzon S, Fisher R and Negri AP (2020) 'Toxicity of ten herbicides to the tropical marine microalgae', *Rhodomonas* salina, Scientific Reports

Tu M, Hurd C and Randall JM (2001) *Weed control methods handbook: Tools and techniques for use in natural areas*. The Nature Conservancy, Virginia, United States of America, 135–141pp. Available from: http://www.invasive.org/gist/products/handbook/methods-handbook.pdf. Accessed 26–28 October 2015.

University of Hertfordshire (2013) The Pesticide Properties Data Base (PPDB) Developed by the Agriculture & Environment Research Unit (AERU), University of Hertfordshire, 2006–2013. Available from: http://sitem.herts.ac.uk/aeru/ppdb/en/Reports/27.htm. Accessed 13 May 2016.

USEPA (2015) *ECOTOX Knowledgebase: ECOTOXicology Database System Version 4.0* [website], United States Environmental Protection Agency. Accessed: May–September, 2015.

Warne MStJ, Batley GE, van Dam RA, Chapman JC, Fox DR, Hickey CW & Stauber JL (2018) 'Revised method for deriving Australian and New Zealand water quality guideline values for toxicants – update of 2015 version', Prepared for the revision of the *Australian and New Zealand guidelines for fresh and marine water quality*. Australian and New Zealand Governments and Australian state and territory governments, Canberra, 48 pp.

Warne MStJ, Westbury A-M and Sunderam R (1998) 'A compilation of toxicity data for chemicals to Australasian aquatic species. Part 1: Pesticides', *Australasian Journal of Ecotoxicology*, 4, 93–144.

WoRMS Editorial Board (2017) World Register of Marine Species. Available from: http://www.marinespecies.org at VLIZ, Accessed: May 2017. doi:10.14284/170.