**Supplementary Materials for:**

Challenges and future prospects for developing Ca and Mg water quality guidelines: A meta-analysis

by

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**Supporting Data S1—**Please note that a separate .xlsx file accompanies this document (Bogart et al\_Supporting Data S1\_Supplementary materials\_Final.xlsx), which contains all datasets used and complete lists of articles collected, preliminarily screened, classified, and rejected.

**Table S1.** Summary data for regions and the province of British Columbia used to calculate and evaluate WQC by different approaches. These data represent those shown in Figure 1 of the main text, for stations that reported both Ca and Mg concentrations (samples were removed if Ca or Mg were not detected).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | # Stations | # Samples | Water Hardness | | | | | | Ca:Mg Ratio | | | | | |
| Min | Max | Mean | Standard Deviation | 10th Percentile | 90th Percentile | Min | Max | Mean | Standard Deviation | 10th Percentile | 90th Percentile |
| REGION |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Cariboo | 99 | 1940 | 5.2 | 569 | 97.6 | 105 | 28.9 | 181 | 0.1 | 15.6 | 4.7 | 3.3 | 1.5 | 8.9 |
| Kootenay | 40 | 664 | 7.3 | 305 | 85.7 | 60.6 | 24.4 | 166 | 2.6 | 17.5 | 5.8 | 2.9 | 3.2 | 9.0 |
| Lower Mainland | 30 | 210 | 5.2 | 264 | 66.1 | 63.7 | 6.5 | 153 | 2.0 | 27.9 | 7.0 | 6.2 | 2.2 | 17.2 |
| Okanagan | 39 | 583 | 17.1 | 636 | 136 | 131 | 25.5 | 260 | 0.6 | 15.9 | 5.6 | 3.4 | 1.9 | 9.8 |
| Omineca | 44 | 270 | 20.8 | 343 | 130 | 69.6 | 45.0 | 206 | 1.8 | 10.1 | 3.6 | 1.5 | 2.2 | 4.9 |
| Peace | 4 | 14 | 34.8 | 95.3 | 65.9 | 32.2 | 36.8 | 94.3 | 2.0 | 5.0 | 3.5 | 1.7 | 2.0 | 5.0 |
| Skeena | 142 | 850 | 2.0 | 217 | 42.4 | 37.6 | 6.4 | 88.3 | 1.2 | 31.7 | 6.2 | 4.9 | 2.7 | 11.8 |
| Southern Interior | 24 | 378 | 15.2 | 781 | 104 | 166.5 | 17.7 | 181 | 1.7 | 36.8 | 8.6 | 8.3 | 2.0 | 17.6 |
| Vancouver Island | 124 | 2063 | 4.4 | 162 | 27.4 | 27.3 | 7.4 | 65.0 | 2.5 | 24.2 | 6.6 | 3.8 | 3.0 | 10.8 |
| PROVINCE | 546 | 6972 | 2.0 | 781 | 70.1 | 84.7 | 9.7 | 158 | 0.1 | 36.8 | 5.9 | 4.4 | 2.3 | 10.2 |

**Table S2.** Endpoints used for SSDs in Figure 4a, b including acute (A) and/or chronic (C) data, respectively.

|  |  |  |
| --- | --- | --- |
| **Species** | **Endpoint** | **Water Hardness (mg/L as CaCO3)** |
| **Fish** |  |  |
| *Mogurnda mogurnda* | 96-h LC05 Mortality (A) | 50 |
| *Rhamdia quelen* | 84-h LOEC Mortality (A) | 66 |
| *Pimephales promelas* | 96-h LC50 Mortality (A) | 2263 |
| **Invertebrates** |  |  |
| *Hydra viridissima* | 96-h IC10 Population growth (C) | 8 |
| *Amerianna cumingi* | 96-h IC10 Reproduction (A) | 22\* |
| *Ceriodaphnia dubia* | 48-h LC50 Mortality (A) | 105\* |
| *Moinodaphnia macleayi* | 3-brood IC10 Reproduction (C) | 149 |
| *Daphnia magna* | 3-week IC16 Reproduction (C) | 337\* |
| **Plants/Algae** |  |  |
| *Lemna aequinoctialis* | 96-h IC10 Growth (C) | 9 |
| *Chlorella* sp. | 72-h IC10 Growth (C) | 178 |

Notes: \*Geometric mean, n = 2

**Table S3.** Endpoints used for SSDs in Figure 4c, d (constrained by BC resident species and/or the effect data points where Ca:Mg ratio >1, respectively). Taxon. group (taxonomic group): P – plant/algae, I – invertebrate, F – fish. A - acute; C - chronic.

|  |  |  |
| --- | --- | --- |
| **SSD**  ***Species* (Taxon. group)** | **Endpoint** | **Water Hardness (mg/L as CaCO3)** |
| **SSD constrained by BC resident species** | | |
| *Ceriodaphnia dubia* (I) | 48-h LC50 Mortality (A) | 105\* |
| *Chlorella* sp. (P) | 72-h IC10 Growth (C) | 178 |
| *Daphnia magna* (I) | 3-week IC16 Reproduction (C) | 337\* |
| *Pimephales promelas* (F) | 96-h LC50 Mortality (A) | 2263 |
| **SSD constrained by BC resident species effects having Ca:Mg ratio >1** | | |
| *Daphnia magna* (I) | 3-week IC16 Reproduction (C) | 337\* |
| *Ceriodaphnia dubia* (I) | 48-h LC50 Mortality (A) | 1457 |
| *Pimephales promelas* (F) | 96-h LC50 Mortality (A) | 4283 |

Notes: \*Geometric mean, n = 2

**Table S4.** All resultant WQG for water hardness and Ca:Mg ratio, relative to background condition at provincial and regional scales (see main text for details). WQG were inside (I), outside (O), or partially overlapped (O-I) the background condition range.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **Background Condition** | | | **Site WQG and Evaluation Results** | | | |
| **n** | **Mean** | **Range** | **All Data** | | **BC Resident spp.** | |
| **WQGa** | **I/O** | **WQGb** | **I/O** |
| **WATER HARDNESS (mg/L as CaCO3)** | | | |  |  |  |  |
| REGIONAL |  |  |  |  |  |  |  |
| Cariboo | 99 | 97.6 | 5.2-569 | 174 | I | 406 | I |
| Kootenay | 40 | 85.7 | 7.3-305 | 153 | I | 357 | O |
| Lower Mainland | 30 | 66.1 | 5.2-264 | 118 | I | 275 | O |
| Okanagan | 39 | 136 | 17.1-636 | 242 | I | 566 | I |
| Omineca | 44 | 130 | 20.8-343 | 231 | I | 541 | O |
| Peace | 4 | 65.9 | 34.8-95.3 | 117 | O | 274 | O |
| Skeena | 142 | 42.4 | 2.0-217 | 75 | I | 176 | I |
| Central Interior | 24 | 104 | 15.2-781 | 185 | I | 433 | I |
| Vancouver Island | 124 | 27.4 | 4.4-162 | 49 | I | 114 | I |
| PROVINCIAL | 546 | 70.1 | 2.0-781 | 125 | I | 292 | I |
| **Ca:Mg RATIO** |  |  |  |  |  |  |  |
| REGIONAL |  |  |  |  |  |  |  |
| Cariboo | 99 | 4.7 | 0.1-15.6 | 2.1-3.8 | I | 1.7-3.8 | I |
| Kootenay | 40 | 5.8 | 2.6-17.5 | 2.6-4.6 | I | 2.1-4.6 | O-I |
| Lower Mainland | 30 | 7.0 | 2.0-27.9 | 3.1-5.6 | I | 2.5-5.6 | I |
| Okanagan | 39 | 5.6 | 0.6-15.9 | 2.5-4.5 | I | 2.0-4.5 | I |
| Omineca | 44 | 3.6 | 1.8-10.1 | 1.6-2.9 | O-I | 1.3-2.9 | O-I |
| Peace | 4 | 3.5 | 2.0-5.0 | 1.5-2.8 | O-I | 1.3-2.8 | O-I |
| Skeena | 142 | 6.2 | 1.2-31.7 | 2.7-5.0 | I | 2.2-5.0 | I |
| Central Interior | 24 | 8.6 | 1.7-36.8 | 3.8-6.9 | I | 3.1-6.9 | I |
| Vancouver Island | 124 | 6.6 | 2.5-24.2 | 2.9-5.3 | I | 2.4-5.3 | O-I |
| PROVINCIAL | 546 | 5.9 | 0.1-36.8 | 2.6-4.7 | I | 2.1-4.7 | I |

Notes: aWQG was a 78% increase in hardness; WQG for Ca:Mg ratio was a 56% decrease and a 20% increase

bWQG was a 316% increase in hardness; WQG for Ca:Mg ratio was a 64% decrease and a 20% increase.

**List S1.** Additional abiotic variables that were required for collected articles to be considered secondary sources, not already outlined in the main text:

|  |
| --- |
| * Full reference |
| * Identity of the chemical/compound tested |
| * Organism name (common or Latin) |
| * Life stage (e.g., egg, embryo, larva, tadpole, alevin, juvenile, adult) |
| * Toxicity test duration, endpoint, and effect |
| * Endpoint type (acute, chronic) |

Additional classification criteria not presented in the main article text (i.e. they were unmodified from the source protocol) are the following: Test conditions had to be reported where flow through tests were considered primary, static renewal tests as primary/secondary, and those with unspecified conditions were deemed unacceptable. Articles were considered as primary sources if the toxicity test method and analytical techniques used were based on standard protocols or published procedures, as secondary sources if novel methods/techniques were used but were fully described, and else were considered as unacceptable. The statistics or method of calculating the effect concentrations had to be appropriate for the data/study design for the article to be considered as primary or secondary.

**Calcs S1.** Example calculation showing application of the 2-component, background condition approach to an example dataset in four steps.

**Step 1)** The exemplar (fictitious) dataset used in the below example calculation is the following:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Species | Effect endpoint | Effect concentration: Water hardness (mg/L as CaCO3) | Effect concentration: Ca:Mg ratio | Background: Water hardness (mg/L as CaCO3) | Background: Ca:Mg ratio |
| X | IC10 reproduction | 350 | 32 | 12 | 3.2 |
| X | IC50 growth | 100 | 0.01 | 0.9 | 6.1 |
| Y | IC20 growth | 1658 | 45 | 234 | 26 |
| Y | IC20 reproduction | 4 | 0.23 | 0.8 | 0.02 |
| Z | LC50 mortality | 27500 | 25 | 175 | 52 |

**Step 2)** The percent change from background condition is calculated for all effect endpoints for both water hardness and the Ca:Mg ratio, following Equation 2.2 of the article, where (using the above Ca:Mg ratio data for species Z as an example):

(effect concentration - background concentration)

Percent change = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ X 100 (2.2)

from background (%) background concentration

= (25 - 52) / 52 X 100

= -51.9 %

That is, without considering the contribution of water hardness to the effect, the lethal effect in species Z was due to a 51.9% decrease in the Ca:Mg ratio.

**Step 3)** After all of the remaining percent change from background calculations have been completed for all endpoints (as below), the smallest increase in water hardness as well as the smallest increase and the smallest decrease in the Ca:Mg ratio causing an effect are identified (here in bold face font):

|  |  |  |  |
| --- | --- | --- | --- |
| Species | Effect endpoint | Percent change from background:  Water hardness (%) | Percent change from background: Ca:Mg ratio (%) |
| X | IC10 reproduction | 2817 | 900 |
| X | IC50 growth | 11011 | -99.8 |
| Y | IC20 growth | 609 | **73.1** |
| Y | IC20 reproduction | **400** | 1050 |
| Z | LC50 mortality | 15614 | **-51.9** |

These values in bold represent the threshold for effects and they are used to indicate the maximum percent change permitted (i.e., percent change WQG).

**Step 4)** The percent change WQG are then applied to site-specific background water hardness and Ca:Mg ratio measurements to calculate local WQG values, using Equations 2.3 and 2.4 in the main text as:

Maximum INCREASE = (Percent change WQG / 100 X Hss or Rss) + Hss or Rss (2.3)

Maximum DECREASE = Rss - ( | Percent change WQG | / 100 X Rss) (2.4)

where Hss is the mean site-specific water hardness in mg/L as CaCO3, and Rss is the mean site-specific Ca:Mg ratio (mass based).

For example, if the background conditions at the exemplar field site of management interest are a mean water hardness (Hss) of 125 mg/L as CaCO3 and a Ca:Mg ratio (Rss) of 4.1, then the local WQG values are the following:

***Site-specific WQG for WATER HARDNESS:***

Maximum INCREASE = (400 / 100 X 125) + 125

= 625 mg/L as CaCO3 water hardness

***Site-specific WQG for Ca:Mg RATIO:***

Maximum INCREASE = (73.1 / 100 X 4.1) + 4.1

= Ca:Mg of 7.1

Maximum DECREASE = 4.1 - ( | -51.9 | / 100 X 4.1)

= Ca:Mg of 2.0