Neonicotinoids in California's Surface Waters

A Preliminary Review of Potential Risk to Aquatic Invertebrates

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Neonicotinoids, a relatively new class of insecticides, are the most widely used insecticides in the world. They are applied to a wide range of agricultural crops as well as in urban settings. Although neonicotinoids are less acutely toxic to mammals and other vertebrates than some older insecticides they have replaced, they are highly toxic to many beneficial invertebrates. Of the neonicotinoids, the nitroguanidine group (clothianidin, dinotefuran, imidacloprid, and thiamethoxam) are the most toxic and longest lived.

Recent reviews and reports have drawn more attention to the risks these insecticides pose to water quality and their potential effects on aquatic systems.[i] While there is still uncertainty, independent research and regulatory evaluations from other countries suggest that the US Environmental Protection Agency's (EPA) invertebrate aquatic life benchmarks may be substantially higher than levels of imidacloprid and other neonicotinoids in surface water that could cause harm to aquatic invertebrates and the systems they support.[ii] Aquatic invertebrates are essential to freshwater ecosystems and beyond. These invertebrates are preyed on by fish, birds, and other species; perform ecological services like shredding and nutrient retention; maintain biodiversity; and are important for human recreation, among other ecosystem functions.[iii] Effects on aquatic invertebrates could also indirectly cause harm to insectivorous fish and bird species, including protected species.

This white paper reviews current research on the effects of nitroguanidine neonicotinoids on aquatic invertebrates and compares the toxicological endpoints identified in those studies with California's surface water monitoring data. Since most aquatic toxicology and monitoring data is available for imidacloprid, our analysis focuses on this compound, but it also raises questions about the other nitroguanidine neonicotinoids. Sampling results show that imidacloprid contamination is widespread and often detected at levels that can cause harms to foundational invertebrate species. From our initial review, it appears that the current aquatic life benchmarks for imidacloprid are under-protective. We are concerned that the levels of imidacloprid currently found in California's waters could harm aquatic species and potentially cause cascading effects up the food chain.

Xerces has brought this information to California's Department of Pesticide Regulation (CDPR) to request a timeline for a review of aquatic invertebrate toxicity data, potentially leading to the development of interim imidacloprid acute and chronic benchmarks to protect aquatic invertebrates. We also recommend that CDPR review the other nitroguanidine neonicotinoids to establish appropriate benchmarks that protect aquatic invertebrates. While the majority of available data is about imidacloprid, our findings raise questions about the effects of other nitroguanidine neonicotinoids as well.

Pesticide Sales and Use Reporting Data

The use of nitroguanidine neonicotinoids in California has climbed since their introduction, both in terms of number of applications and pounds applied. Pesticide use reports are collected by CDPR from agricultural and professional applicators across the state.[iv] This data does not include figures for seed coatings (used on California crops including cotton, corn, and wheat) or non-professional ornamental and urban applications, so it provides an underestimate of actual use.[v] The resulting data set can provide use trends, such as the rise in imidacloprid use over the last twenty years from 5,179 pounds in 1994 to 373,734 pounds in 2014 (Figure 1). The number of applications for clothianidin, thiamethoxam, and dinotefuran are all trending upward as well in recent years.

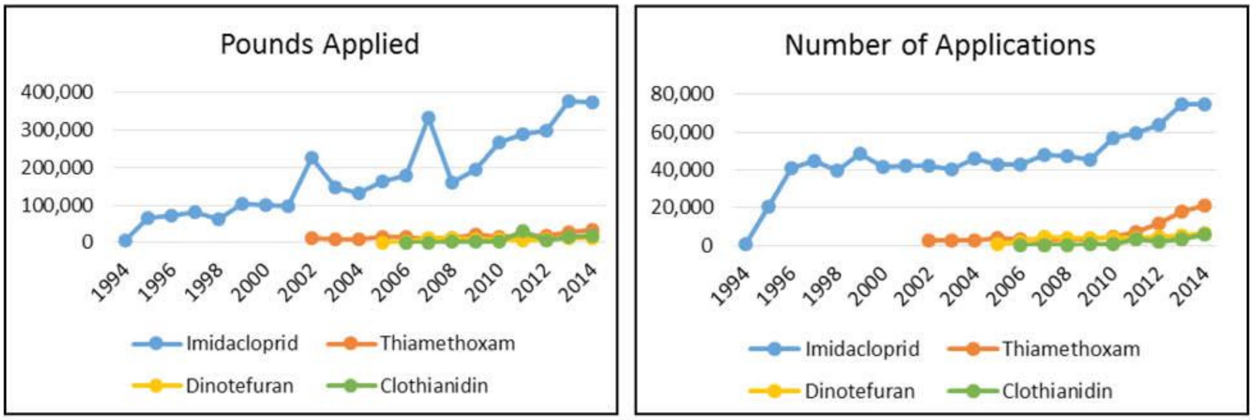

Figure 1: Pounds applied and number of applications of nitroguanidine neonicotinoids in California. This data does not include the planting of seed coated with neonicotinoids or non-professional ornamental and urban applications. The 2002 and 2007 outliers in imidacloprid pounds applied are likely data reporting errors.

California's use reporting data is currently only available up to 2014. Since then permitted uses of nitroguanidine neonicotinoids have expanded (for example, clothianidin has been approved for rice). To better understand possible increases in use since 2014, we reviewed California's pesticide sales data.[vi] Clothianidin sales jumped from 20,916 pounds in 2014 to 119,731 pounds in 2015, a 472% increase in a single year. Sales of the other nitroguanidines also increased notably between 2014 and 2015. Imidacloprid sales rose from 542,262 pounds in to 791,125 pounds (a 46% increase); thiamethoxam from 33,179 pounds to 53,381 pounds (a 61% increase); and dinotefuran from 13,170 pounds to 75,052 pounds (a 470% increase). The continued rise in neonicotinoid sales and use compels CDPR to address the impacts of imidacloprid on aquatic systems, and to review the effects of the other nitroguanidine neonicotinoids as their use increases.

California Surface Water Detections

California's water monitoring records provide valuable information on neonicotinoid water contamination. Imidacloprid monitoring data is available for 790 surface water samples taken at 132 sites from January 2010 to October 2015.[vii] Of those 132 sites throughout the state, 72 (55%) had at least one imidacloprid detection above the level of quantification (typically 0.05 µg/L).[viii] In the 790 samples, imidacloprid was detected 468 (59%) times, up to a maximum of 12.7 µg/L.[ix]

The EPA acute benchmark of 35 µg/L was not exceeded in any sample, but toxicological studies suggest that acute exposures could impact sensitive species well below this level, at concentrations detected in California surface water. Throughout this report detection frequencies and averages will exclude samples where imidacloprid was not detected. The average imidacloprid level among detections was 0.643 µg/L, which can cause sublethal effects in many aquatic invertebrates, especially sensitive groups of species like mayflies.[x] Imidacloprid was detected above the EPA chronic invertebrate benchmark of 1.05 µg/L in 65 (14%) instances.[xi] At or below this level, effects on aquatic species include death, downstream drift, reductions in larval emergence, reproductive impacts, and alterations in feeding behavior.

The prevalence of imidacloprid and other neonicotinoids in surface water samples throughout the state suggests that these compounds could be routinely entering aquatic ecosystems from a variety of sources. Detection levels are sufficient to raise concern for aquatic invertebrates and the ecosystems that depend on them.

Frequently-monitored areas signal risks

Imidacloprid detections are clustered throughout the state, and are particularly common in some agricultural areas like Santa Maria, the Salinas Valley, and the Imperial Valley that have been monitored more frequently (Figure 2). Of note, imidacloprid was detected in 91% (71 of 78) of samples in the Santa Maria area; 82% (178 of 218) of samples in the Salinas Valley area; and 72% (31 of 43) of samples in the Imperial Valley area.[xii] The presence of clustered areas of imidacloprid detections suggests that discrete areas may be particularly at risk. Therefore, throughout this report, we present detections from the Santa Maria area to provide context for detection levels in an agricultural area that was well-studied and where imidacloprid was frequently present. Examining discrete areas separately from the entire state should provide a more representative understanding of surface water contamination in areas where imidacloprid use is high and monitoring data is available. Analyzing the data separately also reduces the potential that risk would be obscured by combining data from high-detection areas with data from locations with infrequent and/or low level detections.

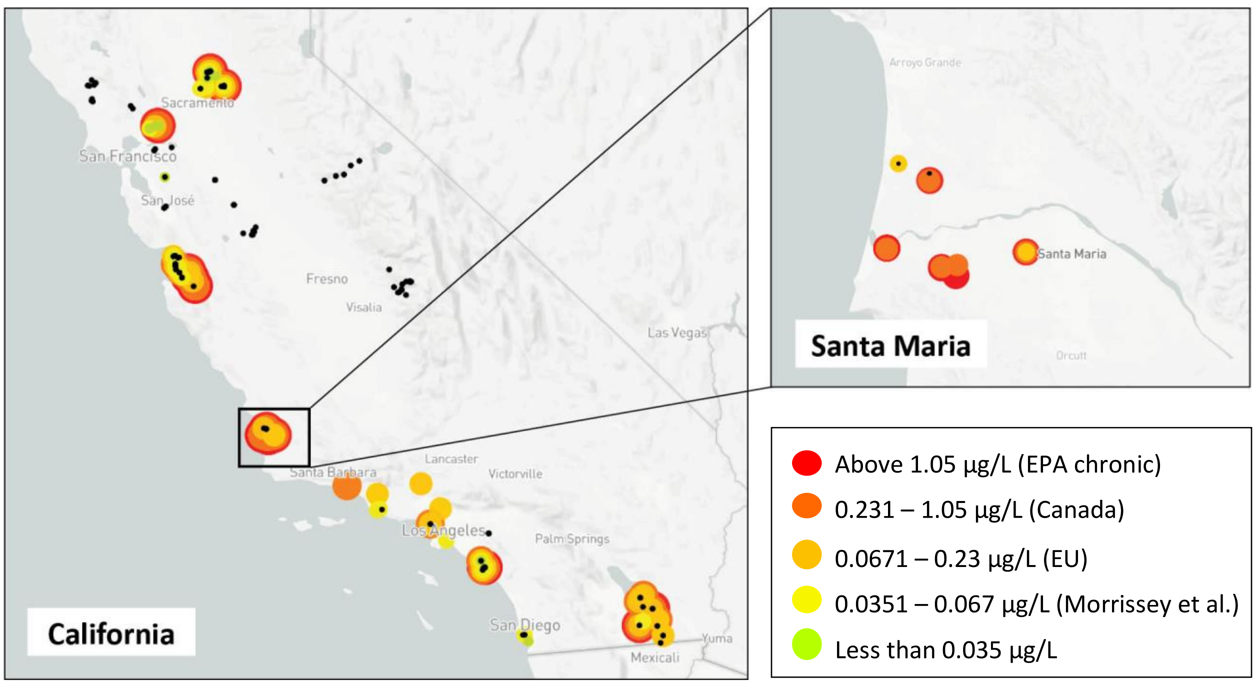

Figure 2: Imidacloprid detections from CDPR monitoring data. All California samples are mapped on the left, with a close-up of Santa Maria area samples on the right. Colors correspond to water quality guidelines for the US and other jurisdictions, black dots are samples where imidacloprid was not detected. No imidacloprid samples were taken north of the Sacramento region.

Imidacloprid in urban waters

Along with agricultural regions, imidacloprid has frequently been found in urban areas, particularly in the Santa Barbara, Los Angeles, and Sacramento regions (Figure 2). There are several potential sources of neonicotinoids in urban waterways, including landscaping, outdoor building products, and flea and tick control products used on pets.[xiii] Data on urban neonicotinoid use is limited because there are no reporting requirements for independent non-professional applications.

Neonicotinoids used in urban areas can move into both storm and sanitary drains. Recent research has shown that neonicotinoids may not be removed during standard wastewater treatment, so they can be transferred to water bodies that receive effluent.[xiv] Urban sampling in the Sacramento area and Orange County from 2008–2011 found that imidacloprid was the second-most commonly detected insecticide, with a maximum of 0.67 µg/L.[xv] The city of Santa Barbara also conducted sampling for neonicotinoids and found imidacloprid in each wet-weather sample.[xvi] While the highest detection in Santa Barbara was 0.076 µg/L, the frequent presence of imidacloprid in urban waterways is concerning.[xvii]

Imidacloprid Toxicity to Aquatic Invertebrates

Imidacloprid toxicity studies have been conducted with a range of experimental designs, concentrations, and species. Experiments with both technical grade imidacloprid and formulated products containing imidacloprid have, in some cases, shown additional toxicity from formulations.[1,xviii] Furthermore, there is wide variation in the sensitivity of different invertebrates between and within taxa. The commonly-used test species for pesticide ecotoxicity studies, *Daphnia magna*, is orders of magnitude less sensitive to imidacloprid than many other invertebrates, particularly Ephemeroptera and Trichoptera species. The insensitivity of *D. magna* combined with the wide-ranging sensitivity of other species adds complexity to setting aquatic life benchmarks that are sufficiently protective. Independent testing completed since imidacloprid's registration has identified acute and chronic sensitivity in certain species at concentrations well below the aquatic life benchmarks. The range of concerning sublethal effects that have been identified could lead to mortality in individuals and population-level impacts. These effects include but are not limited to reproduction inhibition, impaired feeding, and downstream drift. Due to the nature of neonicotinoid binding, it is has been suggested that invertebrates are subject to cumulative and delayed effects from exposure.[xix] Both lethal and sublethal effects impact the structure and ecological functions of aquatic invertebrate communities, with far-reaching consequences for other species that depend on healthy freshwater ecosystems.[xx] Each experiment provides discrete information, but taken together they provide strong evidence that imidacloprid is toxic to freshwater aquatic invertebrates at levels below current EPA aquatic life benchmarks.

[1] Throughout this report, we note if a study used formulated products. Tisler et al. 2009.; *Daphnia magna* 21-day LOLC 40 mg/L for imidacloprid versus 10 mg/L for Confidor (Jemec et al. 2007); *Hyalella azteca* 96h LC_{50} 65.43 µg/L for imidacloprid versus 17.44 µg/L for Admire (Stoughton et al. 2008).

Acute Risks

Our literature review of independent imidacloprid toxicity studies revealed wide-ranging sensitivity among invertebrates (see Appendix A for additional detail on each study). Researchers have defined toxicological endpoints for a range of species, some of which are displayed in Table 1. The commonly used pesticide test species *Daphnia magna* is significantly less sensitive to imidacloprid (48-hour EC_{50} for immobility of 56,500 µg/L[xxi]) than many other species (for example the 48-hour LC_{50} for the mayfly *Baetis rhodani* is 8.49 µg/L[xxii]). In particular, species from the key groups Ephemeroptera and Trichoptera are particularly at risk.

The EPA acute freshwater invertebrate benchmark is set at 35 µg/L, a level that was not seen in Californian monitoring. However, LC_{50}s for certain sensitive species range from 0.65 to 8.49 µg/L (Table 1), suggesting the acute limit may be under-protective. California surface water samples have detected imidacloprid in or above this range in 124 (26%) of 468 detections from 2010 to 2015.[xxiii] Aquatic life benchmarks should be reconsidered given the sensitivity of certain species.

Table 1: Imidacloprid Toxicity for Selected Sensitive and Test Species (µg/L)

	Endpoint	Value (µg/L)	Citation
Lethal Endpoint			
Baetis rhodani (mayfly)	48h LC_{50}	8.49	Beketov and Liess 2008
Chironomus dilutus (midge)	14d LC_{50}	1.52	Cavallaro et al. 2016
Chironomus tentans (midge)	96h LC_{50}	5.75	Stoughton et al. 2008
Epeorus longimanus (mayfly)	24h LC_{50}	2.1*	Alexander et al. 2007
Epeorus longimanus (mayfly)	96h LC_{50}	0.65*	Alexander et al. 2008
Sublethal Endpoints			
Baetis rhodani (mayfly)	Downstream drift (48h)	1	Beketov and Liess 2008
Chironomus dilutus (midge)	40d EC_{50} (emergence)	0.39	Cavallaro et al. 2016
Daphnia magna (daphnid)	48h EC_{50} (immobility)	56,500	Tisler et al. 2009
Daphnia magna (daphnid)	21d NOEC (immobility)	1,250	Tisler et al. 2009

*Testing done with formulated product, Admire (imidacloprid).

Community structure impacts

Lethality from imidacloprid contamination can impact the community structure in aquatic systems by triggering declines in sensitive species while leaving more tolerant species unaffected. In an experiment designed to simulate the effects of spray drift on lentic communities, researchers applied imidacloprid on sunny days when photolysis was expected to play a role in degradation. When the time-weighted average imidacloprid level was 1 µg/L from three weekly pulses, Ephemeroptera declined and certain species were absent.[xxiv] Surface water samples in California equaled or exceeded 1 µg/L in 75 (16%) detections and 30 (42%) Santa Maria detections.[xxv]

Chironomidae species declined significantly in trials with a time-weighted average of 5.2 µg/L of imidacloprid, a level exceeded in 8 (2%) California detections and 4 (6%) Santa Maria detections.[xxvi]

In a separate experiment, imidacloprid applied to stream mesocosms as formulated Admire caused reductions in the total benthic insect population from three weekly 24-hour pulses of 17.60 µg/L (the time-weighted average concentration was not reported, but it would have been significantly lower that the level applied).[xxvii] The researchers saw a 69% decline in Ephemeroptera, Plecoptera, and Trichoptera (EPT) species pooled together and a 75% decline in Oligochaete density.[xxviii] EPT species abundance is commonly used to indicate water quality. Decomposition of leaf matter in coarse bags in the mesocosm also declined significantly, signaling a reduction in ecological functions.[xxix] Because this study reported only the concentration of the pulse dose, it cannot be directly compared to California surface water detections. Shifts in community structure as more sensitive species decline can affect freshwater aquatic ecosystems, altering trophic relationships and functional roles.

Chronic Sublethal Risks

Beyond the lethal effects of imidacloprid on many species, there are various sublethal effects that can impact aquatic invertebrates. The sublethal effects that have been observed include changes in feeding rates, change in individual size, downstream drift, impeded emergence, and declines in reproductive success. Each of these effects has consequences for individual fitness, and thus the resiliency of the individual and how well it can fulfill its ecological role. Shifts in individual health can manifest as changes at the community level that potentially leave more sensitive species behind as tolerant species outcompete them or survive the exposures. Adding uncertainty to assessing chronic risks, research suggests that neonicotinoids can bind irreversibly to receptors, so repeated low doses have the potential to cause harm and some effects can persist in individuals even after the contamination has ceased.[xxx] This preliminary analysis could not determine the potential scope of chronic exposure from available California water monitoring data. Yet, the frequency of detections in the dataset demonstrates a need to further explore chronic risks in order to avoid unreasonable harm.

Reproductive impacts and larval survival

Neonicotinoids can reduce the reproductive fitness of aquatic invertebrates and thus impact the success of their populations. The number of brood-carrying females declined in a long-term chronic study of *Gammarus roeseli*, indicating the potential for delayed reproductive effects from pulsed exposure.[2,xxxi] Adult emergence can also be impacted in certain species. A stream mesocosm study identified *Neureclipsis* spp. caddisflies as the most sensitive to three 12-hour

[2] Brood-carrying females declined in the last 3 weeks of a 70-day course of exposure to 12 µg/L weekly 12-hour pulses of imidacloprid.

pulses of 12 µg/L of imidacloprid, and also saw significant reductions in emergence among mayflies.[xxxii] Dipteran and ephemerid larvae declined more after the second and third imidacloprid pulses, indicating that they were unable to detoxify the compound in the seven days between pulses.[xxxiii] Each of these studies used 12-hour weekly pulses of 12 µg/L of imidacloprid that was then flushed from the system.[xxxiv] These results cannot be directly compared to Californian surface water monitoring because the time-weighted average was not reported (which would be lower and within the realm of California detections), but the maximum detection in the state was 12.7 µg/L, suggesting that while uncommon, these levels could be present in the environment.

Other reproductive effects can include impacts on emergence success and sex ratios. An experiment with chronic exposures to Admire (imidacloprid) found reduced *Epeorus* spp. and *Baetis* spp. mayfly nymph density (20 days of 0.8 µg/L) and *Epeorus* spp. male emergence (no male emergence in 0.25 and 0.8 µg/L), as well as reductions in male thorax lengths for emerged *Epeorus* from all treatment groups.[xxxv] California surface water exceeded 0.25 µg/L in 239 (51%) detections [65 (92%) in Santa Maria], and 0.8 µg/L in 98 (21%) detections [38 (54%) in Santa Maria] (Figure 3).[xxxvi] Over time, reductions in mating success and emergence of aquatic invertebrates could negatively impact their populations, as maintaining reproductive fitness is crucial to healthy populations.

Alterations in feeding behavior

Imidacloprid can also directly impact individual behavior in sublethal doses, with lasting effects that are not captured in short-term acute tests. Individual *Gammarus pulex* feeding rates that were not affected during a four-day constant exposure to imidacloprid (0.81, 2.7, and 9.0 µg/L) increased after the exposure ended, suggesting that compensational feeding could be a response to sublethal contamination.[xxxvii] Imidacloprid exceeded 0.81 µg/L in 98 (21%) California detections and in 38 (54%) Santa Maria detections. In experiments with *Epeorus longimanus* mayflies using the formulated product Admire (imidacloprid), researchers followed the treatment groups for four days after the 24-hour exposure, and noted that only the 0.1 µg/L group fully recovered to control feeding levels.[3,xxxviii] This suggests there may be ongoing sublethal effects after exposures that can be detected but are routinely missed in testing. Many toxicological studies do not follow sublethal effects after the exposure period ends, so researchers and regulators may not have crucial information about an individual's ability to recover. Furthermore, alterations in feeding behavior can cause broader ecosystem effects such as changing the rates of leaf litter breakdown that are crucial to aquatic ecology.

Incidence of downstream drift

Downstream drift of aquatic invertebrates is a common response to disturbance. While drift can be protective at an organism level, at a community level it can disrupt population structure and

[3] The other groups that did not recover to normal rates were 0.5, 1, 5, and 10 µg/L (all the mayflies in the 10 µg/L treatments died).

ecological functions. Experiments with mayflies, amphipods, and blackflies showed that imidacloprid, thiacloprid, and acetamiprid all triggered downstream drift within two hours of exposure.[4,xxxix] The short time frame after exposure suggests that pulses of contaminants in the field may be triggering drift. Imidacloprid triggered drift of *Baetis rhodani* mayflies at 1 µg/L, a level equaled or exceeded in 75 (16%) California detections and 30 (42%) Santa Maria detections (Figure 3).[xl] Another mesocosm experiment saw passive drift in Ephemeroptera and Orthocladiinae from three 12-hour pulses of 12 µg/L of imidacloprid that in some cases lasted after the imidacloprid was flushed out of the system.[xli] These studies suggest that drift has the potential to interrupt functional communities of invertebrates even after imidacloprid concentrations have declined.

<u>Enhanced toxicity from other stressors</u>

Environmental stressors such as food quality and temperature can impact the toxicity of compounds. Researchers provided *Daphnia magna* with algae of varying phosphorous content to assess the effect of lower food quality, finding that individuals consuming the lowest quality food also were affected by the lowest concentrations of imidacloprid.[xlii] While the doses were high and less field-relevant (mortality EC_{10} of 60 µg/L after 7 days of exposure), these results are worth noting here because they show that variable resource conditions in the natural world can affect the toxicity of compounds, and particularly that resource-stressed individuals may be more susceptible to pesticides. A study with *Isonychia bicolor* mayflies examined the effects of temperature on imidacloprid toxicity and found that increasing water temperature decreased the amount of time until impairment occurred.[xliii] For exposures to the EC_{50} (5.75 µg/L) at 15°C, impairment was evident at 60 hours and immobility at 76 hours, while at 24°C impairment occurred at 6 hours and immobility at 26 hours.[xliv] The authors noted that immobility occurred after other forms of impairment, suggesting that more sensitive endpoints would be more appropriate to quantify harm.[xlv] While detections have occurred above 5.75 µg/L in California, this experiment documents a trend at a higher level than commonly found in California's water samples.[xlvi]

Taken together, the lethal, sublethal, and indirect effects described in the literature show that even small concentrations of imidacloprid can trigger harmful effects. Concentrations of imidacloprid that can cause sublethal effects occur commonly in California (Figure 3). Although sublethal endpoints can be difficult to assess, their effects can still negatively affect functional community structures. Reductions in individual fitness can cascade into trophic disruptions and alterations in ecosystem services.

[4] Imidacloprid was tested on mayflies and amphipods, and significantly impacted both; thiacloprid significantly affected blackflies only; and acetamiprid significantly affected mayflies only.

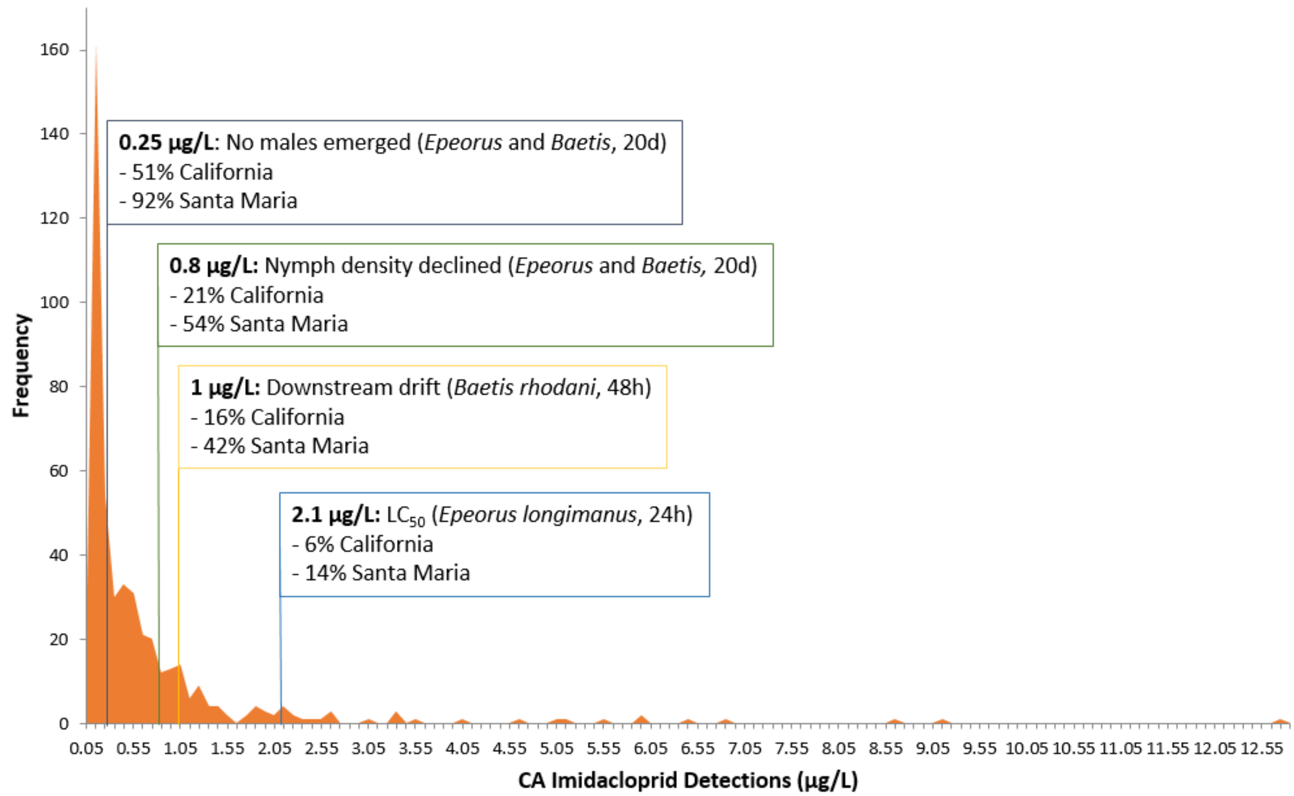

Figure 3: Histogram of imidacloprid surface water detections in California with the percentage of detections in California and Santa Maria that exceed levels shown to cause harm in mayfly species. No male *Epeorus* spp. or *Baetis* spp. emerged at 0.25 µg/L (20-day exposure to formulated Admire, Alexander et al. 2008), at 0.8 µg/L *Epeorus* spp. and *Baetis* spp. nymph density was reduced (20-day exposure to formulated Admire, Alexander et al. 2008), at 1 µg/L downstream drift of *Baetis rhodani* was initiated (Beketov & Liess 2008), and the 24h LC_{50} of *Epeorus longimanus* is 2.1 µg/L (Alexander et al. 2007).

Relative Toxicity of Other Nitroguanidine Neonicotinoids

There has been little research done to identify the relative toxicity of various neonicotinoids or to assess the potential for synergistic effects in aquatic invertebrates. One recent study sought to fill this data gap by comparing the chronic toxicity of imidacloprid, clothianidin, and thiamethoxam to *Chironomus dilutus* (Table 2).[xlvii] They calculated toxic equivalency factors based on 14-day LC_{50} values for clothianidin and thiamethoxam of 1.05 and 0.14, respectively (relative to imidacloprid values).[xlviii] Their results show that imidacloprid and clothianidin have similar toxicities, while thiamethoxam was less toxic—although thiamethoxam degrades into clothianidin. Another pair of studies evaluated the response of *Daphia magna* to Admire (imidacloprid) and Dantotsu (clothianidin).[xlix] In comparing the toxicity of the two chemicals, the studies noted wide variability in responses to the formulated products containing imidacloprid and clothianidin.[l]

Table 2. Chronic toxicity in *Chironomus dilutus* (µg/L)

	Chronic invertebrate aquatic benchmark	**14 day LC_{50}**	**40 day EC_{50} (emergence)**	**Shifts in sex ratio (40 day)**
Imidacloprid	1.05	1.52	0.39	0.17
Clothianidin	1.1	2.41	0.28	0.46
Thiamethoxam	none	23.60	4.13	3.60

Loss of Ecological Services

The toxicological tests outlined above show the wide variation in sensitivity among aquatic species. The most sensitive tend to be species in the orders Ephemeroptera and Trichoptera (mayflies and caddisflies). Both of these are extremely important to freshwater ecosystems. Mayflies are a commonly used water quality indicator because of their sensitivity to disturbance. Immature mayflies feed on detritus, diatoms, and algae, making them a valuable decomposer in aquatic systems.[li] Caddisflies are also good water quality indicators, partially because of their specific habitat requirements.[lii] They are crucial to aquatic food chains because they eat both plant and animal material, providing shredding services and making finer particulate organic matter available to other invertebrates.[liii]

Both mayflies and caddisflies are components of many fish, bird, bat, reptile, and amphibian diets, so any population-level disturbances can impact food resources for these species. Other species that feed on the predators of aquatic invertebrates can also be affected by changes in their abundance. Studies and reports have linked insectivorous bird declines to neonicotinoid use, as bird reproductive success may be affected by food availability.[liv] Populations of aquatic insects can be affected by neonicotinoid water contamination. Herbivorous insects that are a key food source for birds can be exposed to neonicotinoids through their presence in leaves and other parts of plants.[lv] Both of these exposure routes, terrestrial and aquatic, can reduce invertebrate abundance and limit food resources for birds and other insectivorous wildlife.

Water Quality Reference Values

EPA and other jurisdictions have established aquatic life benchmarks for imidacloprid and other neonicotinoids. Currently, the EPA imidacloprid acute aquatic invertebrate benchmark is 35 µg/L and the chronic benchmark is 1.05 µg/L. Canada, which collaborates with the United States on some pesticide risk assessments, has set their water quality guideline at a single value of 0.23 µg/L.[lvi] For reference to Californian detections, the Canadian guideline was exceeded in 246 (53%) detections, and 67 (94%) Santa Maria detections. The European Union, which relies more heavily on the precautionary principle while designing risk assessments, established a chronic guideline of 0.067 µg/L, a level exceeded in 416 (89%) Californian detections and every Santa Maria detection.[lvii] The Netherlands set its chronic reference value even more conservatively at 0.0083 µg/L based on a wider analysis of toxicological information from a species sensitivity distribution approach.[lviii]

EPA benchmarks fail to protect sensitive species

In the case of imidacloprid, there is strong evidence that the EPA aquatic life benchmarks are under-protective of invertebrates. The EPA neonicotinoid risk assessments rely heavily on data for water fleas and midges, which do not represent the greater sensitivity of species like mayflies and caddisflies. Relying on these few less-sensitive test species does not ensure sufficient protection of aquatic invertebrates in instances where a compound's toxicity varies greatly between species, as it does for imidacloprid. A study that sought to quantify the proportion of crustacean species that would be adversely affected by pesticide contamination at water quality guidelines found that more than half of crustaceans could be impacted by imidacloprid at EPA benchmark levels.[lix]

Acute testing does not adequately simulate chronic risks

Water quality benchmarks that are based primarily on acute data may not provide adequate protection from chronic exposures. In a comparison of acute and chronic toxicity for several species, a study found that mayflies and caddisflies were the most acutely sensitive, while mayflies were the most sensitive to chronic exposures.[lx] The acute to chronic ratios the authors derived were all greater than ten.[lxi] Discrepancies between the acute and chronic sensitivity of species can lead to water quality benchmarks that are under-protective, especially for low-level chronic exposures. The recent Dutch review also identified wide variation in sensitivity both between taxa and species, as well as high acute-to-chronic ratios which implied that the typical Dutch 10x safety factor would not be protective for translating acute results into chronic values.[lxii] The discrepancies between acute testing and chronic effects for imidacloprid and other nitroguanidine neonicotinoids mean that there is no straightforward way to predict what percentage of a species' LC_{50} will cause chronic effects. In designing and reviewing risk assessment protocols, regulators must ensure that chronic testing is adequate to identify lasting effects after the exposure and that gaps between acute and chronic tests are considered.

Recommendations

This preliminary review suggests that the current aquatic life benchmarks for imidacloprid may be under-protective of sensitive species, especially those in the orders Ephemeroptera and Trichoptera. As such, current contamination of California's surface water could be causing unreasonable adverse effects to aquatic invertebrate populations. Effects of repeated, chronic exposures to neonicotinoids are a major area of uncertainty in risk assessments. Imidacloprid's large acute-to-chronic ratio introduces additional uncertainty into risk assessments that are based primarily on acute data. Given the critical ecological roles of mayflies and caddisflies, some of the most sensitive aquatic insects, imidacloprid water quality benchmarks must be reviewed and updated to ensure they are protective of sensitive species.

Additional research is needed to quantify and further investigate the impacts of imidacloprid and other nitroguanidine neonicotinoids on California's aquatic life. As the use of these compounds is continuing to rise, now is the time to take action to review potential risks, update aquatic life benchmarks, and identify and implement risk mitigation strategies. Xerces recommends CDPR take the following actions:

1. **Develop an action plan and timeline for reviewing nitroguanidine neonicotinoid aquatic toxicity.** We recommend that CDPR work to develop a plan and timeline for reviewing the aquatic impacts of the nitroguanidine neonicotinoids. A data synthesis and analysis (similar to the one prepared for fipronil[lxiii]) may help CDPR quantify the risks and define regulatory objectives.

2. **Create interim aquatic life benchmarks.** While there are uncertainties in quantifying the exposures that aquatic ecosystems face and the prevalence of acute versus chronic effects, our overall conclusion is that the current aquatic life benchmarks for imidacloprid are out of date. CDPR should create interim aquatic life benchmarks for all the nitroguanidine neonicotinoids if their preliminary review confirms our initial conclusions that the EPA benchmarks are under-protective.

3. **Require risk mitigation strategies.** Mitigation measures, including buffer strips and reductions in use or application rate, should be required to reduce surface water loading and protect sensitive aquatic ecosystems.

4. **Gather more data on surface water contamination.** California should bolster its surface water sampling efforts for neonicotinoid pesticides, especially the nitroguanidine group. Monitoring should particularly target storm events, irrigation returns, and urban areas, including municipal wastewater treatment plants. Including passive monitors could provide valuable additional information along with current snapshot monitoring methods.

5. **Strengthen pesticide use reporting requirements.** California's pesticide use reporting system is among the most robust in the country. Still, gaps in the system, such as the lack of reporting on use of insecticide-coated seeds or insecticide-impregnated outdoor building materials make it difficult to confidently assess pesticide sources and to identify the most effective mitigation measures. Requiring reporting of these unregistered uses would improve accuracy of California's pesticide use reporting system.

6. **Fund additional research on aquatic invertebrate toxicology.** Aquatic life benchmarks are limited in part by their reliance on a few key species selected by registrants to meet EPA's relatively limited aquatic toxicity testing requirements. The toxicological literature on imidacloprid alone demonstrates the wide range of sensitivity among aquatic invertebrates, even within the same taxa. Further toxicological information is lacking for the other nitroguanidines. Additional research would inform regulation and fill critical data gaps to ensure sufficient protection for aquatic species. Confounding factors including mixtures of pesticides and other stressors that invertebrates encounter in the real world should also be better represented in toxicity testing.

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