Declines in Butterflies and Insectivorous Birds in Areas of High Insecticide Use in California

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Background

Declines of colonial nesting populations of Western Purple Martins (*Progne subis arboricola*) and Tricolored Blackbirds (*Agelaius tricolor*) have been documented in the Central Valley of California since 2004 or later and 2006, respectively (Airola et al. 2014, Meese 2014). These declines have been attributed to extensive habitat loss but insecticides may also play a role by reducing the abundance of insects upon which both species depend. Butterflies in the Central Valley have also exhibited declines in species richness and abundance over recent decades. Lacking long-term data on insects in general in the Central Valley, we focus here on butterflies (for which a long term record exists) to investigate potential changes to the food base of the insectivorous birds.

Recent research results in Europe (Van Dijk et al. 2013, Hallmann et al. 2014) showed significant correlations between declines of aquatic insects, invertebrates and avian insectivore populations, and surface water concentrations of neonicotinoid insecticides. Neonicotinoids have a wide range of agricultural and domestic uses; they are water soluble and therefore can be transported to surface water (Hladik and Kolpin, 2015) and can persist in the absence of direct sunlight, with the potential to occur at chronic and acute levels in aquatic ecosystems (Morrissey et al 2015). Pesticide use under application permit is documented since ~1990-91 in California at the section level by the California Department of Pesticide Regulation (CDPR), and continental US-wide at the county level by the US Geological Survey (USGS) Pesticide Use Database.

Hypothesis: Increased usage of neonicotinoids is related to declines in California bird and butterfly populations.

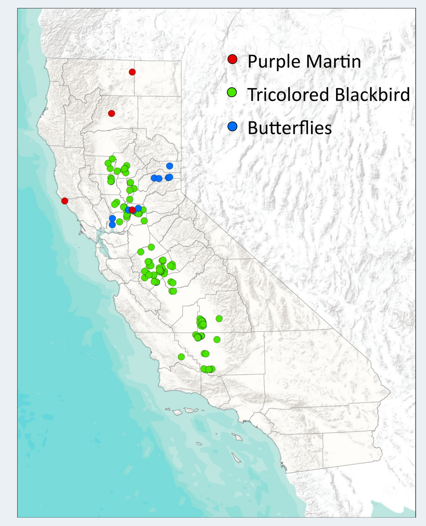


Figure 1. Location map showing monitoring sites for PUMA, TRBL, and butterflies

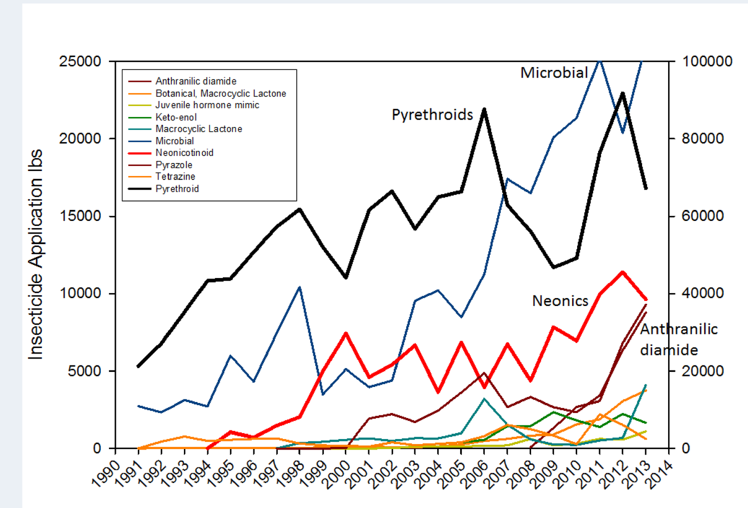


Figure 3. Total reported usage of insecticide by major classes in increasing use in California for 1991-2013 (classes in decreasing use not shown).

Western Purple Martin

The Western Purple Martin (PUMA), an aerial insectivore, is recognized as a Species of Special Concern by the state of California due to substantial reductions in the species' population and geographic range (Airola and Williams 2008). Historic PUMA declines have traditionally been attributed to extensive habitat loss and intensive competition with non-native species for nesting cavities (Airola and Grantham 2003, Airola and Williams 2008). Recent declines have occurred in 'refuge' situations (overpasses, bridges, lava tubes) where such competition is absent or minimized by excess cavity supply.

Female with dragonfly to feed nestling. Chantal Jacques

Study Sites

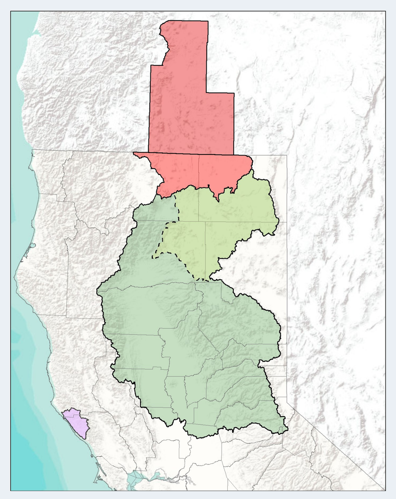


Figure 2. Watershed boundaries used to generate pesticide use summaries for PUMA. Note: Shasta watershed is within Sacramento R. watershed

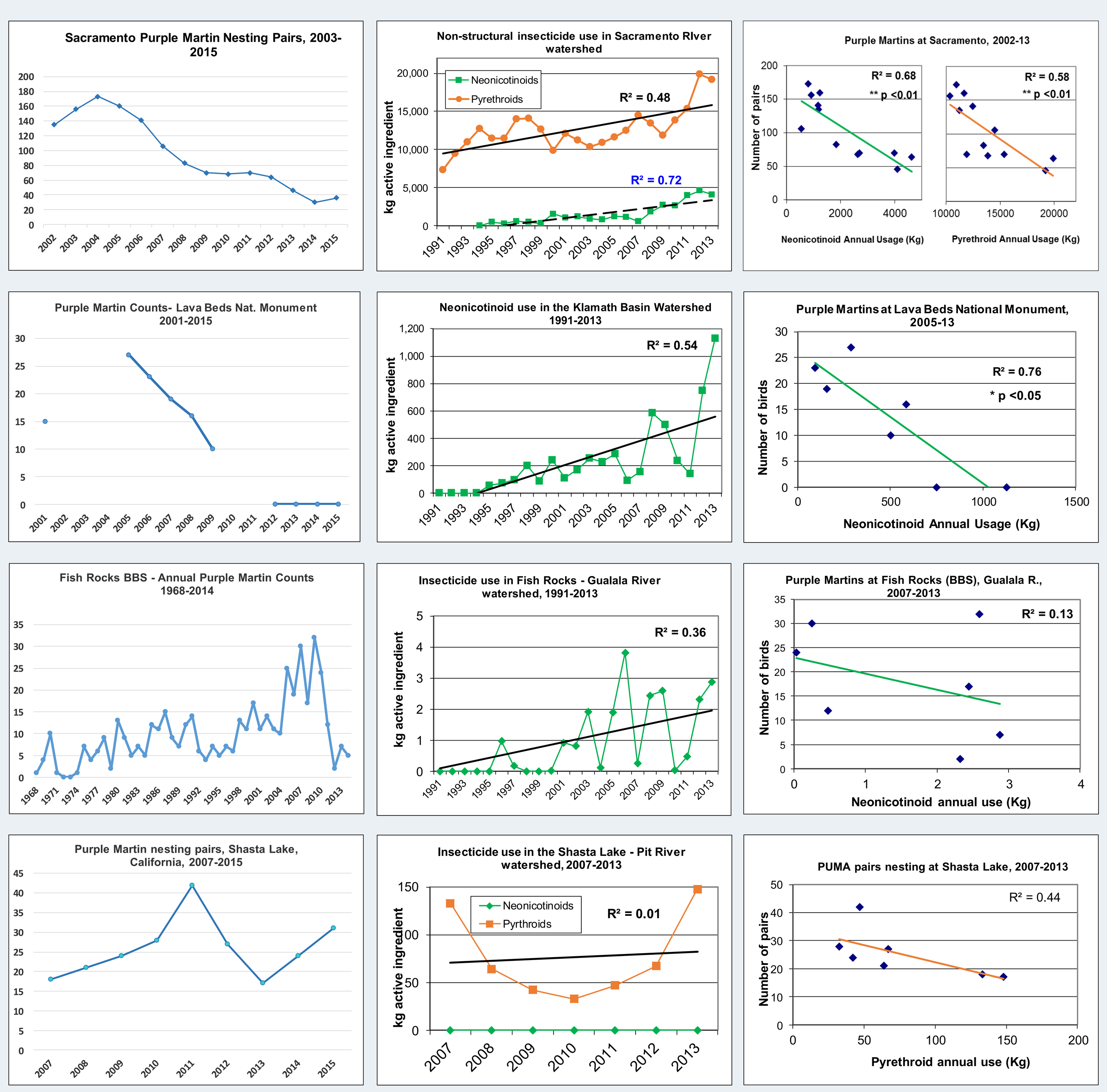
PUMA have been monitored over an extended time at only 4 sites (**Figure 1**) in California and the corresponding watershed areas are shown in **Figure 2**.

- Sacramento: Last sizable PUMA population in Central Valley (Airola and Williams 2008), has declined by 83% from 2004-2014 (Airola et al. 2014).
- Lava Beds National Monument: Supported PUMA since 1899 (Williams 1998), no PUMA recorded since 2009 (N. Nordensten 2015, pers. comm.).
- Sonoma-Mendocino Coast: Populations monitored on Fish Rocks Breeding Bird Survey (BBS) segment since 1966. Rapid decrease in population starting in 2010 (USGS Breeding Bird Survey, 2014).
- Shasta Lake: Monitored continuously since 2007, some fluctuation in population but stable overall (Lindstrand 2008, pers. comm.).

Purple Martin adult pair at nest box. Bruce Cousens

Results

- Five dominant insecticide classes that were widely used in large quantities were considered initially: organophosphates, carbamates, organochlorines, neonicotinoids, and pyrethroids.
- Organophosphates, carbamates and organochlorines declined in use linearly or exponentially by 75%, 95% and 99% respectively in the Sacramento River watershed and similarly elsewhere in California during usage monitoring period; were excluded from further analysis
- Pyrethroid and neonicotinoid use increased substantially (**Figure 3**) over most of the monitoring period so these classes were compared with PUMA (and TRBL) abundance data to look for correlations with avian population declines.



Sacramento

- Reported neonicotinoid usage within the Sacramento R. watershed increased substantially over the usage monitoring period, since introduction in 1994, to 4,000 – 5,000 kg. year in 2011-13.
- PUMA abundance was highly significantly negatively correlated with increasing neonicotinoid annual use over the period of decline.
- PUMA abundance was also highly significantly negatively correlated with increasing pyrethroid use.

Lava Beds National Monument

- Reported neonicotinoid usage within the Klamath Basin watershed increased substantially over the usage monitoring period, since its introduction in 1994.
- PUMA abundance was significantly negatively correlated with increasing annual neonicotinoid use over the period of decline. This population has been extirpated since at least 2012.
- Annual use of pyrethroids in this watershed increased over this period but correlation with PUMA decline was not significant.

Sonoma-Mendocino Coast

- Neonicotinoid usage (kg/sq.km) was more than an order of magnitude lower than in Sacramento R. and Klamath Basin watersheds.
- Purple Martin abundance and the recent sharp population decline (2009-12) were not significantly correlated with the small volume and gradual increase in use of neonicotinoids.
- Pyrethroid use in the Gualala R. watershed was negligible in this period.

Shasta Lake:

- This area serves as a low insecticide-use control site for possible effects of insecticide use
- No reported neonicotinoid use within this region
- Purple Martin abundance was moderately negatively correlated with pyrethroid use over this period.

Tricolored Blackbird

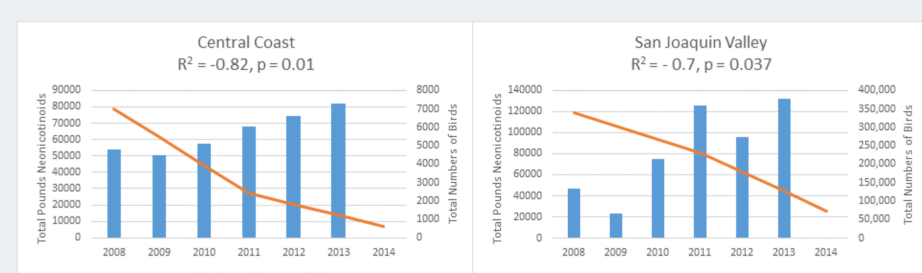
The Tricolored Blackbird (TRBL), an omnivorous species that is insect-dependent during the breeding season, is nearly endemic to lower elevations in California and a majority of breeding birds occur in the Central Valley. TRBL breeding colonies once consisted of tens of thousands of birds and occurred primarily in wetlands in the Sacramento Valley (Neff 1937). Due to chronic low productivity (Meese 2013), the number of TRBL and the average sizes of their breeding colonies have dropped dramatically in the past decade and this rapid decline in abundance led to petitions for listing under both the federal and California Endangered Species Acts. The species faces several threats, primarily wholesale losses of breeding and foraging habitats, colony destruction during the harvest of grain-field nesting substrates, and autumnal shooting while in mixed-species foraging flocks in paddies of ripening rice in the Sacramento Valley. Field work conducted over several years suggests that an insufficient insect food supply is responsible for the observed chronic low reproductive success and population decline (Meese 2013).

Displaying male tricolored blackbird. Phil Robertson

Study

- 127 breeding colonies (**Figure 1**) at lower elevation sites throughout California, from San Diego County in the south to Glenn County in the north.
- We analyze population trend data from the 2008, 2011, and 2014 Statewide Surveys of the species (Meese 2014) and reproductive success data from 2005-2014 distributed among 4 foraging habitats (Meese 2013, unpub. data).

Results



- Bird numbers were strongly negatively correlated with neonicotinoid insecticide use in the San Joaquin Valley and Central Coast bioregions.
- The reproductive success of breeding TRBL was weakly negatively correlated with organic synthetic insecticide use (r=.367), with average reproductive success highest in organic rice where insecticide use was lowest; but average reproductive success lowest in rice where insecticide use was third highest.

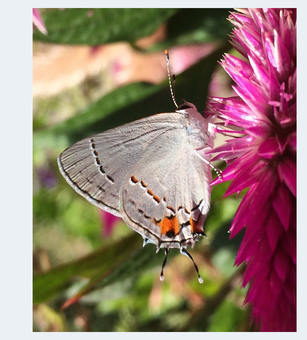
We gratefully acknowledge the valuable assistance of Michelle Hladik, James Orlando and Matthew De Parsia of the U. S. Geological Survey Water Science Center in Sacramento, California, for extracting and providing multiple GIS-referenced insecticide annual usage data sets from the USGS Pesticide Use Database for specific study areas within the Central Valley, as well as mapping these areas, and for poster graphics support.

Butterflies

Results of long term (between 27 and 43 years) monitoring of butterfly populations across Northern California from the Coast Range and valley floor to the high Sierra Nevada mountain range indicate ongoing declines in abundance and species richness, especially at lower elevations (Forister et al. 2010, Casner et al. 2014). These declines have so far been attributed primarily to habitat losses associated with land conversion, and to a lesser extent with recent climatic trends. However, effects of recent increases in widespread insecticide use with intensive agricultural development on the valley floor is a possible additional stressor that has not yet been investigated.

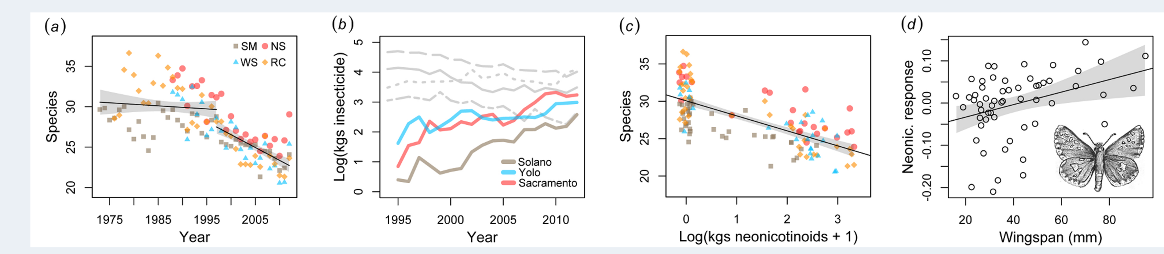
Study

- 10 sites (**Figure 1**) visited every 2 weeks for 27-43 years (Forister et al. 2010) This study focuses on the 4 lowest elevation sites.
- Presence/absence of each butterfly species noted at each site.
- Model developed using county level neonicotinoid use data and butterfly species richness.
- Modified the modelling approach of Casner et al. (2014) to include neonicotinoid use, 4 climatic variables, and 'proportion of working land' (WL).



Strymon melinus

Results



(a)The number of observed butterfly species at four sites. The response variable (in *a* and *c*) is the exponential of Shannon diversity, i.e., the effective number of species; the spline knot in *a* is 1997 (95% confidence interval: 1990-2001).

(b)Insecticide application for neonicotinoids in focal counties (colored lines), and for the four most commonly-applied non-neonicotinoid classes (gray lines). The non-neonicotinoids are, in decreasing order of line elevation in 1995, organophosphates, carbamates, pyrethroids, and organochlorines (lines are county averages). Note the different range of years in the first two panels, as *(b)* starts in the year in which neonicotinoids are first reported.

(c)Relationship between number of butterfly species and neonicotinoids (values of the latter at zero jittered for visualization). The negative association with neonicotinoid application is detectable while controlling for changes in land use, visitation effort and a key climatic variable (previous summer minimum temperature).

(d)Response of individual species to neonicotinoids as predicted by wingspan; more negative values on the y-axis indicate species with more negative associations with neonicotinoids.

- Gray polygons in panels *(a)*, *(c)*, and *(d)* are 95% confidence intervals. *Pyrgus scriptura* (in *d*), is one of the smallest species in the fauna; drawing by MLF.

Conclusions

The population declines of purple martins had significant negative correlations with insecticide application in the two areas with the highest use of neonicotinoid insecticides, but have remained relatively stable in the one area where no use occurred. A recent steep decline in the population in our fourth study area occurred in the absence of a local increase in neonicotinoid use. These results suggest there *may* be an association between observed PUMA population declines and increasing use of neonicotinoid systemic insecticides in agricultural areas of the Central Valley and the Klamath Basin that should be investigated further.

Tricolored blackbirds breed in landscapes dominated by agriculture and this review shows that their highest average reproductive success occurs where insecticide use is lowest, suggesting that reproductive success may in some portions of the species' range be limited by insect abundance which is reduced by insecticides. Data on population trends derived from the 2008, 2011, and 2014 Statewide Surveys show a strong negative correlation between neonicotinoid use and bird numbers in the San Joaquin Valley and Central Coast bioregions, where the highest rates of decline have been documented. These results suggest a possible negative association between use of neonicotinoid insecticides and tricolored blackbird abundance that deserves further study.

Although correlative, and at a crude geographic scale, our results point to a potential association between neonicotinoid use and butterfly declines, which have been concentrated at low elevations in Northern California. Plants growing in and around agroecosystems may take up runoff or residue neonicotinoids and many of the butterflies in the Central Valley do indeed use exotic larval host plants in and around cultivated lands (Graves and Shapiro 2003). Pecenka and Lundgren (2015) have experimentally verified the potential negative effect of at least one neonicotinoid (clothianidin) on monarch butterfly larvae. Similar work needs to be done with a range of butterflies at doses relevant to the Central Valley to test the hypotheses raised here.

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