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Almond organophosphate and pyrethroid use in the San Joaquin Valley and their associated environmental risk

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Abstract
Purpose The purpose of the present study are to analyze the temporal and spatial trends of the pesticide use on almond crops and assess their associated risk to soil, surface water, and air, and to investigate the impacts of pesticide risk on biodiversity.
Materials and methods California Pesticide Use Report database was used to determine the organophosphate (OP) and pyrethroid use trends in the San Joaquin Valley for almonds from 1992 to 2005. Environmental potential risk indicator for pesticides model was employed to evaluate associated environmental relative risks in soil and in surface water. Emission potential of pesticide product was used to estimate the air relative risk. Geographical Information System was used to delineate the spatial distribution patterns of environmental risk evaluation in almonds and biodiversity.
Results and discussion OP pesticide use has been declined in any measurement in almonds. However, a converse result was found for pyrethroid pesticide. Pesticide use trends reflect the profound changes in pest management strategies in the California almond farm community. The model results in this study showed evidence that pyrethroid posed less environmental risks to soil, air, and water resources than OP. The physiochemical properties of pyrethroid reflect a strong tendency to adsorb to organic carbons, and therefore, potentially move off-site attached to sediment. Once in sediments, they can be bioavailable to the aquatic food web. So, more future study on environmental model should address pyrethroid environmental risk on sediment. Ecologists revealed that endangered species diversity has good correlation with total species diversity, so we developed a biodiversity index by using the survey data of endangered and rare animals in California. The results showed a negative relationship between count of animal occurrence and predicted environmental risk. This result would be useful to help conserve California's biological diversity by providing information to promote agricultural management and land-use decisions.
Conclusions Pesticide use trend is directly related to environmental risk. Pyrethroid posed less environmental risk than OP in this study. And also, this study got a noticeable result that pesticide uses in intensive agriculture and their associated environmental risks pose negative impacts on biodiversity.

Keywords Almonds · Animal occurrence · Environmental risk · OP · Pyrethroid · Use trend

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1 Introduction

Approximately 450 million kilogram of pesticides is used in the USA each year, with agriculture accounting for 70–80 % of total pesticide use (USGS 1999). Within agricultural pesticide use, organophosphate (OP) insecticides have gained a wide range of use. By the 1980s, OP accounted for approximately 65 % of total insecticide usage (Moore et al. 2002). Due to increased regulatory scrutiny of OP pesticide use in agriculture and the outright banning of some of the most popular OPs in consumer home and garden products, the "alternative" use of pyrethroid (PY) insecticides is increasing for agriculture, commercial pest control, and residential consumer use. In addition, there is an increasing trend toward the use of newer and more potent pyrethroid compounds (Amweg et al. 2005).

Pyrethroid pesticides have higher organic carbon sorption constant (K_{oc}) and logarithm of octanol–water partition coefficient ($\log K_{ow}$), therefore, are much more "sticky" compared with other pesticides. They can rapidly adsorb to suspended particles and sediments in field runoff, thus enabling them to enter receiving waters, and sometimes accumulating at levels toxic to aquatic species that inhabit sloughs, streambeds, and riverbeds (Laskowski 2002; Weston et al. 2004). Although half-lives in the environment typically are on the order of days to weeks in the aqueous phase (Laskowski 2002), pyrethroids exhibit prolonged persistence in aquatic sediments. In this way, pyrethroid pesticides can be expected to persist longer in the environment. Analysis of about 80 sediment samples from rivers, creeks, and irrigation canals throughout a 10-county area of California found detectable pyrethroids in 75 % of samples (Weston et al. 2004). Gan et al. (2005) characterized the spatial distribution and persistence of pyrethroids in the sediment along a 260-m runoff path. They found the residues of pyrethroid were significantly enriched in the eroded sediment and the magnitude of enrichment was proportional to the downstream distance.

California comprises 2–3 % of the nation's cropland, yet is responsible for 25 % of the nation's pesticide use (Brady et al. 2006). Of the tree crops in California, almonds have the largest area planted, accounting for approximately 5 % of the state's cropland, and producing 99 % of US almonds (Zhang et al. 2005). Commonly referred to as the "fruit basket of the world", the San Joaquin Valley (SJV) is the major agricultural production area in California, as well as the USA. As illustrated in Fig. 1, there are four major rivers running through the watershed: the San Joaquin, Stanislaus, Tuolumne, and Merced Rivers. The valley is very flat in topology and is only about 10 ft above sea level. Soil textures of the western SJV tend to be of finer texture relative to the more sandy soils of the eastern valley (Page 1986). SJV weather resembles a Mediterranean climate, being hot and dry during the summer and cool and damp in the winter months. Rainfall is concentrated in the months of November to March. Due to the dry weather and a relatively deep water table in many areas, water has become a precious natural resource for agricultural production in the valley. Due to many irrigation projects, which built dams and canals to redistribute water, many dry lands are useable for agricultural production. Thus, the valley is intensely farmed with most operations relying on irrigation water (Domagalski 1997). And the pesticide runoff from agricultural drainage and regional agricultural operations has contributed to pesticide contamination in the San Joaquin River (Werner et al. 2003). By 1998, the State of California had placed the Sacramento and San Joaquin Rivers, as well as the associated delta estuary, on the Clean Water Act Section 303 (d). Consequently, pesticide use trends on almond orchards and their associated environmental risk are of particular interest to the state regulatory agencies, Integrated Pest Management (IPM) advisors and environmental groups.

Much research has been conducted on OP pesticide use, especially during the dormant season, demonstrating that dormant OP use on almonds and other tree crops has declined, as measured by the amount applied, hectare treated, and number of growers who treated from 1992 to 1997 (Flint et al. 1993; Hendricks 1995; Epstein et al. 2000, 2001) or from 1992 to 2000 (Zhang et al. 2005). An important pesticide application alternative is OP and pyrethroid use in irrigation season, which is encouraged by the California Department of Pesticide Regulation (DPR) and other organizations (Zhang et al. 2005). Therefore, knowledge of pesticides use trends for almonds need to be updated and is essential to the IPM. Moreover, it is still a problem whether OP or pyrethroid pesticide presents more risk to environment. In this paper, we have a hypothesis that OP presents more environmental risks.

Pesticide uses and their residues were known to be deleterious to endangered species on many different levels, from direct to indirect lethality to nonlethal yet severely degradative. All of these have the potential to further reduce the diversity of organisms we see today. Numerous studies have identified pesticides as potential causes to significant developmental, neurological, and reproductive damage to amphibians. It is therefore important to understand the potential environmental risk of pesticides and devise mitigation strategies to reduce their offsite movement. The objectives of this research are: (1) to analyze the temporal and spatial trends of the OP and pyrethroid pesticide use on almond crops from 1992 to 2005; (2) to assess the temporal and spatial trends of the pesticide risk to soil, surface water, and air; and (3) to investigate the impacts of pesticide risk on biodiversity.

2 Materials and methods

2.1 Data sources

Pesticides selected in this study included OP pesticides of acephate, azinphos-methyl, chlorpyrifos, diazinon, dicrotophos, dimethoate, disulfoton, ethoprop, fenamiphos, malathion, methidathion, methyl parathion, naled, parathion, phosalone, and phosmet, and pyrethroid pesticides of cyfluthrin, cypermethrin, esfenvalerate, lambda-cyhalothrin, permethrin, and tau-fluvalinate. Pesticide use information from 1992

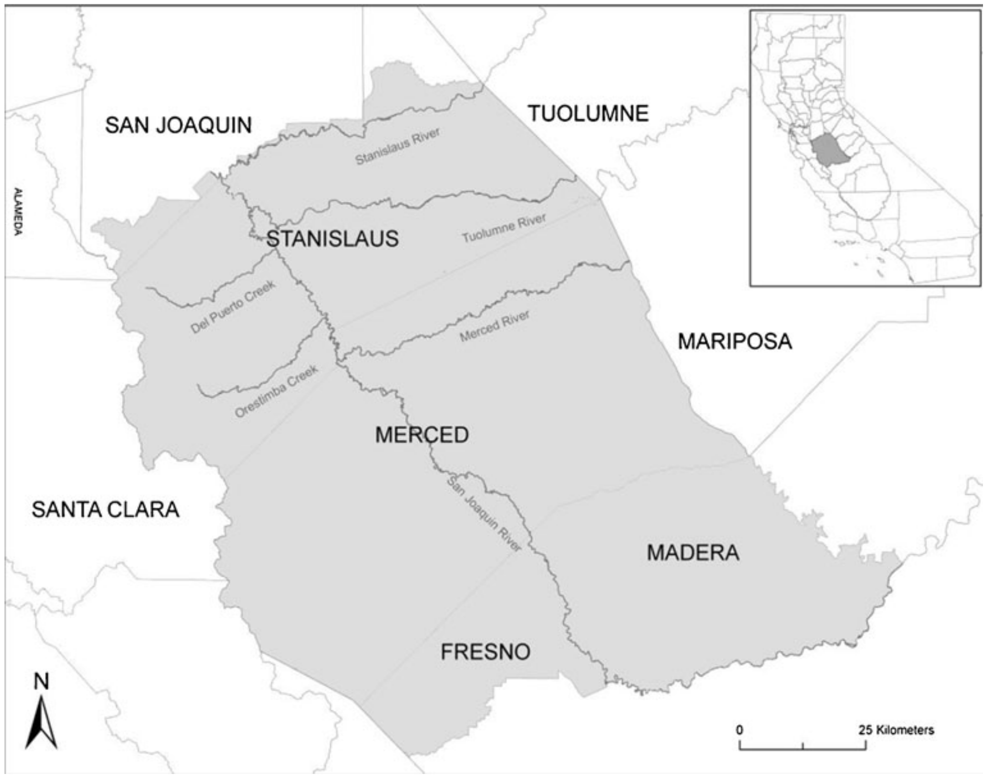

Fig. 1 The San Joaquin Valley, the study area

to 2005 was obtained from the Pesticide Use Report (PUR) database, maintained by the California DPR, which tracks pesticide use by location and time (California Department of Pesticide Regulation 2000). Pesticide usage information is presented in measurements such as amounts of pesticide product used, amounts of active ingredient used, application time, planted area, and treated area. All individual application records on almonds in the SJV watershed were retrieved for the period between 1992 and 2005. All raw data was put on the website http://agis.ucdavis.edu/Upload/almond_risk.zip.

2.2 Descriptor of pesticides

Descriptors in this study used to analyze pesticide use trends are kilogram of active ingredient (AI) and kilogram of AI per hectare planted (use intensity or UI). The following is a detailed explanation of each descriptor:

Kilograms of AI: sum of reported kilograms of AI applied.

Kilograms of AI per hectare planted (UI): sum of kilograms of AI applied divided by hectare planted. We calculated the UI based on data acquired at section level ($1.6\times 1.6\ \mathrm{km}^2$) by using the Eq. (1) below:

$$\mathrm{UI}_i = \frac{\mathrm{totalUse}_i}{\mathrm{plantedAreas}_i} \quad (1)$$

where i is the section number, UI_i is the use intensity in comtrs i, $\mathrm{totalUse}_i$ is the total use (kilogram) of OP/PY in section i, $\mathrm{plantedAreas}_i$ is the cumulative areas planted (hectare) in section i.

2.3 Data cleaning

Although the PUR database is the best database available to reflect pesticide use information in California, it contains errors. The DPR has developed error checking procedures which identify outliers and errors on variables including use intensity, grower identification numbers, and site location identification numbers. The error checking procedures were described in the research by Wilhoit et al. (2001). An error was identified if the record was considered as a duplicate of another one, if the unit for treated areas is unknown, or if the unit was not measured in square feet ($0.09\ \mathrm{m}^2$) or acres (0.40 ha). The error records were then deleted from the database.

An outlier was identified for a single application event if the use intensity of the record is (1) greater than 224.7 kg per hectare treated; (2) 50 times the median kilogram per hectare treated for all uses of that product on almonds; (3) a value determined by a neural network (Wilhoit et al. 2001). However, DPR did not provide replacements for these values when publishing the database. To replace the outlier records, we used the median use rate (kilogram of AI per hectare treated) of the same product on almonds in the same year. For example, a record in 1998 has been identified as an outlier by the criteria described above. The use intensity of this record denoted as UI (old) will be replace with the median rate of all the records with the same product during 1998 denoted as UI (new). Therefore, the new value of amount of AI will be calculated using the following Eq. (2):

$$\text{Kg of AI(new)} = \frac{\text{kgofAI(old)}}{\text{kgofproduct(new)}} \times \text{UI(new)} \times \text{treatedHectares} \quad (2)$$

The data cleaning processes identified 2,386 records as errors and 2,694 as outliers from a total of 625,875 records for pesticide uses to almonds in the study area during 1992 to 2005. The error and outlier records were only 0.81 % of all records, indicating a high accuracy for information within the database.

2.4 Environmental risk evaluation methods

In this paper, soil, surface water, and air were the environmental compartments taken into account. We setup the following approaches after reviewing and comparing a bunch of pesticide environmental risk indicators: environmental potential risk indicator for pesticides (EPRIP) model with algorithm modifications was employed to evaluate their associated environmental relative risks in soil and surface water; emission potential (EP) of pesticide product was chosen to estimate the air relative risk (Spurlock 2002; Padovani and Capri 2004; Bockstaller et al. 2008; Trevisan et al. 2009).

EPRIP was based upon exposure toxicity ratio (ETR) at a local scale (field and surroundings), which was the ratio of predicted environmental concentration (PEC) with short-term toxicological parameters. EPRIP reflected the worst scenario, as it assumes that nontargeted organisms are subjected to the utmost temporal and spatial exposure. ETR was

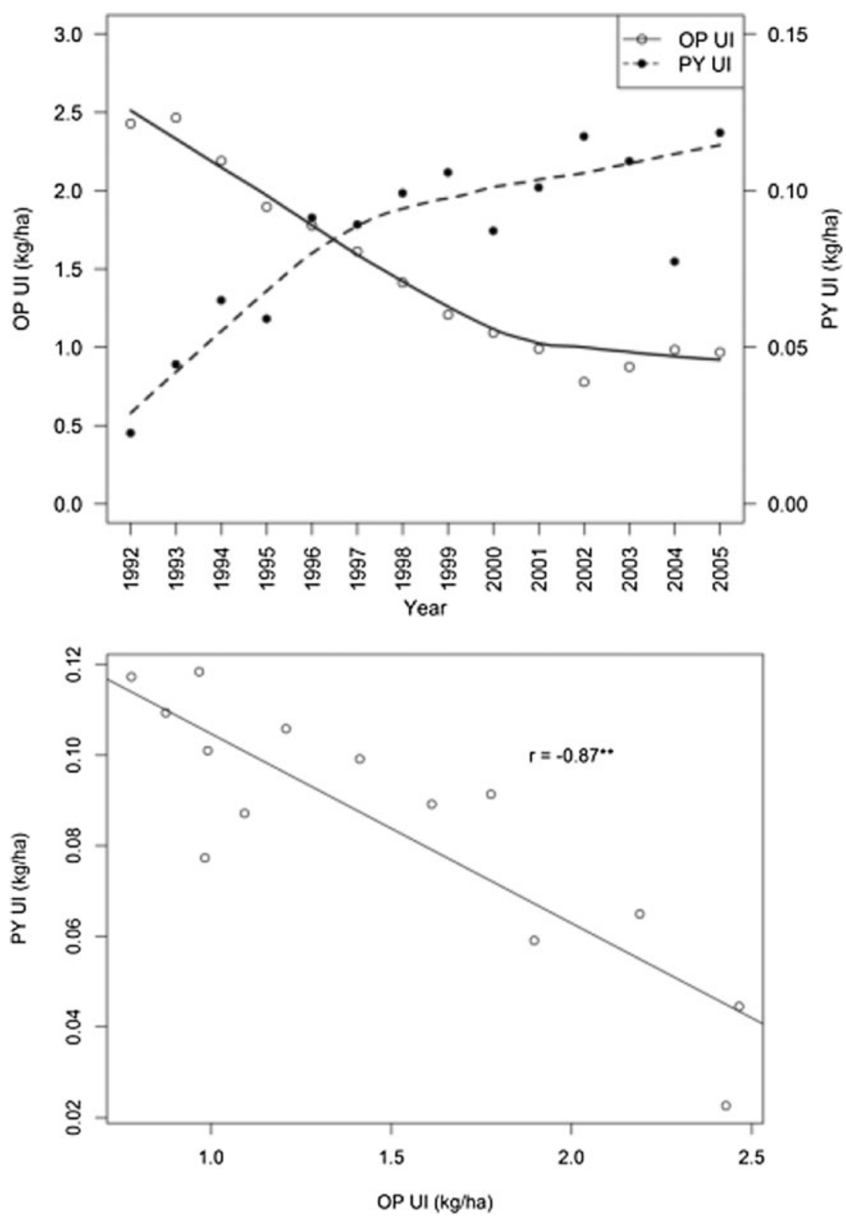

Fig. 2 Relationships between the UI of OP and pyrethroid. The *lines in the left* graph are fitted by local regression (Cleveland et al. 1992); the line in the *right graph* is fitted by simple linear regression

used to identify the fields where the use of pesticides poses high risk to nontargeted organisms.

The ETR for soil (ETR_s) is the ratio of PEC_s to the 50 % lethal concentration for earthworms ($LC_{50,earthworm}$, the concentration required to kill 50 % of earthworms in dry soil; Eq. (3)).

$$\mathrm{ETR}_s = \frac{\mathrm{PEC}_s}{\mathrm{LC}_{50,\mathrm{earthworm}}} \tag{3}$$

The PEC in soil (PEC_s) right after pesticide application is calculated by Eq. (4).

$$\mathrm{PEC}_s = \mathrm{RATE} \times \frac{1 - f_{\mathrm{int}}}{100 \times \mathrm{DEPTH} \times \mathrm{BD}} \tag{4}$$

where, RATE is the application rate, f_{int} is the percent of pesticides intercepted by the crop, DEPTH is the soil mixing depth, and BD is the soil bulk density.

The ETR for surface water in an adjacent ditch (ETR_{sw}) is the ratio of the maximum PEC by drift (PEC_{drift}) and runoff (PEC_{runoff}), to the minimum L/EC_{50} (EC_{50} is the concentration required to take effect on 50 % of the tested organisms) of fish ($LC_{50,fish}$), daphnia ($EC_{50,daphnia}$), and algae ($EC_{50,algae}$;p Eq. (5)). Choosing the maximum of PEC and the minimum of L/EC_{50} would result in the maximum ETR, which reflects the worst scenario in surface water.

$$\mathrm{ETR}_{\mathrm{sw}} = \frac{\mathrm{Max}(\mathrm{PEC}_{\mathrm{drift}}, \mathrm{PEC}_{\mathrm{runoff}})}{\mathrm{Min}(\mathrm{LC}_{50,\mathrm{fish}}, \mathrm{EC}_{50,\mathrm{daphnia}}, \mathrm{EC}_{50,\mathrm{algae}})} \tag{5}$$

PEC_{drift} is estimated from RATE, the percent of pesticides drifting to surface water (f_{drift}), and the area of cross section of the ditch (V; Eq. (6)).

$$\mathrm{PEC}_{\mathrm{drift}} = \frac{\mathrm{RATE} \times f_{\mathrm{drift}}}{V} \tag{6}$$

PECrunoff is calculated as follows:

$$\mathrm{PEC}_{\mathrm{runoff}} = \frac{P_r \times \mathrm{RATE}_{3d} \times F_{\mathrm{aq}}}{D_r} \tag{7}$$

where, Pr is the percent of pesticide lost through runoff, RATE3d is the concentration of remaining pesticides 3 days after application, Faq is the fraction of pesticide dissolved in runoff water. However, it should be noted is that the equation for estimating quantity of runoff water was modified to fit the situation in California, in which SCS curve number method was used instead (SCS 1972).

The following parameters were used for the model: soil and field condition properties (soil organic carbon content, 1.32 %; BD, 1,670 kg/m^3; sand content, 56.4 %; annual rainfall (RAINFALL), 241 mm; average maximum daily rainfall, 27.37 mm; ground slope, 3; mixing depth of soil (DEPTH), 0.05 m; depth of ditches (H), 0.3 m; width of ditches (B), 1 m; interception fraction (f_{int}), 44 % (early) and 78 % (late); drift fraction (f_{drift}), 11 % (early) and 4.5 % (late); SCS curve number, 69.98), and pesticide active ingredient properties (LC_{50} for fish, EC_{50} for daphnia, EC_{50} for algae, LC_{50} for earthworms, water solubility, half-life, and K_{oc}).

Though EPRIP has the risk component on air as well, it did not work effectively in this study. First, the ETRs of air calculated by EPRIP were nearly equally negligible (close to 0) for all evaluated pesticides. Second, inert ingredients in pesticides play an important role in causing volatile organic compound (VOC) problem which induces respiratory disease. Instead, emission potential (EP) was employed to evaluate the pesticide relative risk on air. The EP is the fraction of a pesticide product that is assumed to contribute to atmospheric VOCs. DPR uses EPs to calculate potential VOC emissions from pesticides.

$$\text{Potential VOC emission} = (\text{weight product applied}) \times \mathrm{EP} \tag{8}$$

Currently, thermogravimetric (TGA) analysis is the major method to measure EPs, other methods for estimating EPs has been devised for non-TGA pesticide products. Potential

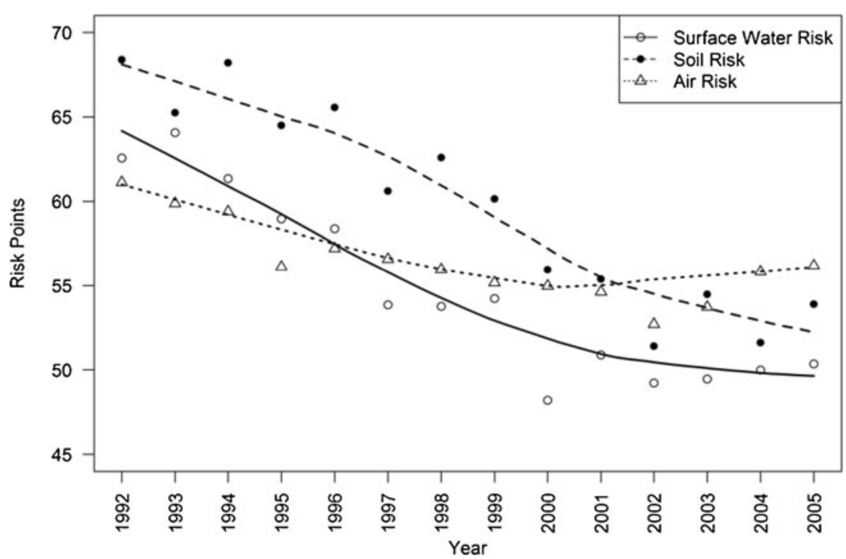

Fig. 3 Weighted average environmental risks to soil and surface water calculated by EPRIP model, and environmental risk to air calculated by EP model. The *lines* are fitted by local regression (Cleveland et al. 1992)

Table 1 Trend summary of weighted average environmental risk (number of sections, 1,241)

	OP	Percentage of the total sections	Pyrethroid	Percentage of the total sections	R_{soil}	Percentage of the total sections	R_{sw}	Percentage of the total sections	R_{air}	Percentage of the total sections
Increase	214	17	898	**72**	214	17	254	20	442	36
$a<0.05$	13	1	237	**19**	10	1	27	2	56	5
Decrease	1001	**81**	269	22	1024	**83**	985	**79**	797	**64**
$a<0.05$	438	**35**	16	1	398	**32**	361	**29**	227	**18**

Bold values are the main trends

VOC emission in a unit area of almond fields was used to indicate the risk to air (ETR_{air}).

ETR for soil, surface water, and air were all transformed to 0–100 for easier interpretation and comparisons. First, ETRs were normalized by using Box–Cox transformation. Second, transformed values were rescaled to make means to be 50 and standard deviations to be 15, thus the data would sit between 5 and 95. Third, values larger than 100 or smaller than 0 were set to be 100 and 0, respectively. Consequently, the value ranges of risk to soil, surface water, and air were all from 0 to 100.

2.5 Pesticide risk indices and biodiversity

Ecologists revealed that endangered species diversity has good correlation with total species diversity (Kerr and Currie 1995; Kerr and Cihlar 2004). We developed a biodiversity index by using the survey data of endangered and rare animals in California. The biodiversity index in a defined area equals to the number of endangered and rare animal species observed in that area. The survey data were compiled from the California Natural Diversity Database (CNDDB) maintained by the California Department of Fish and Game (Roxanne 2001; California Natural Diversity Database 2008). The database includes data on the status and locations of rare and endangered animals in California. The observations were taken during late nineteenth century through nowadays, covering the period of the pesticide risk analysis conducted in this study (1992–2005).

The resultant risk indicators were evaluated by comparing to the developed biodiversity index. Both biodiversity index and predicted risk indices were rearranged based on the California 1:24,000 US Geological Survey quadrangle index. One quadrangle includes about 60 sections (15,540 ha approximately), and this spatial resolution was recommended for biodiversity mapping and analysis (California Natural Diversity Database 2008). Quadrangles with very little almond fields (less than 480 ha annual average) were excluded in the analysis. In those quadrangles, we assumed that pesticide use on almond was one of the major risk sources to animal living. Spatial correlation analysis was conducted between the biodiversity indices and the corresponding pesticide risk indices over quadrangles. Partial correlation coefficients (conditional on almond field areas) were reported by using R (R Development Core Team 2012).

3 Results

3.1 Pesticide use and their weighted average environmental risk trend

From years 1992 to 2005, the number of almond OP use growers decreased, whereas that of pyrethroid use increased. Relationships between the UI of OP and pyrethroid were analyzed (Fig. 2). A linear regression model and an exponential model, respectively, well reflected the relationship between UIs of OP and pyrethroid, and the trend of the ratio of OP to pyrethroid. The models showed that the UI of OP had a significant negative correlation with the UI of pyrethroid (r=0.87, p<0.001); the UI of OP and PY significantly decreased and increased respectively during 1992–2005.

Pesticides weighted average environmental risks to soil, surface water, and air were calculated by the EPRIP model and the EP method. The results are shown in Fig. 3. It displayed that the trends of risk values to soil, surface water, and air all decreased by the year. The risk value to soil decreased from 68 in 1992 to 54 in 2005. There is a decrease from 63 in 1992 to 50 in 2005 for the risk value to surface water, from 61 to 56 during 1992–2005 for the risk value to air.

Table 1 gives the trend summary for pesticide weighted average risks in each section. From 1992 to 2005, there are

Table 2 Categorization of the pesticide use intensity and risk

	Use intensity (kg/ha)		Risk
	OP	Pyrethroid	
Low	<0.90	<0.03	0–35
Moderate low	0.90–1.68	0.03–0.07	35–50
Moderate high	1.68–2.33	0.07–0.15	50–65
High	>2.33	>0.15	65–100

totally 898 sections accounting for 72 % where pyrethroid use increased. And 1,001 sections accounting for 81 % where OP pesticide use decreased, which resulted in that their associated environmental risks to soil, surface water, and air all decreased for most sections. At the 0.05 level of significance, 35 % sections in which OP use decreased, accordingly, 32, 29, and 18 % sections posed decreasing environmental risk to soil, surface water, and air, respectively.

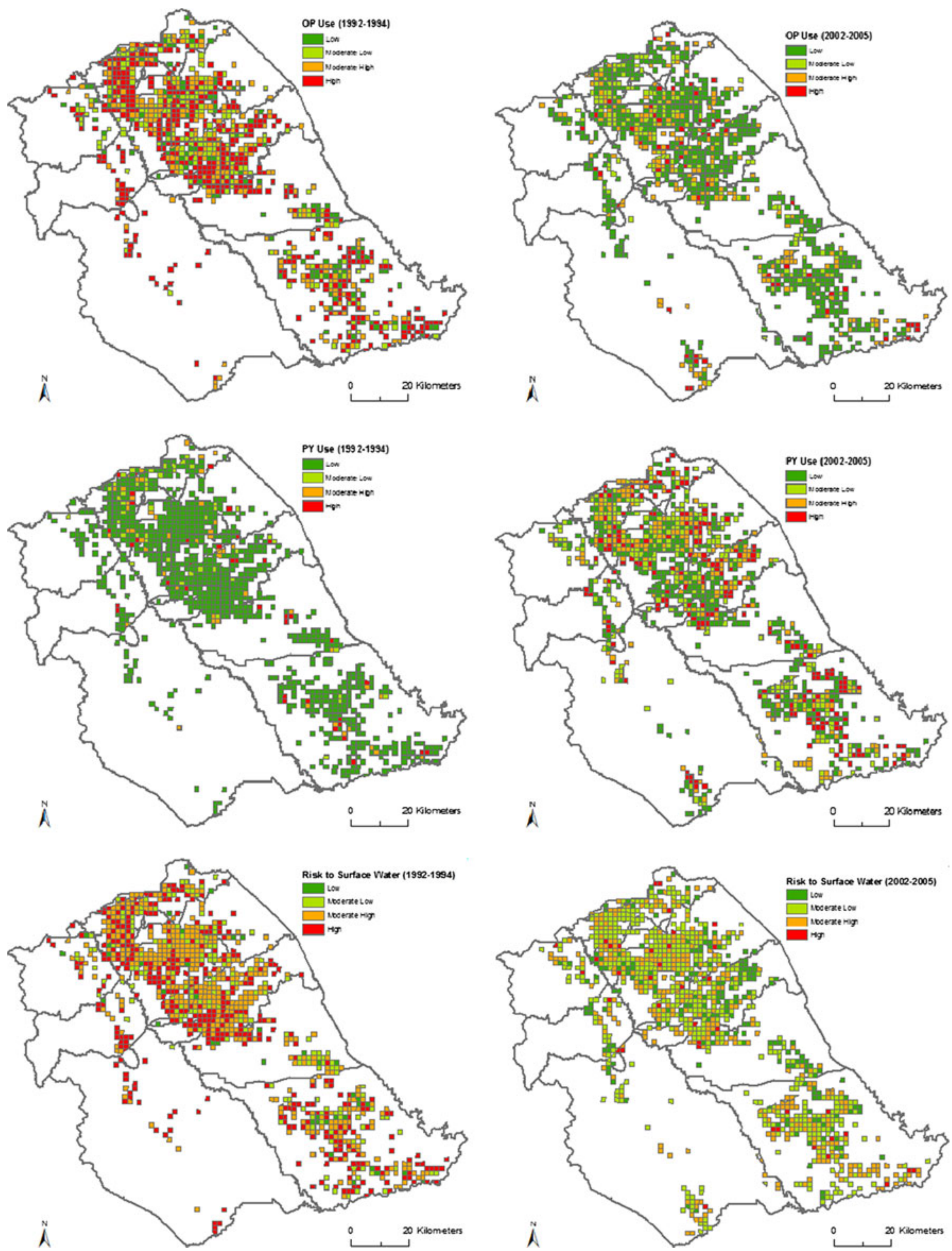

Fig. 4 Temporal changes of spatial distribution patterns of pesticide UI and their associated environmental risks. Categorization thresholds for low, moderate low, moderate high, and high are listed in Table 2

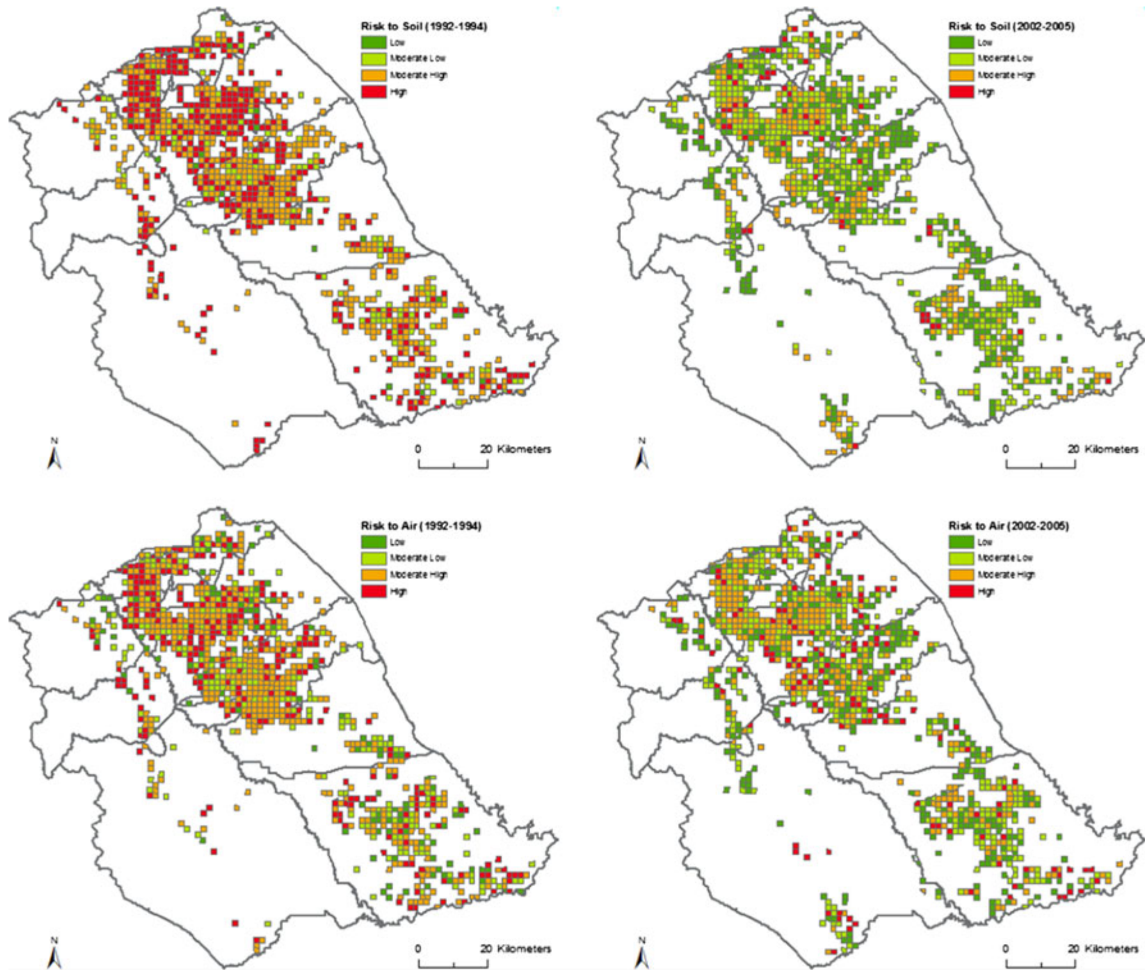

Fig. 4 (continued)

3.2 Spatial analysis for early 3 years (1992–1994) and late 3 years (2003–2005)

Table 2 gave the categorization of pesticide use intensity and their environmental risk. Based on quartile breaks, OP and PY UI were categorized into four groups: low (first quartile), moderate low (second quartile), moderate high (third quartile), and high (fourth quartile). The range of environmental risk values (0–100) was divided into four groups according to the mean and standard deviation of the risk value population: low, moderate low, moderate high, and high. The thresholds for risk were determined by the mean (μ=50) and standard deviation (σ=15). μ is the upper or lower limit for moderate low or moderate high respectively, $\mu-\sigma$=35 is the lower limit for moderate low, $\mu+\sigma$=65 is the upper limit for moderate higher, while the left and right ends of the remaining ranges were classified as low and high accordingly.

Based on the classification criteria in Table 2, we delineated the temporal trends of pesticide use and their associated risk (Fig. 4). OP UI decreased greatly from the early 3 years (1992–1994) to the late 3 years (2003–2005). During 1992–1994, most growers who used moderate high (1.68–2.33 kg/ha) and high (>2.35 kg/ha) OP UI, however, in the recent 3 years of 2002–2005, majority of growers who only used low OP UI (<0.90 kg/ha). On the contrary, most growers who used low UI of pyrethroid (<0.03 kg/ha) during 1992–1994 have changed to use moderate high (0.07–0.15 kg/ha) and high (>0.15 kg/ha) UI of pyrethroid in recent 3 years (2003–2005).

With the temporal changes of pesticide use intensity that OP decreased and pyrethroid increased, their associate environmental risks to soil, surface water, and air have greatly changed accordingly. It displayed in Fig. 4 that the environmental risks to soil, surface water, and air decreased greatly from the early 3 years of 1992–1994 to the late 3 years of 2003–2005. Especially for the environmental risks to soil and surface water, there are only few growers whose pesticides use posed high environmental risk during 2003–2005, which is almost opposite to that in 1992–1994.

3.3 Representative combination trends

Three representative grower pest management practices combinations were selected to study their pesticides use and associated environmental risks. Combination #1 include 135 growers who used decreasing OP and pyrethroid dosage during 1992–2005, combination #2 include 540 growers who used decreasing OP and increasing pyrethroid, and for the combination #3, 38 growers who used increasing OP and decreasing pyrethroid pesticides were included. One representative grower was selected from each combination to analyze their environmental risks.

Figure 5 displayed the statistical results of environmental risk trends for each representative combination grower. With the practice of decreasing OP and pyrethroid use, the environmental risks to soil, surface water, and air all decreased for the grower of combination #1. Induced by a decreasing OP use and an increasing pyrethroid use, the associated environmental risks still decreased for the grower of combination #2. However, when the OP use increased and pyrethroid use decreased for the grower of combination #3, their environmental risks to soil, surface water, and air all increased.

3.4 Environmental risks and biodiversity index

Animal occurrence count in the CNDDB on quadrangle basis were significantly negatively correlated with environmental

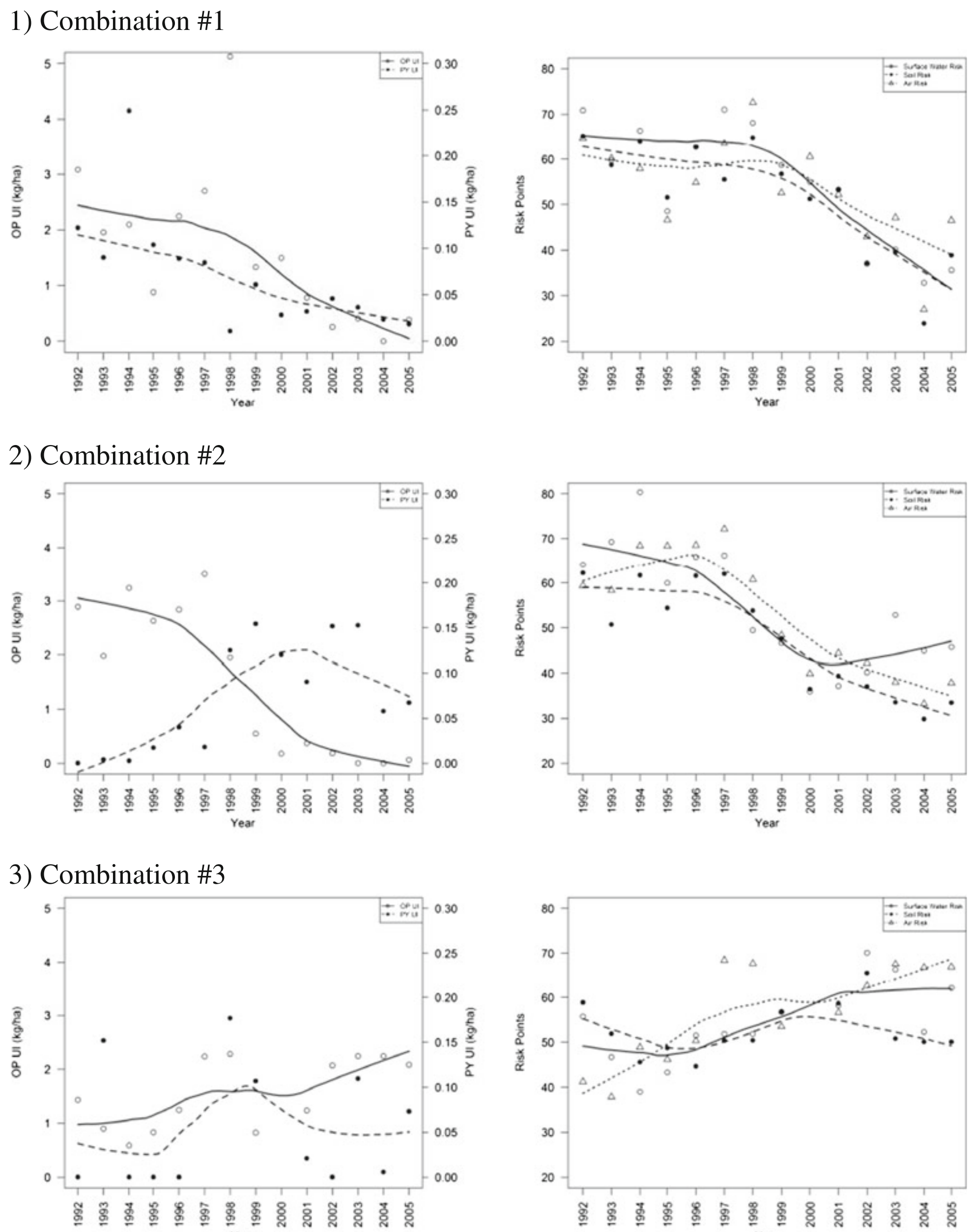

Fig. 5 The statistical results of environmental risk trends for each representative combination grower

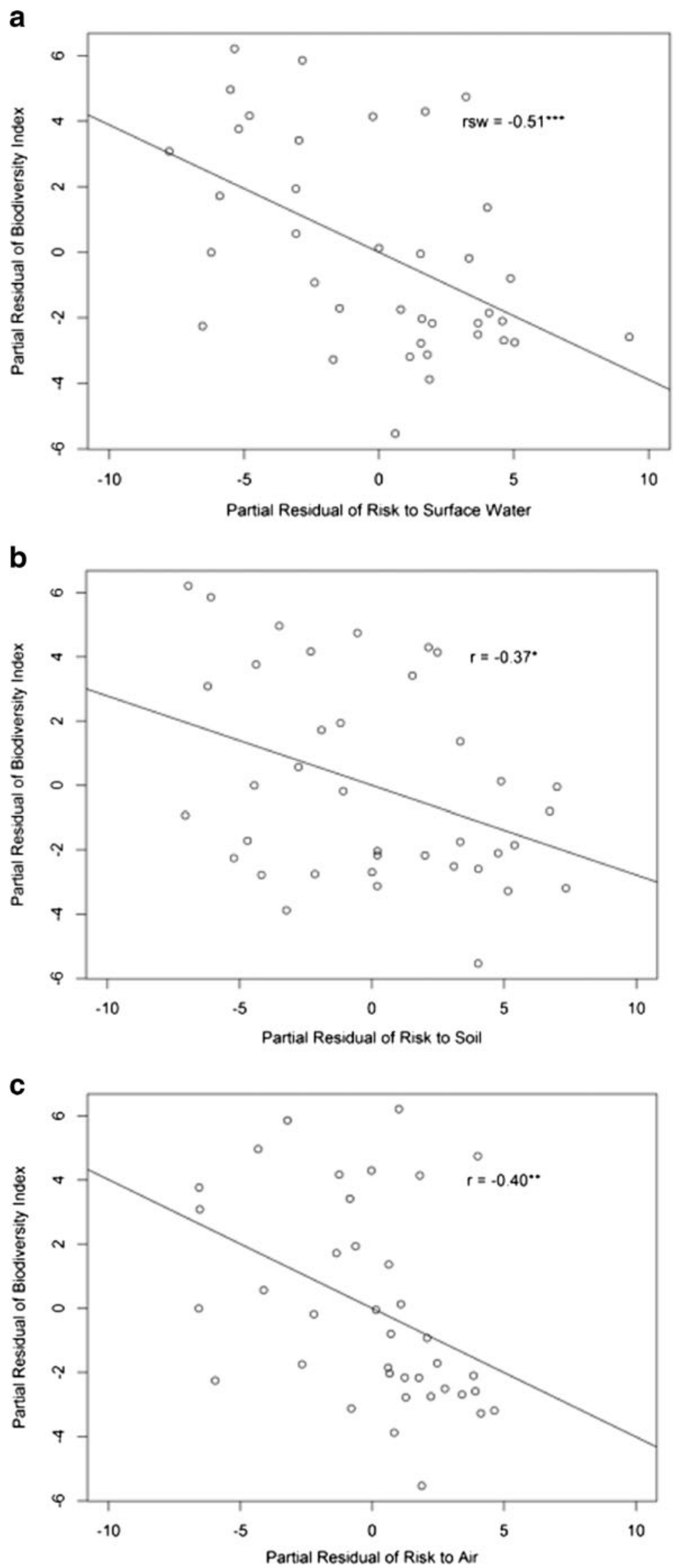

Fig. 6 Partial residuals of biodiversity index and environmental risk to **a** surface water, **b** soil, and **c** air during 1992–2005 on a quadrangle basis in the San Joaquin Valley (*solid line* the fitted linear regression line)

risk indices for surface water, soil, and air, with partial correlation coefficients of −0.51 (p<0.001), −0.37 (p< 0.05), and −0.40 (p<0.01), respectively (Fig. 6). Figure 7 shows the spatial relationship between biodiversity index and environmental risk to air and surface water (1992–2005). The averaged biodiversity index was more than 19 and 6 for quadrangles with low risk (<97 during 1992–2005) and high risk (>121) to air, respectively; while it was 26 and 8 for quadrangles with low risk (<28) and high risk (>42) to surface water, respectively.

4 Discussion

There was a reduction in OP use in almonds. In contrast, a converse result was found for pyrethroid pesticides. These results illustrate the profound changes in pest management strategies in the California almond farm community (Epstein et al. 2000, 2001; Grieshop and Raj 1992; California Department of Pesticide Regulation 2001; Swezey and Broome 2001). Part of the decline in OP use is the result of replacing OP with pyrethroid pesticides as a result of increased OP scrutiny, especially permethrin and esfenvalerate, which are less expensive than OP. In California, primarily three alternative insecticidal treatments were used: the microbial pesticide *Bacillus thuringiensis*, pyrethroids, and oil (Epstein et al. 2001). Zhang et al. (2005) found that the alternatives to OP, including pyrethroid, *B. thuringiensis*, oil alone, and even no treatment with insecticides in SJV, have all been increasing in recent years. In addition, there are other possibilities such as orchard sanitation and conserving beneficial arthropods in crops. These innovative farm practices have been reported as effective ways to reduce the use of more hazardous pesticides and achieve similar productivity (Hendricks 1995; Bentley et al. 1996; Thrupp 2001; Ruano et al. 2003). DPR and other agencies,

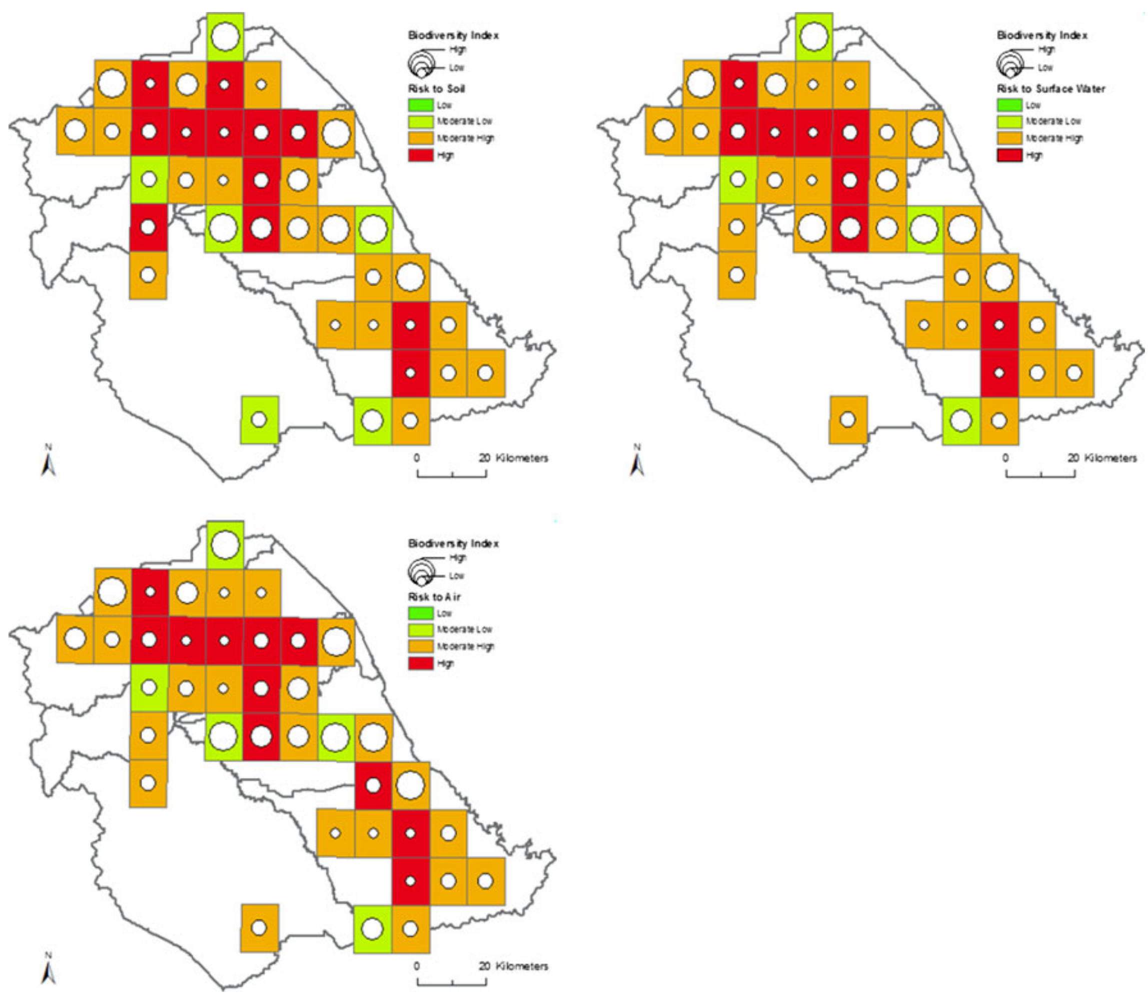

Fig. 7 Spatial patterns of the biodiversity index in CNDDB and predicted environmental risk to **a** air and **b** surface water in the San Joaquin Valley (map projection was adjusted to match the USGS quadrangles). Risk categorization thresholds for low, moderate low, moderate high, and high are list in Table 2. Biodiversity index are divided into four groups accordingly: 0–2 is low, 3–5 is moderate low, 6–8 is moderate low, 9–12 is moderate high

such as University of California Integrated Pest Management program and the California Environmental Protection Agency, have promoted an integrated approach in various projects during the 1990s (Swezey and Broome 2001; Thrupp 2001; California Department of Pesticide Regulation 2002) aimed at reduction or elimination of dormant pesticides.

One of the primary goals of the UC IPM program is to reduce the pesticide load in the environment (Zalom and Flint 1990). In addition, the California Environmental Protection Agency supports the use of IPM programs to reduce pesticide risk in California. Two characteristics of the Central Valley make it an area highly susceptible to contamination. First, the rainy season for the Central Valley occurs during the winter months, thus creating the potential for greater pesticide transport from rain induced runoff following winter spray applications (Domagalski 1997). Secondly, because almond orchard crops flourish in well-drained alluvial soils (Domagalski 1996), they are often located near river channels. As a result, OP and pyrethroid runoff can directly enter surface water (Brady et al. 2006). Though the environmental behavior of pyrethroid enantiomers is not well understood at present (Wong 2006), the model results in this study showed evidence that pyrethroid posed less pollution risk to soil, air, and water resources than OP. However, since the pyrethroid pesticides are more easily attached to sediment and persist longer in environment, they can be bioavailable to the aquatic food web. So, more future study on environmental model should address pyrethroid environmental risk on sediment.

The partial correlation statistics on biodiversity index indicated that pesticide uses and the consequent environmental risk had substantial negative impacts on the biodiversity. Although not all animal are necessarily vulnerable to the pesticides discussed in this study, the negative correlated spatial pattern between animal presence and risk indicators partially supported our results on environmental risk assessment. In addition, the animal species surveyed in the CNDDB reflects California's most imperiled elements of natural diversity. The intense agriculture in California is maybe the major reason not only for high pesticide use, but also for habitat loss, and then poses potential threats to biodiversity. Therefore, the risk assessment conducted in this study would be useful to help conserve California's biological diversity by providing information to promote agricultural management and land use decisions.

5 Conclusions

Our research results showed that OP pesticide use has been declined in any measurement in almonds. However, a converse result was found for pyrethroid pesticide. Pesticide use trends reflect the profound changes in pest management strategies in the California almond farm community. The model results of environmental risks to soil, surface water, and air in the study area and their temporal changes of spatial pattern showed that pyrethroid poses less environmental risk than OP. The statistical results of environmental risk trends for three representative combination growers with various pest management strategies further proved that OP posed more environmental risk than pyrethroid. And also, the partial correlation analysis in this study got a noticeable result that pesticide uses and their associated environmental risks pose negative impacts on biodiversity.

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