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Assessment of pesticide residues in army cutworm moths (*Euxoa auxiliaris*) from the Greater Yellowstone Ecosystem and their potential consequences to foraging grizzly bears (*Ursus arctos horribilis*)

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Abstract

During summer, a grizzly bear (*Ursus arctos horribilis*) in the Greater Yellowstone Ecosystem (GYE) (USA) can excavate and consume millions of army cutworm moths (*Euxoa auxiliaris*) (ACMs) that aggregate in high elevation talus. Grizzly bears in the GYE were listed as threatened by the US Fish and Wildlife Service in 1975 and were proposed for delisting in 2005. However, questions remain about key bear foods. For example, ACMs are agricultural pests and concern exists about whether they contain pesticides that could be toxic to bears. Consequently, we investigated whether ACMs contain and transport pesticides to bear foraging sites and, if so, whether these levels could be toxic to bears. In 1999 we collected and analyzed ACMs from six bear foraging sites. ACMs were screened for 32 pesticides with gas chromatography with electron capture detection (GC–ECD). Because gas chromatography with tandem mass spectrometry (GC–MS/MS) can be more sensitive than GC–ECD for certain pesticides, we revisited one site in 2001 and analyzed these ACMs with GC–MS/MS. ACMs contained trace or undetectable levels of pesticides in 1999 and 2001, respectively. Based on chemical levels in ACMs and numbers of ACMs a bear can consume, we calculated the potential of chemicals to reach physiological toxicity. These calculations indicate bears do not consume physiologically toxic levels of pesticides and allay concerns they are at risk from pesticides transported by ACMs. If chemical control of ACMs changes in the future, screening new ACM samples taken from bear foraging sites may be warranted.

Keywords: Army cutworm moth (*Euxoa auxiliaris*); Grizzly bear (*Ursus arctos horribilis*); Pesticides; Biomagnification; Greater Yellowstone Ecosystem

1. Introduction

Grizzly bears (*Ursus arctos horribilis*) in the lower 48 states of the USA were listed as threatened by the US Fish and Wildlife Service in 1975 (USFWS, 2003), and they were proposed for delisting in November of 2005. A conservation strategy was developed to facilitate delisting, meanwhile questions remain about some key bear foods (USFWS, 2003). For example, there is concern army cutworm moths (*Euxoa auxiliaris*) (ACMs) may contain pesticides that could bioaccumulate in bears (French et al., 1994).

ACMs are migratory noctuids native to North America. During their one-year lifespan they play important ecological roles in low elevations in the Great Plains and

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intermountain west as agricultural pests (Pruess, 1967) and in high elevations in the Rocky Mountains as an important food for grizzly bears (Mattson et al., 1991; French et al., 1994; White et al., 1998a,b). ACMs range from Kansas to California and from central Canada to Arizona and New Mexico (Burton et al., 1980). Their geographic distribution falls within historic grizzly bear range, encompassing the current range of remaining bear populations (Burton et al., 1980; Servheen, 1990).

ACMs oviposit in soil at low elevations, and larvae over-winter underground. Larvae surface in spring to feed on emergent crops and native plants, then burrow underground to pupate (Burton et al., 1980). Farmers control larval outbreaks with various pesticides (Table 1).

Adult moths emerge in late June and migrate hundreds of kilometers to alpine areas in the Rocky Mountains. Here they over-summer, feeding on flower nectar at night, forming large aggregations in talus during the day (Pruess, 1967; Mattson et al., 1991; French et al., 1994; Kevan and Kendall, 1997). While hiding in talus ACMs metabolize nectar into fat and increase their body fat up to 60% over the summer (Kevan and Kendall, 1997). Grizzly bears excavate ACMs from the talus, consuming millions from July through September (Mattson et al., 1991; French et al., 1994; White et al., 1999).

ACMs are the richest bear food in the Greater Yellowstone Ecosystem (GYE) and are an important food during pre-hibernation hyperphagia (Pritchard and Robbins, 1990; French et al., 1994). White et al. (1999) estimated a 115 kg grizzly bear could eat 40 000 ACMs day^{-1} and >1 million month^{-1}, representing 47% of its annual caloric budget (White, 1996; White et al., 1999). O'Brien and Lindzey (1994) estimated that approximately 45% of GYE grizzly bears used moth sites. However, this proportion is likely biased high because bears at moth sites are more conspicuous than bears in other habitats.

Table 1
Chemical compound screened, commercial name, chemical class, analysis method, and state where chemical was listed for controlling ACM larvae (USDA, 2001; NDSU, 2001a; NDSU, 2001b)

Chemical compound	Commercial name[a]	Chemical class[b]	Analysis method[c,d]	State where listed for control[e]
Aldicarb	Temik	C	n.a.	MT,WY
α-BHC, β-BHC, δ-BHC	–	OC	GC–ECD	–
Bifenthrin	Capture	P	n.a.	MT
Carbaryl	Sevin	C	GC–MS/MS	ID,NE,SD
Carbofuran	Furadan	C	n.a.	WY
Chlorpyrifos	Lorsban	OP	GC–ECD, GC–MS/MS	ID,MT,NE,SD,WY
cis-Chlordane, *trans*-Chlordane	–	OC	GC–ECD	–
Cyfluthrin	Baythroid, Tempo	P	n.a.	NE,SD
Dacthal	–	Alkyl phthalate	GC–ECD	–
o,p′-DDD, *p,p′*-DDD	–	OC	GC–ECD	–
o,p′-DDE, *p,p′*-DDE	–	OC	GC–ECD	–
o,p′-DDT, *p,p′*-DDT	–	OC	GC–ECD	–
Diazinon	–	OP	GC–ECD	–
Disulfoton	Di-Syston	OP	n.a.	WY
Dieldrin	–	OC	GC–ECD	–
Endosulfan, Endosulfan II, Endosulfan sulfate	Phaser, Thiodan	OC	GC–ECD, GC–MS/MS	MT
Endrin	–	OC	GC–ECD	–
Esfenvalerate	Asana XL	P	n.a.	MT,NE,SD
HCB, Hexachlorobenzene	–	OC	GC–ECD	–
Heptachlor, Heptachlor epoxide	–	OC	GC–ECD	–
Lambda cyhalothrin	Warrior, Karate	P	n.a.	MT,NE,SD,WY
Lindane	–	OC	GC–ECD	–
Malathion	Malathion	OP	n.a.	WY
Methomyl	Lannate	C	n.a.	ID,MT,NE
Methoxychlor	Marlate	OC	GC–ECD	MT
Methyl parathion	Methyl Parathion, Penncap-M	OP	n.a.	ID,NE,WY
Mirex	–	OC	GC–ECD	–
cis-Nonachlor, *trans*-Nonachlor	–	OC	GC–ECD	–
Oxychlordane	–	OC	GC–ECD	–
PCA, Pyrazon	–	Pyridazinone	GC–ECD	–
cis-Permethrin, *trans*-Permethrin	Pounce, Ambush	P	GC–ECD, GC–MS/MS	NE,WY
Terbufos	Counter	OP	n.a.	MT,WY
Trifluralin	–	2,6-dinitroaniline	GC–ECD	–

[a] Common names of some commercial products containing compound in first column.
[b] C, carbamate; OC, organochlorine; OP, organophosphate; P, pyrethroid.
[c] GC–ECD, gas chromatography with electron capture detection; GC–MS/MS, gas chromatography with tandem mass spectrometry.
[d] n.a. indicates chemicals for which ACMs were not screened.
[e] – Indicates chemicals not listed for control at the time of this study or those that were no longer registered for use.

Long distance transport of elements and chemicals from low to high elevations has been reported for alfalfa webworm moths (*Loxostege cereralis*), Bogong moths (*Agrotis infusa*), and other insects (Halfpenny, 1994; Green et al., 2001). Bogong moth and ACM ecology are similar. Bogong moths migrate from agricultural areas in southwestern Australia to the Snowy Mountains and the Victorian Alps. They aggregate in caves, forming the primary food of the endangered pygmy possum (*Burramys parvus*). Bogong moths contain arsenic, which they transport from low to high elevations, and pygmy possums consume it (Green et al., 2001).

Because grizzly bears consume millions of ACMs, concern exists about transport of pesticides that could bioaccumulate in bears (French et al., 1994).

1.1. Threats of pesticides

It is well known that potentially toxic elements and chemicals can persist in environments and bioaccumulate in organisms (Kelly et al., 2004). At the time of this study, carbamate, organophosphate, and pyrethroid chemicals were listed for controlling ACM larvae in the states of Idaho (ID), Montana (MT), Nebraska (NE), South Dakota (SD), and Wyoming (WY) (Table 1 and Fig. 1). MT also listed two organochlorine pesticides for control of ACM larvae (Table 1).

Organochlorines resist degradation and are ingested by organisms through their water and food (Schuurmann and Markert, 1998). They are soluble in fat, and the amount of fat in an organism influences chemical bioconcentration (Schuurmann and Markert, 1998). Organochlorines have bioaccumulated in various species including bald eagles (*Haliaeetus leucocephalus*) (Bowerman et al., 1998); ringed seals (*Phoca hispida*) and polar bears (*Ursus maritimus*) (Zhu and Norstrom, 1993); Western European river otters (*Lutra lutra*) (Leonards et al., 1997); and the food web comprising lichen (e.g., *Cladina rangiferina* and *Cetraria nivalis*), caribou (*Rangifer tarandus*), and wolves (*Canis lupus*) (Kelly and Gobas, 2001). Although some organochlorines are metabolized by most homeotherms and may not be stored in their tissues (Hoffman et al., 1995; Kamrin, 1997), they are suspected endocrine disrupters that may alter mating behavior, reproduction (Adeoya-Osiguwa et al., 2003), and development (Bevan et al., 2003).

Carbamates, organophosphates, and pyrethroids are metabolized and excreted by most organisms and rarely bioconcentrate in food chains (Smith and Stratton, 1986; Hill, 1995; Kamrin, 1997). However, they can alter animal behavior (Smith and Stratton, 1986; Hill, 1995), disrupt endocrine function (Colborn et al., 1993), inhibit reproduction and development (Mathur and Bhatnagar, 1991; Mantovani, 2002; Adeoya-Osiguwa et al., 2003), and have chronically toxic (Baron, 1991; Kamrin, 1997) and teratogenic effects (Mathur and Bhatnagar, 1991; Kamrin, 1997). Pyrethroids may be carcinogenic (Chen et al., 2002), but organophosphates and carbamates do not appear to be (Baron, 1991; Kamrin, 1997; Chen et al., 2002).

Thus, ACMs are controlled by pesticides that could potentially bioaccumulate and be physiologically toxic to bears (Kamrin, 1997 and references therein) (Table 1). Consequently, we investigated the following questions: (1) do ACMs transport pesticides to high elevation grizzly

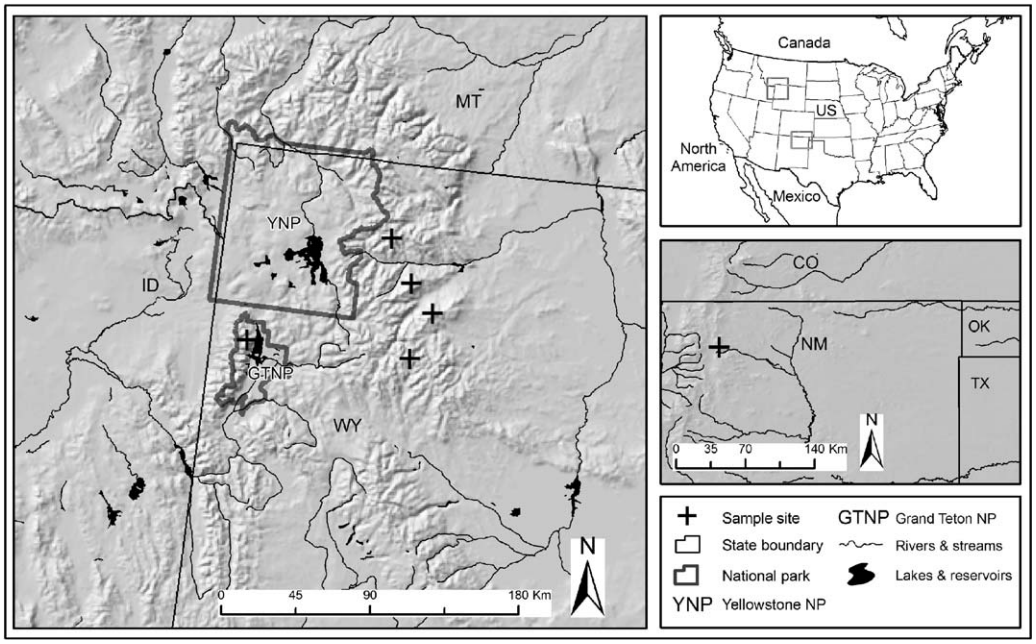

Fig. 1. ACMs sampling sites in the Greater Yellowstone Ecosystem ($N = 5$) and New Mexico ($N = 1$), 1999–2001.

bear foraging sites? (2) if so, do ACMs contain pesticide concentrations sufficient to reach physiological toxicity in grizzly bears?

2. Methods and materials

2.1. Study area

Our study area included the Absaroka and Teton mountain ranges of northwestern WY, USA (Fig. 1). The Absaroka Range runs north to south along the eastern border of Yellowstone National Park (YNP). Elevations range from 1830 m to 4006 m. The Teton Range runs north to south and is bordered north by YNP, east by Jackson Hole, west by the Teton Basin, and south and southeast by the Snake River and Gros Ventre ranges, respectively. Elevations range from 2133 m to 4197 m (Love et al., 2003). Deep valleys, cirques, sharp ridges, and floodplains characterize these ranges (Smith et al., 1993; Sundell, 1993; Love et al., 2003). Climate, geology, vegetation, and fauna have been described previously (Baker, 1944; Patten, 1963; Waddington and Wright, 1974; Dirks and Martner, 1982; Thilenius and Smith, 1985; Despain, 1990; Marston and Anderson, 1991; Sundell, 1993; Smith et al., 1993; Clark et al., 1999; Love et al., 2003).

ACMs aggregate in talus at elevations between 3024 and 3680 m located at the base of large headwalls above timberline. The talus typically contains rocks measuring 8–40 cm and lacks vegetation (Mattson et al., 1991). Alpine tundra and meadows are nearby and support the flowering plants on which ACMs feed.

2.2. Sampling

In 1999, we collected ACMs from each of four high elevation sites in the Absaroka Range and one site in the Teton Range (Fig. 1, see Table 2 for sample sizes). ACMs were collected from one site (Absaroka site 1) four times to evaluate potential temporal differences in pesticide levels. We also analyzed ACMs from an aggregation site used by American black bears (*Ursus americanus*) in New Mexico (Table 2 and Fig. 1). Samples were either stored in ethanol or air-dried and stored in envelopes. In 2001, we revisited Absaroka site 1 and collected additional ACMs, which were frozen shortly after collection.

2.3. Pesticide residue analyses

2.3.1. Gas chromatography with electron capture detection

In 1999, we screened ACMs for organochlorines, carbamates, organophosphates, and pyrethroids listed for controlling larvae in the states of ID, MT, NE, SD and WY (Table 1). Because farmers have used pesticides not listed for control of ACM larvae (e.g., diazinon [Robison, personal observation]), we also screened for additional chemicals.

Table 2
Aggregation sites where ACMs were collected organized by date, elevation, number of moths in sample (*n*), and chemical compound levels in the samples in ng ACM^{-1} when analyzed by GC–ECD[a]

Aggregation site	Date	Elevation (m)	*n*	Compound	ng ACM^{-1}
Absaroka site 1	13 July 1999	3400	60	*o,p′*-DDD	<1
				Diazinon	1
				Heptachlor	<1
				Heptachlor Epoxide	<1
				Oxychlordane	<1
				cis-Permethrin	4
				trans-Permethrin	3
Absaroka site 1	2 August 1999	3400	49	*o,p′*-DDD	<1
				Heptachlor	<1
				Heptachlor Epoxide	<1
				cis-Permethrin	2
				trans-Permethrin	2
Absaroka site 1	3 August 1999	3400	50	Chlorpyrifos	<1
				o,p′-DDD	<1
				Oxychlordane	<1
				cis-Permethrin	4
				trans-Permethrin	3
Absaroka site 1	19 August 1999	3400	69	β-BHC	<1
				Dacthal	<1
				Oxychlordane	<1
				cis-Permethrin	5
				trans-Permethrin	4
Absaroka site 2	21 July 1999	3438	50	β-BHC	1
				Diazinon	3
				Heptachlor	<1
				Heptachlor Epoxide	1
				cis-Permethrin	10
				trans-Permethrin	10
Absaroka site 3	26 July 1999	3390	52	Heptachlor Epoxide	<1
				Oxychlordane	<1
Absaroka site 4	15 August 1999	3352	78	Diazinon	<1
				Heptachlor Epoxide	<1
				Mirex	<1
				Oxychlordane	<1
				cis-Permethrin	6
				trans-Permethrin	4
New Mexico site	23 August 1999	3645	28	β-BHC	<1
				p,p′-DDE	<1
				Diazinon	<1
				Heptachlor Epoxide	<1
				Oxychlordane	<1
				cis-Permethrin	4
				trans-Permethrin	4
Teton site	25 August 1999	3075	38	Oxychlordane	<1
				cis-Permethrin	5
				trans-Permethrin	4

[a] Other compounds not listed were <MQL of 1 ppb and <MDL of 0.33 ppb.

ACMs were analyzed by the USGS Columbia Environmental Research Center (CERC), in Colombia, Missouri,

using gas chromatography with electron capture detection (GC–ECD) (Table 1). A detailed protocol is contained in Lebo et al. (2000). Samples were screened for 32 chemicals comprising a standard CERC pesticide-screening panel (Table 1). Sample dialysates and procedural controls were purified by size exclusion chromatography, and elutes were cleaned-up on Florisil® columns and screened for pesticides. For each compound, the method quantitation limit (MQL) was 1 ppb, and the method detection limit (MDL) was 0.33 ppb.

2.3.2. Gas chromatography with tandem mass spectrometry

Subsequent to analysis of ACMs collected in 1999, we learned GC with tandem mass spectrometry (GC–MS/MS) can be more sensitive for detecting certain contaminants than GC–ECD (Sheridan and Meola, 1999). Therefore, ACMs collected in 2001 were analyzed with GC–MS/MS by the Agricultural Experiment Station Analytical Laboratory at Montana State University, Bozeman. Analyses followed procedures in Sheridan and Meola (1999). ACMs were screened for six of the 32 compounds screened in the 1999 panel including chlorpyrifos, endosulfan I, endsodulfan II, endosulfan sulfate, *cis*-permethrin, and *trans*-permethrin (Table 1). ACMs were also screened for carbaryl, a chemical not included in the 1999 panel (Table 1) but listed for control of ACM larvae in ID, NE, and SD. The MQLs for GC/MS–MS analyses ranged from 10 to 60 ppb.

3. Results

The GC–ECD analyses indicate ACMs contain pesticide residues only in trace amounts (Table 2). Across all sampling sites and per ACM, 12 chemical compounds were found in amounts $\geqslant$MQL. Of these 12, seven were found in amounts of <1 ng ACM^{-1}. Five of the 12 were found in amounts $\geqslant 1$ ng ACM^{-1}.

Permethrin was the chemical detected in the highest amount (10 ng ACM^{-1}) in ACMs collected in 1999 (Table 2). If each of the 40 000 ACMs a 115 kg bear could eat in a day contained 10 ng of permethrin, it could consume 0.003478 mg kg bw^{-1} per day (Table 3). Other chemicals found in ACMs at amounts $\geqslant 1$ ng ACM^{-1} were β-HCH, diazinon, and heptachlor epoxide, which were found at levels of 1, 3, and 1 ng ACM^{-1}, respectively (Tables 2 and 3). The most liberal estimates of the amounts of these chemicals a bear could eat in a day are 0.000347, 0.001043, and 0.000347 mg kg bw^{-1} for β-HCH, diazinon, and heptachlor epoxide, respectively. None of these chemicals reached reported lethal or physiologically toxic levels in mammals (Table 3).

We did not observe temporal differences in pesticide levels in ACMs collected from Absaroka site 1 in 1999 (Table 2). ACMs from Absaroka site 2 contained almost twice as much permethrin as ACMs from other sites (Table 2). Pesticide levels detected in ACMs from New Mexico were similar to those of ACMs from Wyoming.

We did not detect chemicals in the ACMs collected in 2001 and screened by GC–MS/MS (Table 1).

4. Discussion

4.1. Potential chemical toxicity to bears

Our results indicate that although pesticides are present in ACMs in trace quantities, they are likely insufficient to cause direct effects on or to biomagnify in bears.

Analyses of toxicant levels in grizzly bear lipids have not been performed to date, and therefore, we could not calculate biomagnification factors for the chemicals we detected. Hence, we evaluated potential threats of these chemicals to bears based on their levels in ACMs and by comparing these levels to published toxicity values for the most closely related species to bears for which data exist (Table 3). Bears may be more or less sensitive than these species. To calculate conservative estimates of daily chemical ingestion by bears we used the maximum number of ACMs a bear can eat in a day and the maximum chemical levels detected in ACMs (Table 3). Thus, it is likely bears are not ingesting chemical levels approaching our estimates.

During this study, permethrin was listed for controlling ACM larvae in the states of NE and WY but not in the states of ID, MT, and SD. If bears are as sensitive to permethrin as are dogs (*Canis familiaris*) and rats (*Rattus* spp.), bears would have to eat >1400 and >40 000 times their estimated maximum daily ingestion rate to experience chronically toxic and endocrine disrupting effects, respectively (Table 3). The World Health Organization (WHO) acceptable human daily dietary intake (ADI) and the US Environmental Protection Agency (EPA) acceptable daily dose for humans over a 70-year lifetime (RfD) for permethrin are >14 times what a bear could potentially ingest in a day of eating ACMs (Lu, 1995; Kamrin, 1997) (Table 3). These estimates indicate bears are not consuming amounts that are likely to be physiologically toxic. Permethrin does not persist in environments or bioaccumulate (Smith and Stratton, 1986) and is unlikely to biomagnify in bears.

Although diazinon was not listed for controlling ACM larvae in the states of ID, MT, NE, SD, and WY, in 1999 it was detected in ACMs at Absaroka site 1 in trace amounts (Table 2). If bears are as sensitive to diazinon as are swine (*Sus* spp.) and rats, they would have to consume >9500 and >1400 times their estimated maximum daily ingestion rate to experience chronically toxic or endocrine disrupting effects (Table 3). The WHO ADI for diazinon is 1.9 times the maximum daily amount we estimated bears could ingest. At this rate bears would be eating 1.2 to 5.2 times the EPA RfD (Table 3). Diazinon does not appear to bioaccumulate, and bears do not consume physiologically toxic levels. However, our estimates indicate bears could potentially consume more than the acceptable daily level established by the EPA for humans.

ACMs could incorporate diazinon in various ways. Although it was not listed for controlling ACM larvae in

Table 3
Chemicals detected in ACMs > MQL, highest amounts, amount a bear could potentially eat in a day based on consuming 40 000 ACMs, LD_{50}s, amount a bear would have to eat to experience carcinogenic (C), chronic (CH), endocrine disrupting (ED), reproductive (R), or teratogenic (T) effects, the WHO ADI, and the US EPA RfD

Chemical	Highest chemical amount found in ACMs	Chemical amount a bear could eat in a day	LD_{50}	mg kg^{-1} per day a bear would have to consume to incur physiologically toxic effects					WHO ADI	EPA RfD
	ng ACM^{-1}	mg kg^{-1}	mg kg^{-1}	C	CH	ED	R	T	mg kg^{-1}	mg kg^{-1}
β-BHC	1	0.000347	2000[a,b]	⩾0.37[c,d]	⩾0.5[a,b]	⩾0.004[c,e]	⩾0.5[a,b]	no ⩽ 0.1[a,b]	n.a.[f]	n.a.[g]
Diazinon	3	0.001043	143[h,i]	no ⩽ 45[a,j]	⩾10[k,j]	⩾1.5[a,l]	⩾1.5[a,l]	⩾1.0[m,j]	0.002[f]	0.0002[n], 0.0009[a10]
Heptachlor epoxide	1	0.000347	39[a,o]	⩾1.2[a,j]	no ⩽ 0.1[m,j]	⩾5[a,p]	⩾0.5[a,q]	⩾5[a,j]	0.0005[r]	1.3×10^{-5}[g]
Permethrin	10	0.003478	430[a,j]	no[a,s]	no ⩽ 5[m,j]	no ⩽ 150[a,t]	⩾250[a,j]	no ⩽ 1800[a,s]	0.05[j]	0.05[j]
Chlorpyrifos	<1	<0.000347	=82[a,i]	no ⩽ 10 [a,j]	⩾1[m,j]	Yes[u]	no ⩽ 1[a,j]	⩾15[a,j]	0.01[j]	0.003[j]
Dacthal	<1	<0.000347	⩾3,000[a,j]	no ⩽ 500[a,j]	⩾800[m,j]	Yes[v]	no ⩽ 500[a,j]	no ⩽ 300[h,j]	n.a.[j]	0.01[w]
Heptachlor	<1	<0.000347	=40[a,i]	⩾1.2[a,j]	no ⩽ 0.1[m,j]	Yes[x]	⩾0.25[a,j]	⩾5[a,j]	0.0001[j]	0.005[j]
Mirex	<1	<0.000347	=100[m,i]	⩾0.25[a,y]	⩾0.25[a,y]	Yes[x]	⩾0.25[a,y]	⩾6[a,y]	n.a.[y]	0.0002[z]
Oxychlordane	<1	<0.000347	=19.1[a,a1]	no ⩽ 2[a,a1]	⩽2[a,a1]	⩾0.1[a2]	no ⩽ 1.5[a,a1]	⩾3[a,a1]	⩽0.001[a1]	0.0005[a3]
o,p′-DDD	<1	<0.000347	>4000[a,a4]	no < 0.3[a,a4]	no < 0.3[a,a4]	Yes[x,a5]	no < 0.3[a,a4]	Yes[a6]	0.005[a7]	0.0005[a8]
p,p′-DDE	<1	<0.000347	>880[a,a4]	>7.21[c,d]	no < 0.3[a,a4]	⩾200[a,a9]	no < 0.3[a,a4]	Yes[a6]	0.005[a7]	0.0005[a8]

no = no reported effect in these sources at or below levels indicated at the time of this writing.
n.a. = no level available at this time.
[a] Rat.
[a1] WHO (1984a).
[a2] Cassidy et al. (1994).
[a3] EPA (1997)-value for parent compound chlordane.
[a4] WHO (1979).
[a5] Klotz et al. (1996).
[a6] Dorner and Plagemann (2002)-parent compound DDT.
[a7] WHO (1979)-value for parent compound DDT.
[a8] EPA (2004d)-value for parent compound DDT.
[a9] Kelce et al. (1997).
[a10] EPA (1984).
[b] WHO (1991).
[c] Human.
[d] Quintana et al. (2004).
[e] Akkina et al. (2004).
[f] Lu (1995).
[g] EPA IRIS, 2002.
[h] Rabbit.
[i] Ramamoorthy et al. (1995).
[j] Kamrin (1997) and references therein.
[k] Swine.
[l] El Aziz et al. (1994).
[m] Dog.
[n] EPA (2004a)
[o] ATSDR (1993).
[p] Wango et al. (1997).
[q] WHO (1975).
[r] WHO (1984b).
[s] WHO (1990).
[t] Kunimatsu et al. (2002).
[u] Andersen et al. (2002).
[v] Colborn and Short (1999).
[w] EPA (2004b).
[x] Colborn et al. (1993) (and sources therein).
[y] WHO (1984c).
[z] EPA (2004c).

ID, MT, NE, SD, WY, it has been recommended for controlling other pests that feed on crops also eaten by ACM larvae (e.g., sugar beets) (Hein, 2003). So, it is possible that ACMs were not targets of diazinon control, but that they became contaminated with it. Alternatively, ACMs could have migrated to the mountains from states where use of

diazinon was recommended. Also, diazinon is commonly found in air, rain, and fog (EPA, 2001). Hence, it is possible ACMs became contaminated via these mediums.

β-HCH was not listed for controlling ACM larvae in ID, MT, NE, SD, and WY during this study, but it was detected in 1999 in trace amounts (Tables 2 and 3). If bears are as sensitive to β-HCH as are rats (*Rattus* spp.) and humans, they would have to consume >1400 and >11 times the estimated maximum daily ingestion rate to reach chronically toxic and endocrine disrupting levels, respectively (Table 3). There is currently no WHO ADI or EPA RfD for β-HCH. Therefore, we cannot determine whether bear consumption could be higher than the amounts acceptable for humans.

Neither heptachlor nor chlordane was listed for controlling ACM larvae, yet their metabolite heptachlor epoxide was detected at low levels in 1999 (Tables 2, 3). Bears would have to consume >280 and >14 000 times their estimated maximum daily ingestion rate to reach chronically toxic and endocrine disrupting levels (Table 3). This rate is >1.4 times the WHO ADI and >26 times the EPA RfD. Therefore, although bears ingest levels below those causing physiological toxicity, they could potentially consume amounts greater than those considered acceptable for humans.

The parent compounds of β-HCH (e.g., technical HCH) and heptachlor epoxide (e.g., heptachlor, chlordane) were banned in the USA in the 1970s and 1980s (ATSDR, 1993, 2003). Lindane, also a parent compound of β-HCH, has been restricted to specific seed treatments (ATSDR, 2003). Hence, detection of β-HCH and heptachlor epoxide in ACMs likely results from historic use of their parent compounds and their persistence in environments (Oliver and Nimi, 1988; ATSDR, 1993; Zhu and Norstrom, 1993). Although bears are not consuming physiologically toxic amounts of β-HCH and heptachlor epoxide they may potentially bioaccumulate in bears over time. However, the potential of moths to transport these chemicals will decrease as residues of their parent compounds decrease in the environment over time.

Although we were unable to analyze ACMs for residues of all chemicals listed for controlling larvae, we did analyze ACMs for residues of pesticides commonly listed and representing each of the four chemical classes listed to control larvae. Additionally, that GC–MS/MS did not detect chemicals detected by GC–ECD is not surprising because the GC–MS/MS analysis was less sensitive (i.e., the MQLs were higher than those for GC–ECD).

4.2. Management considerations

Results of this study indicate that ACMs do not transport biologically significant (i.e., physiologically toxic) levels of contaminants to high elevations and minimize concerns of chemical bioaccumulation in bears under current pesticide use. The low to undetectable levels we report are logical because ACMs produce most of their fat body in the alpine where pesticides are not used.

However, pesticide use remains relevant to bear conservation. When compared to domestic species typically used to determine chemical toxicities, bears have unique physiology including hyperphagia, brown fat accumulation, and torpor. This could result in differences in their assimilation or excretion of certain chemicals, particularly those stored in fat. Also, because available pesticides and their listed uses change, we recommend repeating this work as necessary in the future. We also recommend collection and pesticide residue analysis of grizzly bear tissue. These analyses should be performed on grizzly bear fat, blood or hair samples (Tsatsakis and Tutudaki, 2004 and references therein) taken from bears suspected of feeding at moth sites. Care must be taken to eliminate alternative sources of pesticides as they could confound residue levels attributable to ACMs. Additionally, we could not find literature documenting synergisms between the chemicals detected in ACMs. If synergisms are discovered, future studies will need to consider their effects.

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