INFORME SOBRE EL ESTADO DE LA MIGRACIÓN DE LA MARIPOSA MONARCA Y SOLICITUD PARA INCLUIR LA RESERVA DE LA BIÓSFERA MARIPOSA MONARCA EN LA LISTA DEL PATRIMONIO MUNDIAL EN PELIGRO

ABRIL DE 2015

AVISO DE SOLICITUD

Para:
The World Heritage Committee
c/o The Secretariat, World Heritage Centre
United Nations Educational, Scientific, and Cultural Organization
7 Place Fontenoy, 75352, Paris 07 SP, France
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Los Solicitantes mencionados debajo solicitan formalmente que el Comité del Patrimonio Mundial pida ayuda e incluya el Sitio de Patrimonio Mundial Reserva de la Biósfera Mariposa Monarca (Ref. 1290) en México a la Lista del Patrimonio Mundial en Peligro, de conformidad con su facultad otorgada según el Artículo 11, párrafo 4 de la Convención para la Protección del Patrimonio Cultural y Natural Mundial.

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Resumen ejecutivo

Esta solicitud pretende poner al tanto al Comité del Patrimonio Mundial de la UNESCO ("el Comité") sobre el estado del Patrimonio Mundial de la Reserva de la Biósfera Mariposa Monarca (Ref. 1290) en México, además de informar al Comité acerca de las amenazas al fenómeno migratorio de las mariposas monarca, en particular, el cambio en el uso del suelo y el uso de glifosato en el hábitat de reproducción de la especie, que justifican la inclusión de la propiedad en la Lista del Patrimonio Mundial en Peligro.

La Reserva de la Biósfera Mariposa Monarca ubicada en el centro de México protege lugares de hibernación críticos para la mariposa monarca (*Danaus plexippus*). La elevada concentración de mariposas que hiberna en la reserva es un fenómeno natural superlativo que confiere al lugar un Valor Universal Excepcional. Sin embargo, desde la década de 1990, la cantidad de mariposas monarca que hiberna en la Reserva de la Biósfera Mariposa Monarca ha disminuido en más del 90 por ciento. El censo de las mariposas monarca de la temporada de invierno 2013-2014 en México encontró los niveles de población más bajos de la historia: aproximadamente 33,5 millones de individuos ocupaban tan solo 0,67 hectáreas de la reserva. Esto constituye una disminución del récord registrado en 1996 cuando aproximadamente 1000 millones de mariposas ocuparon 18,19 hectáreas.[1] Si bien el censo más reciente realizado en diciembre de 2014 indicó un modesto aumento con aproximadamente 56,5 millones de mariposas que hibernaban en 1,13 hectáreas, el tamaño de la población que pasa el invierno en la Reserva sigue siendo peligrosamente pequeño.[2] Según la evaluación de la Perspectiva del Patrimonio Mundial 2014 de la Unión Internacional para la Conservación de la Naturaleza, el estado de conservación de la Reserva de la Biósfera Mariposa Monarca es "crítico" y su Valor de Patrimonio Mundial, es decir, la manifestación del fenómeno de migración de los insectos, se encuentra "en deterioro".[3]

Una compleja combinación de amenazas ha contribuido al deterioro del fenómeno migratorio de las mariposas monarca a lo largo de los años. Sin embargo, las investigaciones científicas recientes

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[1] E. Rendón-Salinas & G. Tavera-Alonso, *Monitoreo de la superficie ocupada por las colonias de hibernación de la mariposa monarca en diciembre de 2013,* CONANP/WWF-México Telcel Alliance informe de monitoreo. http://assets.panda.org/downloads/monitoreo_mariposa_monarca_en_mexico_2013_2014.pdf; Brad Plumber, *Monarch butterflies keep disappearing. Here's why,* Washington Post, Jan. 29, 2014, http://www.washingtonpost.com/blogs/wonkblog/wp/2014/01/29/the-monarch-butterfly-population-just-hit-a-record-low-heres-why/; *Alertan sobre reducción en la migración de la mariposa monarca a México,* Crónica, Jan.30, 2014, http://www.cronica.com.mx/notas/2014/812060.html.

[2] E. Rendón-Salinas et al., *Superficie forestal ocupada por las colonias de hibernación de la mariposa monarca en diciembre de 2014,* CONANP/WWF-México Telcel Alliance informe de monitoreo, http://awsassets.panda.org/downloads/superficie_ocupada_por_la_mariposa_monarca_2014_2015.pdf; Laura Zuckerman, *Monarch butterfly count rises as conservationists warn of extinction*, Reuters, Jan. 27, 2015, http://www.reuters.com/article/2015/01/27/us-usa-endangered-butterflies-idUSKBN0L02UU20150127.

[3] International Union for Conservation of Nature, *IUCN World Heritage Outlook, 2014: a conservation assessment of all natural World Heritage sites,* (2014) https://portals.iucn.org/library/node/44889, *see also* IUCN, *Site assessment for Monarch Butterfly Biosphere Reserve,* http://www.worldheritageoutlook.iucn.org/search-sites/-/wdpaid/en/903135?p_p_auth=5ihHhY7D

indica que la amenaza actual más urgente es la pérdida del hábitat de reproducción y la fuente alimentaria de las larvas en los Estados Unidos y Canadá relacionada con la expansión de la agricultura industrial y el uso de herbicidas que contienen el químico glifosato.[4] La población de la mariposa monarca demuestra una clara tendencia a la baja que pone en riesgo la capacidad de la especie de soportar mayores presiones debido a la pérdida forestal y al clima adverso. Si bien los esfuerzos de conservación han ayudado a disminuir la degradación forestal y la deforestación en la propiedad de forma significativa en los últimos años, esta amenaza no se ha eliminado por completo.[5] El clima extremo periódico, que puede verse agravado por el cambio climático, también constituye una amenaza. De hecho, en 2002, una tormenta arrasó con 273 millones de mariposas en tan solo dos colonias, una cantidad muy superior a la población que se calcula en la actualidad.[6]

Debido a que la disminución en la población de la mariposa monarca puede influir en la capacidad de la especie para soportar las amenazas de la degradación forestal y el clima adverso, es fundamental implementar medidas de mejora que puedan ayudar a incrementar el número mariposas monarca mediante la protección de su hábitat de reproducción y el algodoncillo, la fuente principal de alimento para las larvas. La naturaleza transfronteriza del fenómeno migratorio requiere de acciones de conservación en todos los países por los cuales viaja la mariposa monarca, y conforme al Artículo 6 de la Convención para la Protección del Patrimonio Cultural y Natural Mundial ("Convención del Patrimonio Mundial"), todos los Estados miembros tienen el deber de "prestar su concurso para…proteger, conservar y revalorizar el patrimonio natural".[7] Una forma eficaz de proteger la población migratoria de las mariposas monarca que hibernan en México sería la aplicación de restricciones de sentido común al uso del glifosato así como la implementación de programas de siembra de algodoncillo en los Estados Unidos y Canadá, a fin de mantener hábitat crítico de reproducción y la fuente alimentaria de la especie.

En conocimiento de esta grave amenaza a la vulnerable población restante de mariposas monarcas migratorias, respetuosamente solicitamos al Comité: *i)* evaluar la inclusión de la Reserva de la Biósfera Mariposa Monarca en la Lista del Patrimonio Mundial en Peligro mediante el envío de una misión de investigación al bien en México y al hábitat de reproducción crítico en los Estados Unidos, a fin de evaluar la necesidad de tomar medidas de mejora; *ii)* instar a los Estados miembros de la Convención por los cuales viaja la mariposa monarca durante su ciclo de vida —es decir, Canadá, Estados Unidos y México— a que intensifiquen sus esfuerzos para proteger el hábitat de las

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[4]D.T. Flockhart, *Unravelling the annual cycle in a migratory animal: breeding-season habitat loss drives population declines of monarch butterflies,* Journal of Animal Ecology, Volume 84, Issue 1 (Jan. 2015), http://onlinelibrary.wiley.com/doi/10.1111/1365-2656.12253/abstract

[5]O.Vidal et al, *Trends in deforestation and forest degradation after a decade of monitoring in the Monarch Butterfly Biosphere Reserve in Mexico*, Conservation Biology, Volume 28, Issue 1 (Sept. 3, 2013) http://onlinelibrary.wiley.com/doi/10.1111/cobi.12138/pdf

[6]L. Brower et al. *Catastrophic Winter Storm Morality of Monarch Butterflies in Mexico during January 2002*, Oberhauser, K.S. & SM.J. Solensky, eds., The Monarch Butterfly: Biology and Conservation, Cornell University Press, (2004), http://monarchlab.org/biology-and-research/research/publications/#overwintering

[7]Convention Concerning the Protection of the World Cultural and Natural Heritage, Nov. 16, 1972 at Art 6(2) [World Heritage Convention]

mariposas de las amenazas existentes y *iii)* ayudar a generar consciencia acerca de la necesidad urgente de restaurar y proteger el hábitat de reproducción de la mariposa monarca. Asimismo, solicitamos que, conforme a los resultados de la misión de investigación, el Comité emita recomendaciones sobre medidas de mejora para ayudar a limitar el impacto adverso del uso de glifosato sobre la población de la mariposa monarca.

I. Antecedentes: Reserva de la Biósfera Mariposa Monarca

La Reserva de la Biósfera Mariposa Monarca, ubicada entre los estados centrales mexicanos de Michoacán y el Estado de México, protege el hábitat crítico donde la mariposa monarca pasa el invierno. Cada año, en una de las migraciones de insectos más largas del mundo, millones de mariposas monarca completan un espectacular viaje multigeneracional de más de 4000 kilómetros (km) desde zonas de reproducción en Canadá y Estados Unidos hacia este hábitat de invierno. Las mariposas comienzan a llegar a los bosques de la reserva de la biósfera a principios de noviembre, donde permanecen durante el invierno. La generación final que emerge a mediados de agosto completará el ciclo migratorio al viajer de vuelta a los sitios de hibernación en México. En la reserva, las millones de mariposas que hibernan forman densas colonias que tapizan las ramas de los árboles que les brindan refugio de los elementos. La siguiente primavera, las mariposas comienzan el viaje de retorno hacia el norte y se reproducen en Texas y en los estados vecinos del este y el norte. Los descendientes de estas mariposas continúan su viaje hacia el este de los Estados Unidos y el sur de Canadá. Se producen hasta tres generaciones más.[8]

Los sitios de hibernación de las mariposas monarcas en México recibieron protección por primera vez en 1980, cuando se decretaron como zonas de reserva y refugios de fauna silvestre. En ese momento, no se identificaron áreas específicas a ser conservadas y las actividades de extracción se restringieron solamente durante el período de hibernación. En 1986, el poeta y ambientalista mexicano Homero Aridjis logro convencer al gobierno mexicano de que las mariposas monarca requerían mayor protección. En abril de ese año, coincidente con el Día del Niño en México, el gobierno anunció su intención de crear un santuario para la mariposa monarca.[9] En octubre, se identificaron cinco santuarios (un total de 16 110 hectáreas entre las zonas núcleo y de amortiguamiento), que fueron designados como áreas protegidas en el *Diario Oficial de la Federación*. Las actividades de extracción se prohibieron en las zonas núcleo, pero se permitió el aprovechamiento sustentable de recursos en las zonas de amortiguamiento. Posteriormente, como resultado del diálogo entre comunidades ejidatarias,[10] otras comunidades afectadas y el sector de conservación, la reserva se expandió aún más y se creó un sistema de compensación económica a los ejidos y las comunidades. La actual Reserva de la Biósfera Mariposa Monarca se creó mediante a un decreto publicado en el

[8] O. Vidal and E. Rendón-Salinas, *Dynamics and trends of overwintering colonies of the monarch butterfly in Mexico*, Biological Conservation, 180 (Dec. 2014), http://www.sciencedirect.com/science/article/pii/S0006320714003589 .
[9] H.Aridjis and B. Ferber, *Noticias de la Tierra,* Debate/Random House, Mondadori, Mexico (2012), at 82-83.
[10] En México, un ejido es una zona de tierras comunales que los miembros individuales de la comunidad poseen y utilizan tradicionalmente para la agricultura.

Diario Oficial de la Federación el 10 de noviembre de 2000 con una superficie total de 56 259 hectáreas. La reserva expandida unió a los santuarios previamente aislados para mejorar la protección de los sitios de hibernación de las mariposas. La reserva se compone de tres zonas núcleo con una superficie de 13 551 hectáreas rodeadas por zonas de amortiguamiento que alcanzan un total de 42 707 hectáreas.[11]

En 2008, Aridjis trabajó una vez más para resaltar la necesidad de proteger el hábitat de hibernación de las mariposas monarca cuando, como embajador de México ante la UNESCO, se movilizó para que la Reserva de la Biósfera Mariposa Monarca se declare Patrimonio Mundial de la UNESCO.[12] La decisión del Comité del Patrimonio Mundial de inscribir la propiedad en la Lista del Patrimonio Mundial reconoció que la Reserva de la Biósfera de Mariposa Monarca tenía un "Valor Universal Excepcional" (VUE) debido a que la concentración de mariposas monarca que hiberna en la propiedad es un "fenómeno natural superlativo" que es la "manifestación más significativa del fenómeno de la migración de insectos". El Comité adoptó una Declaración de Valor universal Excepcional que destacó que "presenciar este fenómeno único es una experiencia excepcional de la naturaleza".[13] Es importante destacar que el Comité también observó que, además de proteger los bosques de la reserva en México donde las mariposas hibernan, el mantenimiento del "fenómeno de hibernación también requiere atención a la conservación de las mariposas monarca por parte de los países por los que viajan las mariposas durante su ciclo de vida".[14]

II. Estado de la población de la mariposa monarca en Norteamérica

La abundancia de mariposas que hibernan en la Reserva de la Biósfera Mariposa Monarca ha experimentado un importante declive desde finales de 1990. Los científicos calculan la población de mariposas que hibernan en función de la cantidad de hectáreas de la reserva ocupadas con colonias de mariposas.[15] Se calcula que la concentración de mariposas en la reserva llegó hasta aproximadamente 1000 millones de ejemplares que ocupaban 18,19 hectáreas (ha) en la temporada de hibernación

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[11] C. Galindo-Leal and E. Rendón-Salinas, *Danaidas: Las Maravillosas Mariposas Monarca,* WWF México-Telcel. Special Publication No. 1 (2005), at 50-53, http://awsassets.panda.org/downloads/2005_danaidas_las_maravillosas_mariposas_monarca_galindo_rendon_wwf.zip.

[12] H.Aridjis and B. Ferber, *Noticias de la Tierra,* Debate/Random House, Mondadori, Mexico (2012), at 127-128.

[13] Decision 32 COM 8B.17, WHC-08/32.COM/24Rev, Quebec City 2008, at 159 (Examination of nomination of natural, mixed and cultural properties to the World Heritage List – Monarch Butterfly Reserve, Mexico), http://whc.unesco.org/archive/2008/whc08-32com-24reve.pdf (the decision found the property met the World Heritage Convention Operational Guidelines' Outstanding Universal Value Criterion (vii) of "contain[ing] superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance"); UNESCO World Heritage Committee, *Operational Guidelines for the Implementation of the World Heritage Convention* , WHC 13/01 at II.D(77) (July 2013) [WHC Operational Guidelines]

[14] *Id.*

[15] W. Caldwell, *2015 Population Update and Estimating the number of Overwintering Monarchs in Mexico,* Monarch Joint Venture (Jan. 27,2015)
(Los científicos estiman que hay cerca de 50.000 mariposas por hectárea), http://monarchjointventure.org/news-events/news/2015-population-update-and-estimating-the-number-of-overwintering-monarchs

1996-1997.[16] Para el invierno 2013-2014, el censo de mariposas monarca en México encontró los niveles de población más bajos de la historia: la ocupación era de solo 0,67 ha, que representa una cifra aproximada de 33,5 millones de ejemplares.[17] El censo 2014-2015 detectó que se ocuparon 1,13 ha de bosques, un aumento del 68,7 % con respecto al año anterior, atribuible a mejores condiciones climáticas durante la temporada de reproducción. A pesar de este aumento, el cálculo de la población que hiberna de aproximadamente 56,5 millones sigue siendo el segundo nivel más bajo desde 1993.[18] La última densidad registrada también se encuentra muy por debajo de las 4 a 5 hectáreas que los expertos considerarían como un indicio de recuperación significativa.[19]

III. Amenazas a la mariposa monarca en Norteamérica

Una compleja combinación de amenazas ha contribuido al deterioro drástico del fenómeno migratorio de la mariposa monarca. La amenaza más urgente actualmente es la pérdida del hábitat de reproducción y de la fuente de alimento de las larvas en los Estados Unidos y Canadá vinculada con prácticas agrícolas que incluyen el aumento del uso del herbicida glifosato, lo cual contribuye a una menor producción de mariposas monarca. Asimismo, la tendencia de poblaciones más pequeñas disminuye la capacidad de la especie de soportar otras presiones, tales como la degradación forestal y las condiciones climáticas adversas.

Según la evaluación de la Perspectiva del Patrimonio Mundial 2014 de la Unión Internacional para la Conservación de la Naturaleza (IUCN), el estado de conservación de la Reserva de la Biósfera Mariposa Monarca es "crítico" y su Valor de Patrimonio Mundial,es decir, la manifestación del fenómeno de migración de los insectos, se encuentra "en deterioro". La evaluación del IUCN destaca que, entre otros elementos, la tala y el cambio/la alteración del hábitat debido al cambio climático constituyen amenazas a la propiedad. De forma significativa, la evaluación reconoce que otras amenazas fuera del control de la gestión de la propiedad, tales como los agroquímicos en todo el rango de la mariposa monarca, también constituyen riesgos "muy elevados".[20]

A. Impacto del glifosato sobre el fenómeno migratorio de la mariposa monarca

El glifosato es un herbicida que se utiliza para muchas actividades agrícolas y no agrícolas en los Estados Unidos y Canadá.[21] La Agencia Estadounidense de Protección Ambiental (EPA por sus siglas en inglés) ha aprobado el uso de glifosato para más de 100 cultivos agrícolas, incluidos frutas,

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[16] E. Rendón-Salinas & G. Tavera-Alonso, *supra* note 1.
[17] *Id*.
[18] E. Rendón-Salinas et al. *supra* note 2; Zukerman *supra* note 2.
[19] *Monarch butterflies rebound but levels in Mexico still at near-record low*, The Guardian, Jan. 27, 2015, http://www.theguardian.com/environment/2015/jan/27/monarch-butterflies-rebound-mexico-near-record-low

[20] International Union for Conservation of Nature, *supra* note 3.
[21] U.S. EPA, Glyphosate Final Work Plan (FWP): Registration Review Case No. 0178, at2 (2009) [2009 Glyphosate Final Work Plan].

verduras y cultivos de campo.[22] El glifosato también se permite para usos en entornos no agrícolas, generalmente para lograr un control total de la vegetación.[23] Las áreas no agrícolas en las cuales se aplica el glifosato incluyen zonas residenciales, industriales, forestales, de invernaderos, ornamentales y acuáticas, entre otras.[24]

El glifosato ha contribuido a una pérdida significativa del hábitat a lo largo de rutas migratorias de la mariposa monarca, principalmente en los Estados Unidos. El aumento en la aplicación de glifosato en el centro occidental estadounidense, impulsado por la adopción generalizada de cultivos genéticamente modificados para ser resistentes al glifosato, ha disminuido de forma drástica la presencia de algodoncillo (la única fuente alimentaria de las larvas de las mariposas monarca) durante la última década. La eliminación del algodoncillo, a su vez, ha contribuido a un profundo declive en la población de la mariposa monarca. En 1997, antes de la adopción generalizada de los cultivos resistentes al glifosato, aproximadamente 1000 millones de mariposas monarca viajaban entre el hábitat de verano en los Estados Unidos y Canadá y los sitios de hibernación en México.[25] En un marcado contraste, durante la temporada de hibernación 2013-2014 solamente 33,5 millones de mariposas llegaron a su refugio invernal.[26] Los científicos han advertido que la migración anual de mariposas monarca puede estar en riesgo de desaparecer.[27]

i. Aumento significativo del uso de glifosato desde la década de 1990

Como herbicida no selectivo,[28] el glifosato no discrimina entre las especies vegetales objetivo y no objetivo. En los Estados Unidos, la EPA aprobó el glifosato para uso en pesticidas por primera vez en 1974.[29] Sin embargo, debido al daño a los cultivos, inicialmente el uso del glifosato era limitado.[30] En un año típico entre 1989 y 1991, se aplicaron aproximadamente 8,5 millones de kilogramos de glifosato como ingrediente activo en pesticidas a entre 5,2 y 8 millones de hectáreas.[31] De de esta cantidad total de glifosato empleado en todos los tipos de terrenos, se aplicaron entre 498 952 y 544 311 kilogramos del herbicida a entre 526 092 y 687 966 hectáreas de maíz. También se aplicaron

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[22] *Id.*
[23] U.S. EPA, Reregistration Eligibility Decision Facts: Glyphosate 1 (1993) [1993 Glyphosate R.E.D. Facts].
[24] 2009 Glyphosate Final Work Plan, *supra* note 19, at 2; 1993 Glyphosate R.E.D. Facts, *supra* note 21, at 1.
[25] Michael Wines, *Migration of Monarch Butterflies Shrinks Again Under Inhospitable Conditions*, N.Y. Times, Jan. 29, 2014, http://www.nytimes.com/2014/01/30/us/monarch-butterflies-falter-under-extreme-weather.html?_r=0; Sylvia Fallon, Monarch Butterfly Population Hits a New Low, *Switchboard: Natural Resources Defense Council Staff Blog* (Jan. 29, 2014), http://switchboard.nrdc.org/blogs/sfallon/monarch_butterfly_population_h.html; O. Vidal and E. Rendón-Salinas, *supra* note 8.
[26] *Id.*
[27] *Id.; see also* Michael Wines, *Monarch Migration Plunges to Lowest Level in Decades*, N.Y. Times, Mar. 13, 2013; *see also* Tracy Wilkinson, *U.S., Mexico and Canada are Asked to Protect Monarch Butterflies*, L.A. Times, Feb. 14, 2014.
[28] 2009 Glyphosate Final Work Plan, *supra* note 19, at 2
[29] Nat'l Pesticide Info. Ctr., Glyphosate Technical Fact Sheet 1, *available at* http://npic.orst.edu/factsheets/glyphotech.pdf.
[30] *See* J.M. Pleasants & K.S.Oberhauser, *Milkweed Loss in Agricultural Fields Because of Herbicide Use: Effects on the Monarch Butterfly Population,* Insect Conservation and Diversity1, 2 (2012).
[31] Special Review and Reregistration Div., Office of Pesticide Programs, U.S. EPA, Reregistration Eligibility Decision Document: Glyphosate 9 (1993) [1993 Glyphosate R.E.D.].

entre 997 903 y 1 088 622 kilogramos del herbicida a entre 1 y 1,9 millones de hectáreas de soja.[32] En 1993, cuando la EPA decidió volver a aprobar el glifosato para el uso en pesticidas, se supuso que se utilizaba conforme a estos cálculos.[33]

Sin embargo, desde mediados de la década de 1990, la agricultura estadounidense ha adoptado variedades de cultivos genéticamente modificados para ser resistentes al glifosato. La soja resistente al glifosato apareció por primera vez en 1996,[34] seguida por el maíz resistente al glifosato en 1998.[35] Hacia 1999, la soja resistente al glifosato representó la mayoría de todos los cultivos de soja.[36] La ascendencia de los cultivos resistentes al glifosato se refleja en los datos del denominado "cinturón de maíz y soja" de Estados Unidos; por ejemplo, hacia 2006, el 75 % de los agricultores del estado de Iowa reportó que plantaba cultivos resistentes al glifosato.[37] Hacia 2011, el 94 % de todos los cultivos de soja, y el 72 % de todos los cultivos de maíz, eran resistentes al glifosato.[38]

La proliferación de cultivos resistentes al glifosato facilitó una drástica expansión en el uso del glifosato.[39] En un análisis del uso basado solamente en cifras reportadas, la EPA calculó que, en un año promedio entre 2004 y 2011, el 95 % de todos los cultivos de soja y el 60 % de todos los cultivos de maíz se trataron con glifosato; esto requirió el uso de 39,1 millones de kilogramos de glifosato anuales en el caso de la soja y de 24,7 millones de kilogramos de glifosato anuales en el caso del maíz.[40] Entre 2008 y 2009, aproximadamente 82,5 millones de kilogramos de glifosato[41] se aplicaron a más de 105,6 millones de hectáreas[42] —una suma diez veces mayor a las cantidades y la superficie utilizadas para sustentar la decisión de la EPA cuando volvió a aprobar el glifosato en 1993.

ii. Aumento del uso de glifosato y su contribución fundamental al deterioro de la población de la mariposa monarca

El uso expandido del glifosato ha contribuido a una drástica disminución en los niveles de población de la mariposa monarca mediante la eliminación a gran escala del algodoncillo. El algodoncillo es una planta perenne de la familia *Asclepiadaceae*, y el algodoncillo común es nativo del centro norte y

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[32] *Id.* At 7-8
[33] *See id*. at 8-9.
[34] G.M. Dill et al., *Glyphosate-resistant Crops: Adoption, Use and Future Considerations*, 64 Pest Mgmt.Sci. 326 (2008).
[35] Pleasants & Oberhauser, *supra* note 28, at 2.
[36] R.G. Hartzler, *Reduction in Common Milkweed (Asclepias Syriaca) Occurrence in Iowa Cropland from 1999 to 2009*, 29 Crop Protection 1542, 1542 (2010).
[37] *Id*.
[38] Pleasants & Oberhauser, *supra* note 28, at 2.
[39] *See* Pleasants & Oberhauser, *supra* note 28, at 1-2; Ctr. for Food Safety, Comments to EPA on Opening of Glyphosate Docket for Registration Review 2-8 (Sept. 21, 2009) [2009 Ctr. for Food Safety Comments].
[40] Memorandum (EPA Updated Screening Level Usage Analysis (SLUA) Report in Support of Registration Review of Glyphosate) from Sepehr Haddad, Envtl. Prot. Specialist, Bio. and Econ. Analysis Div., EPA, to Carissa Cyran, Chem. Review Manager, Pesticide Reevaluation Div., EPA (Dec. 6, 2012).
[41] 2009 Ctr. for Food Safety Comments, *supra* note 37, at 4 (conversión de la estimación de la EPA de 135 millones de libras de glifosato en forma de equivalente de ácido a 182 millones de libras de glifosato en forma de sal de isopropilamina, la forma más común de glifosato como ingrediente activo).
[42] Am. Farm Bur. Fed'n, Comments to EPA in Support of Reregistration of Glyphosate 1 (Sept. 17, 2009).

el noreste de los Estados Unidos.[43] Los miembros de esta familia de plantas constituyen la única fuente de alimento para las larvas de la mariposa monarca.[44] El análisis de isótopos estables ha revelado que el 50 % de la población de mariposas monarcas de Norteamérica que hiberna en México se alimenta de algodoncillo en el centro occidental de los Estados Unidos durante su ciclo de vida.[45]

El glifosato se aplica en parte para controlar el algodoncillo.[46] Sin embargo, tal como se describe en las secciones anteriores, debido a que el glifosato también es perjudicial para los cultivos, su uso no se generalizó hasta la creación y la aprobación de los cultivos resistentes al glifosato. El rápido reemplazo de las variedades de cultivos tradicionales con variedades resistentes al glifosato aceleró considerablemente el aumento en el uso del glifosato, lo cual contribuyó a una disminución significativa en las comunidades de algodoncillo. Por ejemplo, antes de la adopción generalizada de los cultivos resistentes al glifosato, un sondeo de 1999 de las cosechas en Iowa reveló que aproximadamente el 50 % de todos los campos de maíz y soja contenían algodoncillo común.[47] Hacia 2009, el algodoncillo estaba presente solamente en el 8 % de los campos sondeados.[48] Asimismo, el área ocupada por el algodoncillo común en estos campos disminuyó en un 90 %.[49] Desde 1996, la adopción de maíz y soja resistente a herbicidas ha contribuido a la pérdida de aproximadamente 60,7 millones de hectáreas del hábitat para las mariposas monarca; esta pérdida probablemente aumente, ya que los terrenos no cultivados se convierten cada vez más en campos plantados con cultivos resistentes al glifosato.[50]

Ha habido una pérdida pronunciada del hábitat agrícola y no agrícola para la mariposa monarca desde la adopción de los cultivos resistentes al glifosato.[51] Sin embargo, el algodoncillo agrícola ha desaparecido a una mayor velocidad, y su pérdida es especialmente perjudicial para la mariposa monarca.[52] Estudios han demostrado que las mariposas monarca en el centro occidental de los Estados Unidos preferentemente utilizan el algodoncillo en el hábitat agrícola frente al hábitat no agrícola. Los campos de soja y maíz producen más de 70 veces más mariposas monarca que los

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[43] R.G. Hartzler & D.D. Buhler, *Occurrence of Common Milkweed (Asclepias syriaca) in Cropland and Adjacent Areas*, 19 Crop Protection 363, 363 (2000).
[44] *Id.*
[45] L.I. Wassenaar & K.A. Hobson, *Natal Origins of Migratory Monarch Butterflies at Wintering Colonies in Mexico: New Isotopic Evidence*, 95 Proc. Nat'l Acad. Sci. U.S. 15436, 15439 (1998).
[46] *See* Pleasants & Oberhauser, *supra* note 28, at 2; W.A. Pline et al., *Weed and Herbicide-resistant Soybean (Glycine max) Response to Glufosinate and Glyphosate Plus Ammonium Sulfate and Pelargonic Acid*, 14 Weed Tech. 667, 667 (2000).
[47] Hartzler, *supra* note 34, at 1542.
[48] *Id.*
[49] *Id.*
[50] *See* Chip Taylor, *Monarch Population Status*, MonarchWatch.org (Jan. 29, 2014), http://monarchwatch.org/blog/2014/01/monarch-population-status-20/; *see also* Scott Faber et al., *Plowed Under: How Crop Subsidies Contribute to Massive Habitat Losses* 8 (2012), available at http://static.ewg.org/pdf/plowed_under.pdf (documentando el número de hectáreas de praderas, humedales y tierras de arbustos convertidos a campos agrícolas de maíz y soja entre 2008 y 2011).
[51] *See* Pleasants & Oberhauser, *supra* note 28, at 3-5.
[52] *See id.* At 3-6

hábitats no agrícolas en Iowa, Minnesota y Wisconsin.[53] Este patrón de mariposas monarca que prefieren lugares agrícolas sobre los no agrícolas quedó confirmado por Pleasants and Oberhauser en 2012.[54]

La desaparición del algodoncillo a lo largo de las rutas migratorias de las mariposas monarca ha tenido un impacto significativo en la producción de estas mariposas.[55] Las hembras adultas ahora deben viajar más y gastar más energía para hallar plantas de algodoncillo sobre las cuales poner sus huevos.[56] Con la grasa corporal agotada, las mariposas ponen menos huevos y enfrentan un mayor riesgo de muerte antes de tener la posibilidad de reproducirse.[57] Durante el período marcado por el aumento del uso del glifosato y la siembra de maíz y soja resistentes al glifosato, Pleasants and Oberhauser midieron la cantidad de huevos y larvas sobre el algodoncillo para analizar la producción de mariposas monarca en el centro occidental de los Estados Unidos.[58] Detectaron una disminución del 58 % en el algodoncillo y de un 81 % en la producción de mariposas monarca en el centro occidental entre 1999 y 2010.[59] Durante este período, también hubo una disminución del 65 % en el tamaño total de la población de mariposas monarca que hibernan en México.[60]

Según un censo realizado en diciembre de 2013 de la población que hiberna en México, el área ocupada por mariposas monarca se había reducido a una cifra históricamente baja: tan solo 0,67 hectáreas, el equivalente a alrededor de un campo de fútbol y un cuarto.[61] Esta no solo era la cifra más baja históricamente, sino que representaba tan solo el 56 % del área ocupada el año anterior, lo cual ya era el nivel más bajo registrado.[62] El área de hábitat invernal ocupada por las mariposas monarca, que se ha monitoreado de forma anual desde 1993, ofrece una idea de la cantidad de mariposas que sobreviven al arduo viaje de más de 4000 kilómetros entre Canadá y México.[63] El censo de 2013 reflejó una población restante de tan solo unas 33,5 millones de mariposas, una disminución del promedio anual de aproximadamente 350 millones de ejemplares durante los últimos 15 años.[64] El censo más reciente, realizado en diciembre de 2014, reveló que se ocuparon 1,13

[53] *See* K.S. Oberhauser et al., *Temporal and Spatial Overlap Between Monarch Larvae and Corn Pollen*, 98 Proc. Nat'l Acad. Sci.U.S. 11913, 11917 (2001).
[54] Pleasants & Oberhauser, *supra* note 28, at 8.
[55] *See id*. at 1-10; *see also* Ctr. for Food Safety, *Correlation Between Glyphosate Use and Monarch Migration Routes and Breeding*, http://www.centerforfoodsafety.org/issues/304/pollinators-and-pesticides/map-of-monarchmigration-breeding-and-glyphosate-use# (last visited Feb. 19, 2014).
[56] Wines, *supra* note 25.
[57] *Id.*
[58] *See* Pleasants & Oberhauser, *supra* note 28, at 1.
[59] *See id.*
[60] *Id.* at 8; *see also* L.P. Brower et al., *Decline of Monarch Butterflies Overwintering in Mexico: Is the Migratory Phenomenon at Risk?*, Insects Conservation and Diversity, at 1 (2011).
[61] Wines, *supra* note 25; *see* E. Rendón-Salinas & G. Tavera-Alosno, *supra* note 1, at 1; World Wildlife Fed'n, *La Migración de la Mariposa Monarca en Riesgo de Desaparecer*, WWF México (Jan. 29, 2014), http://www.wwf.org.mx/?214870/Lamigracin-de-la-mariposa-Monarca-en-riesgo-de-desaparecer.
[62] Wines, *supra* note 25; Rendón-Salinas and Tavera-Alonso *supra* note 1.
[63] Monarch Joint Venture, *supra* note 13.
[64] Fallon, *supra* note 23.

hectáreas de bosques, un aumento del 68,7 % con respecto al año anterior atribuible a condiciones climáticas favorables en las zonas de reproducción de la mariposa.[65] Si bien el aumento es una buena noticia, esta población de aproximadamente 56,6 millones de individuos sigue siendo el segundo nivel más bajo en la historia. La densidad registrada también se encuentra muy por debajo de las 4 a 5 hectáreas que los expertos considerarían como un indicio de recuperación significativa.[66]

La población migratoria de la mariposa monarca ha disminuido tanto que las posibilidades de recuperación a niveles observados incluso hace sólo cinco años se están esfumando.[67] Con menos mariposas, la población puede ser cada vez más vulnerable a factores de estrés tales como el cambio climático, el clima extremo y la deforestación.[68] La posible aprobación en Estados Unidos de nuevos cultivos resistentes a herbicidas,[69] lo cual puede facilitar un aumento importante en el uso de otros herbicidas que eliminen el algodoncillo aún más, presenta otra amenaza para la mariposa monarca. En vista de la disminución pronunciada y continua de la población, el fenómeno migratorio de la mariposa monarca, por el cual la Reserva de la Biósfera Mariposa Monarca fue designada como Patrimonio Mundial de la UNESCO, está en riesgo de desaparecer.[70]

B. Impacto de la tala ilegal en el hábitat forestal de la Reserva de la Biósfera Mariposa Monarca

La tala ilegal constituye una amenaza histórica a la Reserva de la Biósfera Mariposa Monarca que los esfuerzos de conservación de los últimos años han ayudado a disminuir de forma significativa. En el período comprendido entre 1971 y 1999, el 44 % del hábitat forestal de alta calidad en la reserva de la mariposa monarca fue degradado debido a la tala ilegal, lo cual resultó en la eliminación o la disminución significativa de algunas colonias de mariposas monarca. Los oyameles y pinos en la reserva actúan como "paraguas y manta" que protegen a las mariposas de los elementos. Los huecos en el dosel del bosque generados por la tala exponen a las colonias de mariposas monarca a la lluvia y permiten que las mariposas pierdan el calor corporal.[71] Sin embargo, durante los últimos años ha habido una mejora notable. En 2001, la organización de conservación WWF México comenzó a monitorear la cubierta forestal de la reserva. El resultado de más de una década de monitoreo demuestra que, si bien la tala ilegal no se ha eliminado por completo, una mejor aplicación de los

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[65] E. Rendón-Salinas et al. *supra* note 2; Zuckerman *supra* note 2.
[66] Associated Press, *Monarch butterflies rebound but levels in Mexico still at near-record low*, The Guardian, Jan. 27, 2015, http://www.theguardian.com/environment/2015/jan/27/monarch-butterflies-rebound-mexico-near-record-low
[67] Wines, *supra* note 25.
[68] Pleasants & Oberhauser, *supra* note 28, at 9; Wines *supra* note 25.
[69] *See* Animal Plant and Health Inspection Serv. (APHIS), USDA, *Petitions for Determination of Nonregulated Status*, http://www.aphis.usda.gov/biotechnology/petitions_table_pending.shtml#not_reg (last visited Jan. 31, 2014) (listado de los cultivos modificados genéticamente, incluidos los que tienen tolerancia a varios herbicidas, para los que se han presentado peticiones para la determinación de estado no regulado).
[70] Wines, *supra* note 25.
[71] O. Vidal et al, *supra* note 5; See also H. Aridjis and L. Brower. *Twilight of the Monarchs*. N.Y. Times, Jan. 26, 1996. (Un editorial que describe el impacto de la degradación forestal para la conservación de la mariposa monarca y las medidas que podrían tomarse para proteger los bosques), http://www.monarchwatch.org/read/articles/snow.htm.

reglamentos, la colaboración con las comunidades y el apoyo a actividades alternativas de generación de ingresos están generando un impacto positivo y una disminución en la deforestación y la degradación forestal en la reserva.[72]

Entre 2001 y 2012, se detectó que un total de 2057 hectáreas habían sido afectadas por la tala ilegal (incluida la degradación y la deforestación). Durante este período, la tala a gran escala realizada por grupos organizados afectó 1503 hectáreas. Sin embargo, desde 2009, esta actividad ha disminuido en forma significativa. En 2012, no se detectó ninguna degradación ni deforestación debido a la tala ilegal a gran escala —el menor índice desde el comienzo del monitoreo forestal.[73] Sin embargo, los resultados del monitoreo en el período 2012-2013 revelaron una vez más indicios de tala ilegal a gran escala con signos de degradación en 5,02 hectáreas.[74] En el período de 2013-2014 se detectó un nivel de degradación similar.[75] Si bien la tala ilegal a gran escala continúa en algunos sitios, la mejora es notable, y los expertos la atribuyen a una aplicación más estricta de la ley por parte de las autoridades, pagos por servicios ambientales y apoyo a programas de actividades económicas alternativas.[76]

La vigilancia a largo plazo también ayudó a determinar el nivel de tala ilegal a pequeña escala, a la cual es más difícil dar seguimiento en períodos más cortos. Entre 2001 y 2012, la tala a pequeña escala afectó 554 hectáreas.[77] Según datos del período 2012-2013, se degradaron 3,96 hectáreas debido a la tala ilegal a pequeña escala.[78] Al año siguiente, gracias a una vigilancia más estricta, con la participación de comunidades locales, se logró detener esta actividad, y la verificación de campo reveló que no hubo tala ilegal a pequeña escala en la zona central de la Reserva en el período 2013-2014.[79]

C. Impacto de las condiciones climáticas adversas y del cambio climático

Las condiciones climáticas extremas pueden amenazar el ciclo de vida y el hábitat de la mariposa monarca a lo largo de la ruta migratoria y en el hábitat de hibernación. En los sitios de hibernación de la mariposa, los científicos han registrado varios casos en los que las temperaturas inusualmente frías o el clima húmedo dieron lugar a elevada mortandad de las mariposas. En enero de 2002, una tormenta invernal eliminó a 273 millones de mariposas en tan solo dos colonias.[80] Esto es mucho más

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[72] O.Vidal et al, *supra* note 5
[73] *Id.*
[74] WWF Mexico and Fondo Monarca, *Degradación forestal en la zona núcleo de la reserva de la Biosfera Mariposa Monarca 2012-2013*(July 25, 2013), http://www.wwf.org.mx/que_hacemos/mariposa_monarca/publicaciones/
[75] WWF, *Disminuye la degradación forestal por factores climáticos en la Reserva Monarca, pero persiste la tala clandestina a gran escala,* (Oct. 2, 2014) http://www.wwf.org.mx/?230231/Disminuye-degradacion-forestal-por-factores-climaticos-en-Reserva-Monarca-pero-persiste-la-tala-clandestina#
[76] O.Vidal et al, *supra* note 5.
[77] *Id.*
[78] WWF Mexico and Fondo Monarca, *supra* note 71.
[79] WWF, *supra* note 72.
[80] L.P. Brower et al., *supra* note 6.

que el cálculo actual de la población que hiberna, lo cual sugiere que la población no sería capaz de recuperarse de otro evento extremo similar. Más recientemente, durante la temporada de hibernación de 2009-2010, las mariposas estuvieron expuestas a una combinación de niveles históricos de precipitación seguidos por temperaturas bajo cero, lo cual produjo un índice de mortalidad aproximado del 50 %.[81] Las mariposas monarca también son susceptibles a los impactos de la sequía en su hábitat. Entre 2008 y 2011, las condiciones de sequía extrema contribuyeron a la degradación del hábitat forestal en la Reserva de la Biósfera Mariposa Monarca.[82]

Si bien es difícil vincular instancias específicas de clima extremo con el cambio climático, un clima cambiante puede aumentar la frecuencia de inviernos más fríos o húmedos o la gravedad de las sequías, lo que aumenta aún más la presión sobre la especie.

IV. Lista del Patrimonio Mundial en Peligro

Conforme al Artículo 11.4 de la Convención del Patrimonio Mundial, el Comité debe establecer, actualizar y publicar una Lista del Patrimonio Mundial en Peligro que incluya los bienes del Patrimonio Mundial amenazados por "peligros graves y precisos".[83] El Comité puede inscribir bienes en esta lista cuando "se necesitan obras importantes para salvaguardar ese bien" y cuando "se ha prestado una solicitud de asistencia para ese bien con arreglo a lo estipulado en la *Convención*... y cualquier miembro del Comité o la Secretaría podrá solicitar esa forma de asistencia".[84]

De conformidad con el Artículo 11.5 de la Convención del Patrimonio Mundial, el Comité ha definido criterios para inscribir propiedades en la Lista del Patrimonio Mundial en Peligro. Estos criterios se detallan en el Artículo IV(B) de las *Directrices prácticas para la aplicación de la Convención del Patrimonio Mundial*.[85] En el caso de bienes naturales, el Comité puede incluir un sitio en la Lista del Patrimonios Mundial en Peligro cuando se cumpla al menos uno de los criterios para determinar un Peligro Comprobado o un Peligro Potencial. Los criterios son los siguientes:

PELIGRO COMPROBADO: el bien corre un peligro comprobado, concreto e inminente, por ejemplo:

i) Una grave disminución de la población de especies amenazadas o de otras especies de Valor Universal Excepcional para cuya protección se estableció jurídicamente el bien; esa disminución puede ser causada por factores naturales, como una enfermedad, o por factores humanos, por ejemplo la caza furtiva.

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[81] L.P. Brower et al., *supra* note 58.
[82] O.Vidal et al., *supra* note 5.
[83] World Heritage Convention, Arts.11(4).
[84] UNESCO World Heritage Committee, *Operational Guidelines for the Implementation of the World Heritage Convention* , WHC 13/01 (July 2013) at IV.B (177) [WHC Operational Guidelines]
[85] *Id. at* 177-191

ii) Una grave alteración de la belleza natural o del interés científico del bien, que resulte, por ejemplo, de un asentamiento humano, de la construcción de embalses que provoquen la inundación de una superficie considerable del bien , del desarrollo industrial y agrícola, por ejemplo obras públicas de gran envergadura, explotaciones mineras, contaminación de pesticidas o abonos, explotación forestal, recolección de leña, etc.
iii) La intrusión de asentamientos humanos en los límites o las zonas limítrofes de los bienes cuya integridad ponen en peligro río arriba que amenaza la integridad de la propiedad.

PELIGRO POTENCIAL: sobre el bien pesan peligros graves que podrían tener repercusiones perjudiciales en sus características esenciales, por ejemplo:

i) Modificación de la condición jurídica que protege el bien.
ii) Proyectos de reasentamiento humano o de desarrollo que afectan al bien directamente, o cuya ubicación entraña riesgos para el bien.
iii) Estallido o amenaza de conflicto armado.
iv) Carencia, inadecuación o aplicación incompleta de un plan de gestión.
v) Impactos amenazantes de factores climáticos, geológicos u otros factores medioambientales.

V. Solicitud para inscribir la Reserva de la Biósfera Mariposa Monarca de México en la Lista del Patrimonio Mundial en Peligro

La Reserva de la Biósfera d Mariposa Monarca se inscribió en la Lista del Patrimonio Mundial debido al reconocimiento de que "la concentración de mariposas que hiberna en el bien es un fenómeno natural superlativo" que confiere al sitio un Valor Universal Excepcional. Sin embargo, tal como se detalla en las secciones anteriores y como se analiza a continuación, el VUE de la propiedad se ve amenazado por un "peligro grave y preciso" debido a la disminución en el hábitat de reproducción y la fuente alimentaria de las larvas de la mariposa monarca. Para mantener de manera efectiva el fenómeno de hibernación y garantizar la conservación del VUE del bien, "se requieren obras importantes" a lo largo de todo la ruta migratoria. Para salvaguardar el VUE de la Reserva de la Biósfera Mariposa Monarca, las medidas correctivas para proteger el hábitat de reproducción de la mariposa y la fuente alimentaria de las larvas son tanto esenciales como viables.

En vista de esto, los solicitantes respetuosamente solicitan que el Comité solicite asistencia para la Reserva de la Biósfera Mariposas Monarca y su inclusión en la Lista del Patrimonio Mundial en Peligro.

A. El bien cumple con los criterios para la inscripción en la Lista del Patrimonio Mundial en Peligro

La Reserva de la Biósfera Mariposa Monarca cumple con los criterios de inscripción de las categorías de Peligro Comprobado y Peligro Potencial, como se detalla a continuación:

Específicamente, el bien enfrenta un "Peligro Comprobado" debido a que se enfrenta a una " grave disminución de la población de especies amenazadas o de otras especies de Valor Universal Excepcional para cuya protección se estableció jurídicamente el bien"[86]. La población migratoria de mariposas monarca ha sufrido una grave disminución de más del 90 % en tan solo las últimas dos décadas. Si bien múltiples causas han contribuido a este declive, investigaciones recientes[87] indican que la reducción en el hábitat de reproducción y la fuente alimentaria de las larvas en los Estados Unidos provocada por el cambio de uso del suelo y la aplicación generalizado de herbicidas con glifosato ahora constituye el principal factor que contribuye a la disminución de la población de mariposas monarca, para cuya protección se estableció la Reserva de la Biósfera Mariposa Monarca.

Asimismo, la población restante de mariposas monarca ahora es cada vez más vulnerable y necesita medidas de conservación firmes y rápidas. Si la tendencia a la baja de la población de mariposas continua, disminuirá aún más la concentración de mariposas que hibernan en la biósfera y que confieren al lugar su Valor Universal Excepcional. Esto implicaría una "grave alteración de la belleza natural o del interés científico del bien, que result[a]…de pesticidas o abonos".[88]

Esta reducción importante en el tamaño de la población también significa que el VUE del bien está en mayor riesgo debido a la "intrusión de asentamientos humanos en los límites….de los bienes cuya integridad ponen en riesgo", [89] por ejemplo, por la degradación forestal y la deforestación.

Asimismo, la propiedad enfrenta un "Peligro Potencial" debido a que "sobre el bien pesan peligros graves que podrían tener repercusiones perjudiciales en sus características esenciales", tales como los "impactos amenazante de los factores climáticos".[90] Debido a la vulnerabilidad de la especie a los cambios en la temperatura y las precipitaciones, la disminución en el número de mariposas aumenta el riesgo de que la población que migra e hiberna pudiera verse erradicada por condiciones climáticas graves y anómalas que pueden empeorar debido al cambio climático inducido por los seres humanos.

B. Se necesitan "obras importantes" en la ruta migratoria para conservar el valor universal excepcional del sitio

Si bien México debe continuar con sus esfuerzos para reforzar la gestión de la propiedad y proteger su integridad frente a las amenazas locales, la naturaleza transfronteriza del fenómeno migratorio también requiere "obras importantes" para proteger el hábitat de reproducción en los Estados Unidos y Canadá.

Conforme al Artículo 6 de la Convención, todos los países que hayan ratificado la Convención del Patrimonio Mundial se han comprometido a colaborar en la conservación de los bienes de Patrimonio Mundial y a abstenerse de tomar medidas que puedan dañarlos:

86 WHC Operational Guidelines at IV.B(180).
87 Flockhart, *supra* note 4.
88 WHC Operational Guidelines at IV.B(180).
89 *Id.*
90 *Id.*

> *"1. Respetando plenamente la soberanía de los Estados en cuyos territorios se encuentre el patrimonio cultural y natural a que se refieren los Artículos 1 y 2, y sin perjuicio de los derechos reales previstos por la legislación nacional sobre este patrimonio, los Estados Partes en la presente Convención reconocen que constituye un patrimonio universal en cuya protección la comunidad internacional entera tiene el deber de cooperar.*
>
> *2. Los Estados Partes se obligan, en consecuencia y de conformidad con lo dispuesto en la presente Convención, a prestar su concurso para identificar, proteger, conservar y revalorizar el patrimonio cultural y natural de que trata el Artículo 11, párrafos 2 y 4, si lo pide el Estado en cuyo territorio está situado.*
>
> *3. Cada uno de los Estados Partes en la presente Convención se obliga a no tomar deliberadamente ninguna medida que puede causar daño , directa o indirectamente, al patrimonio cultural y natural de que tratan los Artículos 1 y 2 situado en el territorio de otros Estados Partes en esta Convención".*

En función de esto, es responsabilidad de las Partes en la Convención a través de las cuales viajan las mariposas monarca durante su ciclo de vida trabajar para proteger el fenómeno migratorio.

i. Esfuerzos trilaterales de conservación en la actualidad

A principios de 2014, cuando se tornó evidente que la población que hiberna en la reserva de la biósfera había bajado a un nivel histórico, los científicos y ambientalistas se movilizaron para instar a los líderes de Norteamérica a que aborden la situación de las mariposas monarca. En un esfuerzo liderado por el *Grupo de los Cien* de Aridjis, más de cien científicos, autores y artistas, y ambientalistas de México, Estados Unidos y Canadá enviaron una carta al presidente Peña Nieto, al presidente Obama y al primer ministro Harper para exigirles que demostraran la voluntad política necesaria para salvar a las mariposas monarca y solicitar que el problema se analice en la próxima reunión regional de los tres líderes. La carta destacaba la importancia de la colaboración entre los tres países e indicaba que *"para que el fenómeno de la migración e hibernación de las mariposas monarca persista en el este de Norteamérica, debe ponerse en marcha un plan de mitigación de la pérdida del hábitat de reproducción. Así como México aborda la problemática de la tala, los Estados Unidos y Canadá deben abordar los efectos de nuestras políticas agrícolas actuales".*[91]

En respuesta, durante la reunión de líderes norteamericanos del 19 al 20 de febrero de 2014 en Toluca, México, el presidente Obama, el presidente Peña Nieto y el primer ministro Harper acordaron lanzar un Grupo de Trabajo de Alto Nivel trinacional para trabajar en la conservación de la mariposa monarca y actualizar el Plan de Conservación de la Mariposa Monarca en Norteamérica de 2008 para la reunión de líderes norteamericanos de 2015. Cada gobierno aceptó formar un grupo de trabajo de

[91] Make Way for the Monarchs Website. "A Letter for President Enrique Peña Nieto, President Barack Obama and Prime Minister Stephen Harper", February 14, 2014. http://makewayformonarchs.org/i/archives/525

alto nivel en su país integrado por representantes de organismos gubernamentales, el sector académico y la sociedad civil.[92]

El grupo de trabajo en México ha identificado seis problemas prioritarios para proteger a las mariposas monarca en el país: economía de la conservación; restauración y conservación; investigación y supervisión; inspección y vigilancia; participación social; educación y conservación medioambiental; y coordinación y financiación.[93]

En los Estados Unidos, el Servicio de Pesca y Vida Silvestre (FWS, por sus siglas en inglés) ha liderado el grupo de trabajo interorganizacional y coordinado la estrategia para la mariposa monarca con la Estrategia Federal de Polinizadores, además de coordinar con estrategias en México y Canadá. El objetivo es definir una estrategia coordinada para las tierras públicas y privadas en los Estados Unidos que fomente la restauración y mejora del hábitat, la investigación y educación, y la investigación y supervisión. Hasta el momento, la FWS ha lanzado un programa de 3,2 millones de dólares para respaldar los proyectos de conservación en terreno a fin de proteger y restaurar el hábitat de las mariposas monarca y lograr la participación de los ciudadanos. [94]
El gobierno canadiense aún no ha realizado anuncios públicos acerca de sus planes para ayudar a la conservación de la mariposa monarca.[95]

Si bien los esfuerzos descritos anteriormente de parte de México y los Estados Unidos constituyen un paso positivo, no son suficientes por si solos. Notablemente, ninguno de los esfuerzos aborda directamente la necesidad de fortalecer la regulación de los herbicidas con glifosato, que es el principal factor que impulsa la pérdida del hábitat del algodoncillo. Asimismo, si bien la FWS recientemente destinó 3,2 millones de dólares a la mejora del hábitat, su objetivo declarado es restaurar 81 000 ha (200 000 acres) de hábitat para la mariposa monarca.[96] Sin embargo, la escala a la cual se requiere la restauración del hábitat para poder lograr realmente la recuperación de la mariposa monarca se encuentra en el orden de millones de hectáreas de hábitat.[97] Por lo tanto, el conjunto de esfuerzos actuales de parte de los países no son suficientes para restaurar la población de la mariposa monarca a un nivel seguro.

C. Medidas de mejora para proteger la fuente alimentaria de las larvas y el hábitat de reproducción de la mariposa monarca

[92] Soy Monarca. "Background, "http://www.soymonarca.mx/en/historial.html
[93] Soy Monarca. "Actions, "http://www.soymonarca.mx/en/acciones.html
[94] U.S.Fish and Wildlife Service, "Monarch Butterfly Factsheet" http://www.fws.gov/uploadedFiles/MonarchfactsheetSept152014%20(1).pdf ; Wendy Caldwell, "Monarch Joint Venture Plans Next Steps," Monarch Joint Venture, October 16, 2014, http://monarchjointventure.org/news-events/news/monarch-joint-venture-plans-next-steps ; U.S. Fish and Wildlife Service, "U.S. Fish and Wildlife Service Teams with Conservation Partners to Launch Campaign to Save Beleaguered Monarch Butterfly, Engage Millions of Americans," February, 9, 2015, http://www.fws.gov/news/ShowNews.cfm?ID=6F9989BD-0738-14CE-50EAC980BE1A75FC.
[95] Colin Perkel, *Federal government urged to save monarch butterflies with milkweed program*, The Star, Feb. 25, 2015, http://www.thestar.com/news/canada/2015/02/25/federal-government-urged-save-monarch-butterflies-with-milkweed-program.html
[96] U.S. Fish & Wildlife Service, "Save the Monarch Butterfly," http://www.fws.gov/savethemonarch/
[97] Chip Taylor, "Monarch Conservation: Our Choice," MonarchWatch.org, January, 28, 2015, http://monarchwatch.org/blog/2015/01/28/monarch-conservation-our-choices/

Además de cumplir con los criterios para la inscripción en la Lista de Patrimonio Mundial en Peligro, las amenazas o sus impactos sobre un bien deben poder ser "corregidas mediante acción humana".[98] El éxito de México en disminuir la deforestación en la Reserva de la Biósfera Mariposa Monarca ilustra la forma en que es factible corregir mediante acción humana las amenazas al hábitat de hibernación de las mariposas. Las amenazas al algodoncillo y al hábitat de reproducción de las mariposas también pueden ser corregidas. Proteger el hábitat de reproducción y limitar el uso indiscriminado de herbicidas con glifosato son acciones viables que podrían ayudar a incrementar el número de mariposas monarca y, así, reforzar la capacidad de la especie de soportar otras presiones.

Al decidir sobre la inclusión de un bien en la Lista del Patrimonio Mundial en Peligro, el Comité "solicitará a la Secretaría que compruebe... el estado actual del bien , los peligros que lo amenazan y la posibilidad de aplicar medidas de mejora ". El Comité también puede enviar una misión de "expertos cualificados... para inspeccionar el bien, evaluar el índole y amplitud de los riesgo y proponer medidas que se deben adoptar".[99] Además de visitar la propiedad en México, la misión también debería planificar visitas al hábitat de reproducción crítico de las mariposas monarca en los Estados Unidos que se encuentra bajo presión y contribuye a la disminución de la población de mariposas monarca.

Conforme a su compromiso en función del Artículo 6 de la Convención de "prestar su concurso para identificar, proteger, conservar…el patrimonio cultural y natural," los Estados Unidos y Canadá podrían ayudar a limitar la declive en la población de la mariposa monarca y evitar el deterioro de la belleza natural y el valor científico de la Reserva de la Biósfera Mariposa Monarca mediante la implementación de las siguientes medidas, entre otras:

- Programas de conservación que mejoren y protejan el hábitat actual de las mariposas monarca para forraje, reproducción y migración y que reemplacen las plantas de algodoncillo destruidas mediante el uso de pesticidas.
- Restricciones sobre el uso de glifosato y otros herbicidas a lo largo de caminos, líneas eléctricas y otras vías de paso.
- Mejores prácticas de gestión integrada de plagas que disminuyan el uso general de pesticidas, incluidos los herbicidas con glifosato, y que requieran zonas de amortiguación libres de herbicidas alrededor de áreas agrícolas (o zonas seguras dentro de ellas) a lo largo de las rutas migratorios de la mariposa monarca.
- Creación de zonas de hábitat amigables para el algodoncillo, en las que se prohíba el uso de glifosato y otros herbicidas, tanto en entornos agrícolas como no agrícolas.
- Protección de las mariposas monarca de un mayor daño al momento de aprobar o volver a aprobar el uso de herbicidas, resguardándolas frente a posibles aumentos drásticos en el uso de herbicidas como resultado de nuevos cultivos resistentes a herbicidas, tales como el trigo

[98] *Id.* At IV.B(181).
[99] *Id.* at IV.B(184).

resistente al glifosato, o nuevas combinaciones de pesticidas que incluyan el herbicida 2,4-D, tal como "Enlist Duo".
- Incentivos para que los agricultores utilicen prácticas agrícolas que disminuyan el uso de productos con glifosato.
- Programas que eduquen a las comunidades acerca de la importancia del algodoncillo para las mariposas monarca y apoyo a estas comunidades para la siembra de algodoncillo.

Para proteger la población migratoria de mariposas monarca que hiberna en México es esencial proteger su hábitat de reproducción crítico y su fuente alimentaria de algodoncillo mediante la implementación de semejantes restricciones de sentido común sobre el uso de glifosato, así como a través de programas de siembra de algodoncillo en los Estados Unidos.

D. Factores suplementarios que deben tenerse en cuenta para la inclusión de un bien en la Lista del Patrimonio Mundial en Peligro

El Artículo IV (B) de las *Directrices prácticas para la aplicación de la Convención del Patrimonio Mundial* también detalla factores suplementarios que el Comité puede tener en cuenta al decidir si incluirá un bien en la Lista del Patrimonio Mundial en Peligro. Entre otros, el Comité "deberá tener en cuenta en sus apreciaciones todas las causas de origen desconocido o inesperado que hagan peligrar un bien cultural o natural".[100]

Si bien es cierto que algunas de las amenazas a la Reserva de la Biósfera Mariposa Monarca pueden ser "inesperadas" debido a que se originan fuera de la reserva y, de hecho, fuera de las fronteras nacionales de México, existe evidencia suficiente como para demostrar que existe una relación causal entre el uso de pesticidas con glifosato en el hábitat de reproducción de las mariposas monarca (es decir, en los Estados Unidos y en Canadá) y el impacto perjudicial de esta acción sobre el Valor Universal Excepcional de la Reserva de la Biósfera Mariposa Monarca.

VI. Conclusiones y recomendaciones

El Comité del Patrimonio Mundial tiene la oportunidad de ayudar a fomentar las acciones urgentes necesarias para proteger una de las migraciones más espectaculares y misteriosas del mundo. Debido a que se estableció a la Reserva de la Biósfera Mariposa Monarca como un bien del Patrimonio Mundial para proteger lo que constituye intrínsecamente un fenómeno trans-fronterizo, son fundamentales las acciones de conservación a lo largo de toda la ruta migratoria.

El Comité del Patrimonio Mundial está en una buena posición para animar a los Estados Partes en la Convención a tomar las medidas individuales y coordinadas necesarias para proteger el valor

[100] *Id.* at 182.

universal superlativo del Patrimonio Mundial de la Reserva de la Biósfera Mariposa Monarca. Solicitamos cordialmente al Comité que:

- Evalúe la inclusión de la Reserva de la Biósfera Mariposa Monarca en la Lista del Patrimonio Mundial en Peligro mediante el envío de una misión de investigación para analizar la situación y proponer medidas de mejora centradas en el hábitat de reproducción de las mariposas monarca.
- Inste a los Estados Partes a que refuercen los programas de conservación en todas las jurisdicciones estatales y federales para proteger el terreno de reproducción de las mariposas monarca, especialmente mediante la implementación de límites necesarios en el uso del glifosato y otros pesticidas que destruyen el algodoncillo.
- Inste a los Estados Partes a adoptar e intensificar los esfuerzos de colaboración para proteger y restaurar el hábitat de reproducción de las mariposas monarca, incluida, si resulta necesario, la realización de estudios adicionales para identificar áreas prioritarias para la restauración.
- Apoye a los Estados Partes y los esfuerzos comunitarios para desarrollar políticas y mejores prácticas para proteger y restaurar el hábitat de la mariposa monarca, y que trabaje con estos para tal fin.
- Coordine con otros organismos internacionales que trabajen sobre prácticas agrícolas para educar a estas entidades y a los Estados Partes sobre los impactos del uso indiscriminado de pesticidas sobre la biodiversidad y la salud humana.

Anexos:

A. Gráfico que ilustra la disminución de la población de mariposas monarca
B. Mapa del hábitat de reproducción de la mariposa monarca
C. Fotografías
D. Perspectiva del Panorama del Patrimonio Mundial 2014 de la Unión Internacional para la Conservación de la Naturaleza (IUCN)
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Foto en portada: Margaret Hsieh

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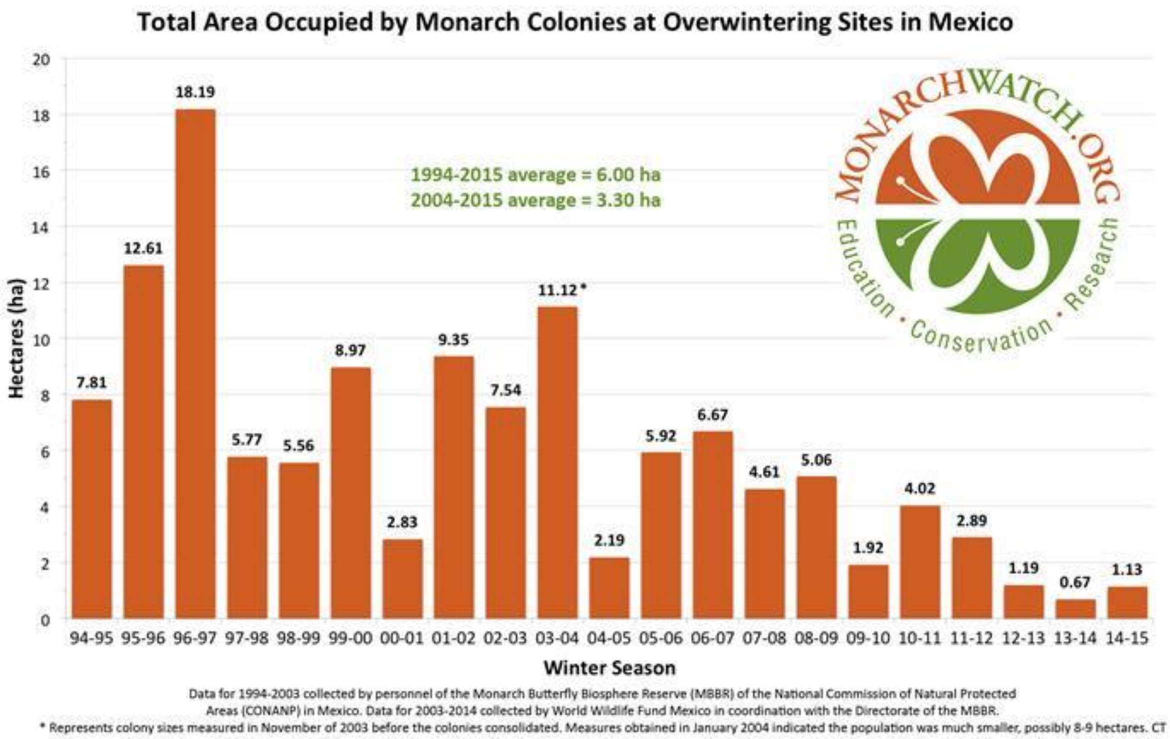
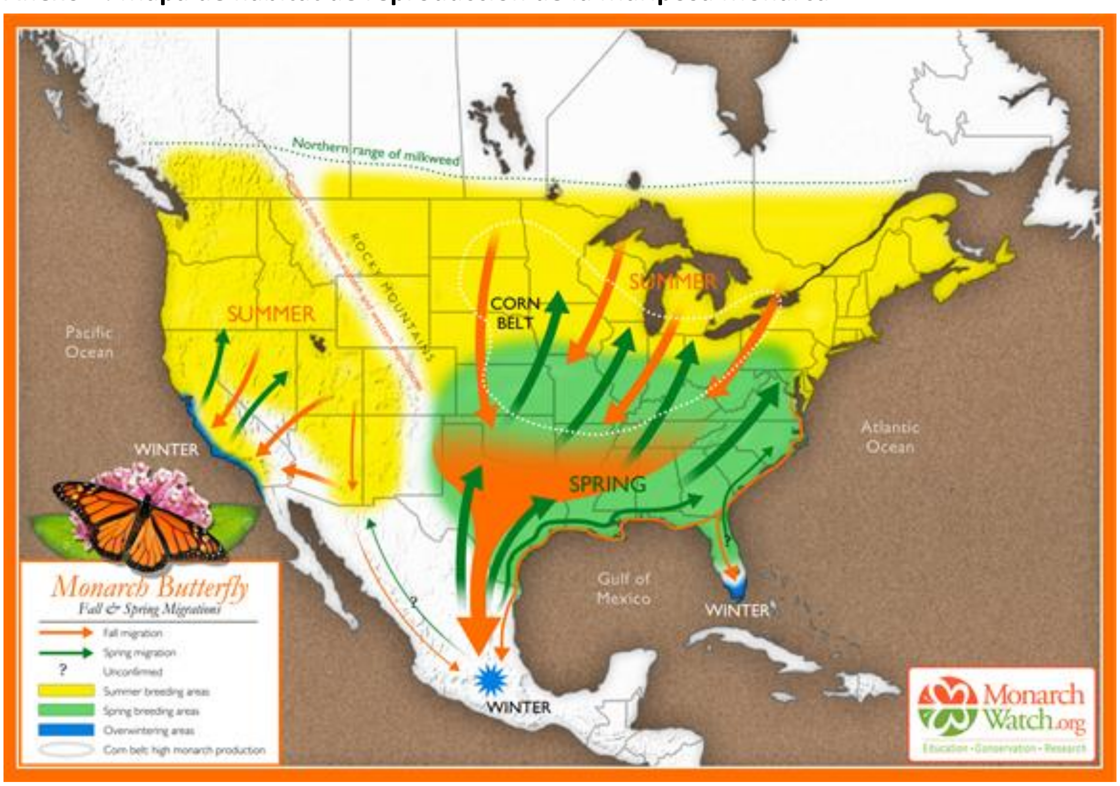
Anexo A. Gráfico que ilustra la disminución de la población de la Mariposa Monarca



Anexo B. Mapa de hábitat de reproducción de la Mariposa Monarca



Anexo C. Fotografías

Mariposa monarca hembra en la parte Cerro Pelón de la Reserva de la Biosfera Mariposa Monarca. Foto: Margaret Hsieh.

Colonia de mariposas monarcas que cuelgan de la rama de árbol oyamel en Cerro Pelón de la Reserva de la Biosfera Mariposa Monarca. Foto: Margaret Hsieh.

Anexo D

Perspectiva del Panorama del Patrimonio Mundial 2014 de la Unión Internacional para la Conservación de la Naturaleza (IUCN)

Sitename:-Monarch Butterfly Biosphere Reserve

Site Description:-The 56,259 ha biosphere lies within rugged forested mountains about 100 km northwest of Mexico City. Every autumn, millions, perhaps a billion, butterflies from wide areas of North America return to the site and cluster on small areas of the forest reserve, colouring its trees orange and literally bending their branches under their collective weight. In the spring, these butterflies begin an 8 month migration that takes them all the way to Eastern Canada and back, during which time four successive generations are born and die. How they find their way back to their overwintering site remains a mystery.

Conservation Outlook

Rating:-Critical
Justification:-The conservation outlook for the property with respect to its outstanding natural phenomenon and flagship species is one of significant concern. While recent all time lows in wintering population sizes may have been aggravated by severe weather conditions, there are broader trends of loss and degradation of breeding habitat in the United States of America and Canada due to the expansion of industrial agriculture and land development associated loss of host plants. While some of these concerns require management responses at a scale beyond site and even national level, even the factors that can be influenced at site level are not fully under control. Challenges on location include illegal resource extraction, insufficiently regulated tourism and visitation and inadequate inter-institutional coordination. A team of authors behind a recent study concluded that the observable declines call into question the long-term survival of the monarchs' migratory phenomenon (Brower et al. 2012; Vidal et al. 2013). Clearly, a much stronger response is needed both locally and across the three range states, building upon encouraging existing efforts.

Current state and Trend of values

State:-Critical
Trend:-Deteriorating
Justification:-While substantial progress has been achieved in reducing threats from logging and inappropriate tourism, threats in the summering habitats and along the migration corridors, as well as from inadequate coordination among the approximately 60 entities participating in management of the property are of high concern While recent all time lows in wintering population sizes may have been aggravated by severe weather conditions, there are broader trends of loss and degradation of wintering habitat, breeding habitat in the United States of America and Canada due to use of herbicides, expansion of industrial agriculture and land development associated loss of host plants. A team of authors behind a recent study concluded that the observable declines call into question the long-term survival of the monarchs' migratory phenomenon (Brower et al. 2012; Vidal et al. 2013).

Overall Threats

Overall Rating:-Very High Threat
Summary:-The relatively small property consists of vulnerable and degraded fragments of once extensive montane conifer forests. Longstanding commercial logging into the recent past has transformed the landscape and illegal logging is still not fully under control. The combination of ongoing habitat loss and degradation, agricultural encroachment in the surroundings, insufficiently regulated and controlled tourism and visitation indicating capacity constraints and jointly amount to a very high degree of threat. Furthermore, there are concerns about the expected impacts of climate change and factors outside the property and beyond the control of management affecting the butterfly populations.
There are 3 primary threats to the monarch butterfly in its range in North America: deforestation and degradation of forest by illegal logging of overwintering sites in México; widespread reduction of breading habitat in the United States due to land-use changes and the decrease of this

butterfly´s main larval food plant (common milkweed [Asclepias syriaca]) associated with the use of glyphosate herbicide to kill weeds growing in genetically engineered, herbicide-resistant crops; and periodic extreme weather conditions throughout its range during the year, such as severe cold or cold summer or winter temperatures. These threats combined are responsible for the dramatic decline over the last decade in the number of monarch butterflies in the hibernation colonies in México, which reached a 20-year low during the 2013-2014 season (Vidal et al. 2013).

Protection and Management

State:-Some Concern

Justification:-There are encouraging management efforts which have resulted in recent improvements regarding illegal logging. Mexican federal and state authorities are to be commended for the important enforcement, as well as financial (through payment for environmental services by the National Commission on Forests of SEMARNAT) efforts to protect the monarch reserve. Their efforts and the strategic, uninterrupted, decade-long financial support for generation of alternative income and employment by committed Mexican and international philanthropists and businesses have dramatically reduced large-scale illegal logging in recent years. However, ongoing concerns include limited capacities to manage tourism and to support alternative livelihood options for local communities. Moreover, the forests in the buffer zones have been, and continue to be, degraded significantly by unsustainable forest exploitation, fires, grazing, and agricultural expansion, all of which would eventually play a key role in further degrading the already degraded and particularly vulnerable core zones.

Inherent to any long-distance animal migration many critical challenges are beyond the control of site management and even the State Party and require consolidation of international cooperation. The best conservation strategies to augment the capacity of the monarch butterfly to respond to unpredictable and changing climate-related conditions are to protect its habitat from direct human disturbances, such as illegal logging in México and habitat loss and degradation in the United States and Canada, and to restore its habitat in the 3 countries.

Assessment Information

Value

World Heritage Values

State:-Critical

Trend:-Deteriorating

1: The most dramatic known manifestation of the phenomenon of insect migration

State:-Critical

Trend:-Deteriorating

Description:-The overwintering concentration of the Monarch Butterfly in this serial property is the most dramatic known manifestation of long-distance insect migration and therefore recognized as a superlative natural phenomenon. Up to an estimated billion monarch butterflies return annually, from breeding areas in southern Canada and the United States, to land in close-packed clusters

within 19 overwintering colonies in the montane oyamel fir forests of central Mexico. The property protects 14 of these colonies and an estimated 70% of the total hibernating population of the Monarch Butterfly's eastern population (SoOUV, 2008; Vidal et al. 2013).

Other Biodiversity values

State:-Critical

1: Other international designations

Description:-The Park lies within a Conservation International-designated Conservation Hotspot, a WWF Global 200 Eco-region, a BirdLife-designated Endemic Bird Area. The three components constitute the core zones of a UNESCO Biosphere Reserve (UNEP-WCMC, 2011).

Threats

Current Threats

1: Impact of tourism/ visitors/ recreation

Threat Rating:-High Threat

Justification:-The property is a major tourist attraction with a great potential for, local economic benefits, conservation financing and visitor education. The potential has not been fully realized and concerns about damage and disturbance caused by tourists persist. Tourists may also increase the risk of accidental fires. While progress has been achieved in managing tourism remaining constraints include insufficient specialized staff and capacity, inadequate visitor facilities and conclusive impact assessments (35com.Monarch.SPreport; Consultation form, 2012). Many communities benefit from monarch-associated tourism: 87,335 people visited (November to March) the different colonies in 2002-2003, 133,263 in 2003-2004, 126,896 in 2004-2005, 54,515 in 2011-2012 and 72,591 in 2012-2013 (Vidal et al. 2013).

2: Logging/ Wood Harvesting

Threat Rating:-Very High Threat

Justification:-From 2001 through 2013, 1254 hectares were deforested in the monarch reserve, 934 ha were degraded, and 126 ha were affected by climatic conditions (Vidal et al 2013). Of the total 2195 ha of affected (deforested and degraded forest) area, 2066 ha were affected by illegal logging: 1507 ha by large-scale logging and 558 ha by small-scale logging. Mexican authorities effectively enforced efforts to protect the monarch reserve from illegal logging, particularly from 2007 to 2012. Those efforts, together with the decade-long financial support from Mexican and international philanthropists and businesses to create local alternative-income generation and employment, resulted in the decrease of large-scale illegal logging from 731 ha affected in 2005-2007 to 9 ha affected in 2013, although small-scale logging is of growing concern (Vidal et al. 2013)

3: Livestock Farming / Grazing of domesticated animals
Threat Rating:-High Threat
Justification:-Agricultural use continues to threaten the property in multiple ways. Agricultural encroachment in the buffer zones reduces the extent of available forest habitat required by the butterfly colonies. Grazing and associated intentional burning increases the risk of forest fires. Furthermore, water diversion for agriculture is reported to be a concern (Brower, 2013; UNEP/WCMC, 2011). The situation is complicated due to the tenure arrangements which include land rights within the property. The forests in the buffer zones have been, and continue to be, degraded significantly by unsustainable forest exploitation, fires, grazing, and agricultural expansion, all of which would eventually play a key role in further degrading the already degraded and particularly vulnerable core zones (Vidal et al. 2013)

4: Habitat Shifting/ Alteration
Threat Rating:-High Threat
Justification:-Climate change is already affecting the property, but also the butterfly habitat across the US and Canada. In combination with the effects of longstanding commercial logging and illegal logging droughts and increased temperatures have contributed to insect infestations while severe storms have toppled trees; and provoked landslides, floods, erosion, and sedimentation of water courses (35COM.SPreport; Caranza Sánchez, 2010). From 2001 to 2013, floods, strong winds, and fire affected 125 hectares in the core zone (Vidal et al. 2013)

Potential Threats

1: Other
Threat Rating:-Very High Threat
Justification:-It is important to understand that factors beyond the control of site management and even directly the State Party can fundamentally influence the key natural phenomenon making the site so exceptional. The Monarch Butterfly is susceptible to habitat change, climate change and agrochemicals throughout its range, including migration corridors.

1: Mining/ Quarrying
Threat Rating:-High Threat
Justification:-There have been several attempts (April 2005, May 2007, and more recently in November 2013) by the mining company Industrial Minera Mexico (“Proyecto Angangueo”) to re-activate the exploitation of copper, zinc, silver and gold.

Protection and management

Overall Rating:-Some Concern
Justification:-There are encouraging management efforts which have resulted in recent improvements regarding illegal logging. Mexican federal and state authorities are to be commended for the important enforcement, as well as financial (through payment for environmental services by the National Commission on Forests of SEMARNAT) efforts to protect the monarch reserve. Their efforts and the strategic, uninterrupted, decade-long financial support

for generation of alternative income and employment by committed Mexican and international philanthropists and businesses have dramatically reduced large-scale illegal logging in recent years. However, ongoing concerns include limited capacities to manage tourism and to support alternative livelihood options for local communities. Moreover, the forests in the buffer zones have been, and continue to be, degraded significantly by unsustainable forest exploitation, fires, grazing, and agricultural expansion, all of which would eventually play a key role in further degrading the already degraded and particularly vulnerable core zones.
Inherent to any long-distance animal migration many critical challenges are beyond the control of site management and even the State Party and require consolidation of international cooperation. The best conservation strategies to augment the capacity of the monarch butterfly to respond to unpredictable and changing climate-related conditions are to protect its habitat from direct human disturbances, such as illegal logging in México and habitat loss and degradation in the United States and Canada, and to restore its habitat in the 3 countries.

Protection and management value

1: Research

Protection Rating:-Effective
Justification :-The overwintering sites were a scientific mystery until 1975 when, after decades of butterfly tagging a site was last found on Cerro Pelón. Many studies have ensued, from North American universities. The nomination bibliography lists 120 papers and books on the subject. The butterfly species has prompted research into migration ecology, pest suppression, geo-magnetism and other factors influencing orientation, and their use as environmental indicators over its migration range (UNEP/WCMC, 2011). However, it is of concern that the impacts of visitors on butterfly behavior continue to be poorly understood.

2: Monitoring

Protection Rating:-Effective
Justification :-Forest cover, forest condition, and monarch butterfly colonies are monitored on a regular basis by CONANP, WWF, jointly with scientists (IUCN Evaluation, 2008; 35COM.Monarch.SPreport; Caranza Sánchez, 2010).

3: Tourism and interpretation

Protection Rating:-Some Concern
Justification :-While coherent visitor programs and infrastructure are being developed and implemented, there is still a general lack of information available for visitors with respect to the basic natural history of butterflies and their environment, and appropriate behavior while approaching and viewing the butterfly colonies. It is of concern that the impacts of visitors on butterfly behavior are not fully understood and considered. The tourism season begins before colonies have had a chance to settle down in their selected hibernation areas and visitor movements can disturb them easily. While guide training programs are in place, there is no certification program and insufficient personnel are available to adequately manage and control tourism (35COM.Monarch.SPreport; Consultation form, 2012).

4: Education and interpretation programmes

Protection Rating:-Some Concern
Justification :-A large number of projects have been undertaken related to environmental education for local communities. Guide training has been an important component (35COM.Monarch.SPreport; Consultation Form, 2012).

5: Sustainable use
Protection Rating:-Some Concern
Justification :-Significant funding has been provided to work with local and indigenous communities in the core and buffer zones of the biosphere reserve to develop a wide range of activities as alternatives to logging of the core zones, i.e. the property (35COM.Monarch.SPreport).

6: Staff training and development
Protection Rating:-Some Concern
Justification :-Several programs have contributed to staff training and development, but given the around 60 entities of federal and state government institutions, and civil society organizations that are involved in management), the training and development of staff remains a considerable challenge. This holds true in particular as regards specialized capacities for tourism and visitor management (IUCN, 2008; 35COM.Monarch.SPreport).

7: Sustainable finance
Protection Rating:-Some Concern
Justification :-Financing has been provided by several federal, state and international sources from governments, private sector, philanthropists and civil society. While the diverse funding sources are positive, challenges exist in terms of inter-institutional coordination. The Monarch Butterfly Fund (MBF) serves as a focal point for establishing a long term endowment which has been supported by the federal and state governments, civil society (international and national), and individual donors (35COM.Monarch.SPreport).

8: Boundaries
Protection Rating:-Some Concern
Justification :-The property's boundaries are defined by Presidential Decree declaring a biosphere reserve at the national level in 2000. The three defined core zones of the biosphere reserve constitute the property while the two buffer zones of the biosphere reserve also serve as the buffer zones of the property. Jointly, the core zones cover 14 of the historically-recorded overwintering colonies of the eastern population of the Monarch Butterfly. The remaining populations hibernate outside the property where some colonies have been lost altogether (Brower, 2013; Vidal et al. 2013). While the boundaries of the property are adequate for the protection of 70% of the overwintering population of the monarch butterfly, the overwintering colonies outside the property should be considered as a serial extension in the future (IUCN, 2008). The boundaries of the small core zones of the biosphere reserve are not demarcated on the ground. This represents a significant problem for the protection and management of the core zones.

9: Implementation of World Heritage Committee decisions and recommendations, if applicable

Protection Rating:-Some Concern
Justification :-As recently as 2010, a World Heritage Committee decision (34COM 7B.35) had noted with concern ongoing illegal logging within the property triggering a reactive monitoring mission. The subsequent Committee decision in 2011 (35COM 7B.32) requested the State Party to implement the recommendations of the above mentioned reactive monitoring mission. The focus of the implementation is on benefit-sharing with communities and tourism (35COM.Monarch.SPreport; 35COM.Monarch.SOC).

10: Management effectiveness
Protection Rating:-Data Deficient
Justification :-Overall data on management effectiveness is not available, but the increasingly successful response to illegal logging serves as an indicator of recent enhancements in terms of management effectiveness (35COM.Monarch.SPreport; Brower, 2010)

11: Management system
Protection Rating:-Some Concern
Justification :-The Monarch Butterfly Biosphere Reserve is managed by CONANP assisted by 46 federal and state agencies. In addition, 13 NGOs and academic institutions and the Monarch Butterfly Trust Fund provide inputs to management. Management is guided by a Management Program, a general document that lays out policies on sustainable development, wildlife management, public use, scientific research and monitoring, operations and law enforcement, rather than specific prescriptions for management. The document forms the basis for the Annual Operational Plans that are used to guide the day-to-day management activities of the many organizations involved (IUCN, 2008; 325COM.Monarch.SPreport; 35COM.Monarch.SOC).

12: Integration into regional and national planning systems
Protection Rating:-Some Concern
Justification :-An Advisory Council, made up of 21 representatives of rural cooperatives, communities and NGOs, has been established to assist CONANP in implementing the Management Program and Annual Operational Plans. At a broader scale, a Regional Committee has been established to integrate the efforts of the States of Michoacán and México and 27 municipalities in developing and implementing a regional land use plan. The work of the Advisory Council and Regional Committee was originally complemented by Annual Regional Fora, which include all interested stakeholders and serve to share information, coordinate activities, and inform Annual Operational Plans. However, at the time of evaluation no Regional Fora had been undertaken in the previous years (IUCN, 2008).

13: Legal framework
Protection Rating:-Some Concern
Justification :-Building upon earlier national designations, in 2000, the "Reserva de la Biosfera Mariposa Monarca" was established and in 2007 the same area was formally designated as a biosphere reserve under UNESCO's Man and the Biosphere (MAB) Programme. In 2008, the cores zones of the biosphere reserve were inscribed as a World Heritage property. Law enforcement, especially with respect to illegal logging, has been an on-going challenge and has included the Army, Federal Environmental Police, State Police of Michoacán and Mexico, and local communities (UNEP?WCMC, 2011; 35COM.SPreport). Of 19 butterfly colonies reported to date, 14 are in the federal Reserve and thus protected, 3 are in a protected area in Estado de

Mexico, and 2 are in Michoacán state and not protected

14: Relationships with local people
Protection Rating:-Some Concern
Justification :-Almost all of the property is located on communal lands or private property. Conservation and management programs must be implemented through cooperative activities with the landowners. Considerable efforts have been underway to promote alternative livelihood projects, environmental education and training, compensation schemes for conservation, reforestation, and voluntary surveillance to halt illegal logging (35COM.Monarch.SPreport). Conflicts remain in terms of the use of the "ejido" lands within the property. Given widespread rural poverty, incentives to log and collect firewood remain high. There are also concerns about benefit-sharing in the realm of tourism.

Assessment of the effectiveness of protection and management in addressing threats outside the site

Rating :-Some Concern
Justification :-Most threats originate outside the property. Of these, many can still be considered local challenges, and these have been the focus of most protection and management activities. Other challenges (threats) originate elsewhere, including beyond national borders.

Best Practice Examples

Justification :-no Jstification avilable

Additional Information

Key Conservation Issues

1: Long-distance migration
Scale :-Local
Description :-Although the concentrated nature of monarch use of wintering habitat makes it easy to quantify the loss of this habitat, it is important to remember that the majority of monarchs that winter in México depend on habitat in the United States and Canada for breeding and migrating. Concomitant with overwintering habitat loss, there have been large losses of breeding and migrating habitat. The direct relation between the loss of milkweed host plants in agricultural areas in the United States and the number of monarchs wintering in México was recently documented by Pleasants and Oberhauser (2012). Thus, it is important that citizens; local, state, and federal government agencies; nonprofit organizations; and private donors in the United States and Canada restore and protect habitat within their own territories (Vidal et al. 2013).
As any other animal migration the reliance on different seasonal ranges and migration corridors adds to the vulnerability of the species. In the case of butterflies, the intensification of agriculture

and associated use of chemicals are considered critical issues for the longer term survival of the migration phenomenon.

2: Climate change

Scale :-Local

Description :-Climate change is already affecting the property. Droughts have led to bark beetle infestations while severe storms have toppled trees; and provoked landslides, floods, erosion, and sedimentation of water courses (35COM.Monarca.SPreport; Caranza Sánchez, 2010; Brower, 2010; Vidal et al. 2013).

3: Inappropriate tourism and visitation

Scale :-Local

Description :-Though progress has been achieved in controlling and guiding tourism so that it causes less damage to butterfly colonies and their surrounding environment, four major constraints remain: (1) CONANP has only one person assigned to the tourism program, and this is clearly insufficient to provide the leadership, coordination, and oversight that is required. (2) Though planned, no visitor centers have yet been built to inform and orient visitors before they enter the Reserve. (3) While guides are offered the opportunity to attend training courses, there is no certification program for guides. This results in varying levels of knowledge and aptitude. (4) A definitive study on the effect of tourism on the butterfly colonies is needed to inform management decisions (35com.Monarch.SPreport; Consultation form, 2012).

4: Illegal logging

Scale :-Local

Description :-Sustained law enforcement efforts by a combination of the Army, Federal Environmental Police, State Police, and local communities have finally drastically reduced large-scale illegal logging, although small-scale (tala homiga) logging is of growing concern. However, given the widespread local poverty and unemployment and well-documented challenged in law enforcement, the threat has not disappeared (35COM.SPreport)
The best conservation strategies to augment the capacity of the monarch butterfly to respond to unpredictable and changing climate-related conditions are to protect its habitat from direct human disturbances, such as illegal logging in México and habitat loss and degradation in the United States and Canada, and to restore its habitat in the 3 countries. A strategy needs to be devised and implemented as a matter of urgency to address the socioeconomic and environmental problems and opportunities of both the monarch reserve and the region as a whole.

Benefits

1: Environmental Services

Community within site :-Major

Community outside site :-Major

Wider Community :-Major

Summary :-The protection of watersheds upstream of communities and dams in the buffer zones is an important benefit, especially in the face of climate change (Caranza Sanchez, 2010).

2: Health and recreation

Community within site :-Major

Community outside site :-Major

Wider Community :-Major

Summary :-Visitation to the site is significant and growing, and is important as an additional source of income for local communities. Visitation to the site also benefits the regional and national tourism industry though its importance is relatively small compared to other tourism attractions.

3: Knowledge

Community within site :-Major

Community outside site :-Major

Wider Community :-Major

Summary :-The numerous studies on the species and its migration have provided scientific insights into several fields, such as plant-animal interactions, migration ecology, including but not limited to orientation.

4: Nature conservation values

Community within site :-Major

Community outside site :-Minor

Wider Community :-Major

Summary :-The aggregation is an inspiring phenomenon appealing to the wider public in the three countries and around the world.

Projects

Active Conservation Projects			
N.O	Organization/individuals	Brief description of Active Projects	Contact Details
1	Supporting since 2003 numerous sustainable development projects on communal tree nurseries, reforestation, eco-tourism, communal local surveillance, making and selling of handicrafts, etc., as well as monitoring of forest cover and monarch butterfly colonies. Monarch Butterfly Trust Fund Training of guides; training of environmental education teachers.	Alliance WWF-Telcel and Alliance WWF-Carlos Slim Foundation WWF & Fondo Mexicano para la Conservación de la Naturaleza, A.C. (FMCN) WBF, Biocenosis	http://www.wwf.org.mx/ www.biocenosis.org.mx
2	Payments to landowners as compensation for conservation of private lands within the property; and reforestation.	MBF, CONAFOR	www.monarchbutterflyfund.org www.conafor.gob.mx
3	Restoration of landslide and erosion areas.	Fondo Mexicano para la Conservación de la Naturaleza, A.C. (FMCN)	http://fmcn.org/
4	Improvement of tourism infrastructure in the buffer zone of the biosphere reserve.	FONATUR	www.fonatur.gob.mx

Active Conservation Projects

N.O	Organization/individuals	Brief description of Active Projects	Contact Details
5	Sustainable tourism program, which supports the development of infrastructure and training of local communities inside the property.	CONANP/ PROCODES, PET	http://www.conanp.gob.mx/acciones/procodes.php
6	Development and implementation of the North American Monarch Conservation Plan with a focus on (1) prevention of threats, mitigation, and control; (2) innovative cooperative agreements; (3) research, monitoring, evaluation and development of reports; and (4) education, training, and capacity building.	Commission for Environmental Cooperation of North America (CEC; U.S.A, Canada, and Mexico)	http://www.cec.org/
7	Development of voluntary surveillance brigades to halt illegal deforestation.	PROFEPA, MBF, PROCODES	http://www.profepa.gob.mx/
8	Alternative livelihoods for communities in the Monarch Butterfly Biosphere Reserve.	MBF, Aztec Movement	.

Active Conservation Projects

Brief description of Active Projects			
N.O	Organization/individuals	Brief description of Active Projects	Contact Details
1	Consolidating coordination and cooperation across the three range countries	Building upon existing agreements and cooperation, the consolidation of coordinated international efforts across North America is of critical importance.	.
2	Extension of the World Heritage property	The size of the property is small and it appears that the important additional wintering colonies of the Monarch Butterfly are highly vulnerable. Efforts to add the remaining wintering sites as components of an enlarged serial site deserve to be considered.	.
3	Consolidation of Forest Restoration	The stunning rate of historic forest loss raises the question of reforestation and/or promotion of natural regeneration. The experience with reforestation is mixed and conventional efforts have often been met with limited success. Methods are needed to promote cheap and effective natural regeneration.	.

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Anexo E

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Unravelling the annual cycle in a migratory animal: breeding-season habitat loss drives population declines of monarch butterflies

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Summary

1. Threats to migratory animals can occur at multiple periods of the annual cycle that are separated by thousands of kilometres and span international borders. Populations of the iconic monarch butterfly (*Danaus plexippus*) of eastern North America have declined over the last 21 years. Three hypotheses have been posed to explain the decline: habitat loss on the overwintering grounds in Mexico, habitat loss on the breeding grounds in the United States and Canada, and extreme weather events.

2. Our objectives were to assess population viability, determine which life stage, season and geographical region are contributing the most to population dynamics and test the three hypotheses that explain the observed population decline.

3. We developed a spatially structured, stochastic and density-dependent periodic projection matrix model that integrates patterns of migratory connectivity and demographic vital rates across the annual cycle. We used perturbation analysis to determine the sensitivity of population abundance to changes in vital rate among life stages, seasons and geographical regions. Next, we compared the singular effects of each threat to the full model where all factors operate concurrently. Finally, we generated predictions to assess the risk of host plant loss as a result of genetically modified crops on current and future monarch butterfly population size and extinction probability.

4. Our year-round population model predicted population declines of 14% and a quasi-extinction probability (< 1000 individuals) > 5% within a century. Monarch abundance was more than four times more sensitive to perturbations of vital rates on the breeding grounds than on the wintering grounds. Simulations that considered only forest loss or climate change in Mexico predicted higher population sizes compared to milkweed declines on the breeding grounds. Our model predictions also suggest that mitigating the negative effects of genetically modified crops results in higher population size and lower extinction risk.

5. Recent population declines stem from reduction in milkweed host plants in the United States that arise from increasing adoption of genetically modified crops and land-use change, not from climate change or degradation of forest habitats in Mexico. Therefore, reducing the negative effects of host plant loss on the breeding grounds is the top conservation priority to slow or halt future population declines of monarch butterflies in North America.

Key-words: agricultural intensification, annual cycle, conservation planning, genetically modified organisms, matrix modelling, migratory connectivity, transboundary conservation

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Introduction

Hemispheric migrations of wildlife involving billions of individuals each year are in widespread decline (Robbins *et al.* 1989; Bolger *et al.* 2008; Brower *et al.* 2012). Migratory animals face multiple threats at different portions of the annual cycle that are often separated by vast geographical distances (Webster *et al.* 2002), which pose enormous challenges for predicting population abundance and designing effective management plans (Martin *et al.* 2007; Norris & Marra 2007; Small-Lorenz *et al.* 2013). Underscoring good management is an understanding of how various environmental and anthropogenic threats interact to influence population dynamics, through their impact on vital rates, in the face of global change. Addressing threats to population viability of migratory animals therefore requires integrating detailed information of how individuals move, survive and reproduce throughout the annual cycle and respond to these threats (Webster *et al.* 2002; Norris & Marra 2007; Taylor & Norris 2010; Jenouvrier 2013).

Monarch butterflies (*Danaus plexippus*), which undergo a long-distance migration between breeding and non-breeding locations typical of vertebrates, have traditionally been considered most vulnerable to disturbance on the overwintering grounds. In Mexico, forest habitat loss (Brower *et al.* 2002) and severe weather patterns (Oberhauser & Peterson 2003; Brower *et al.* 2004) are known to affect local butterfly population abundance by increasing the probability of catastrophic mass mortality events (Anderson & Brower 1996; Brower *et al.* 2012). Alternatively, declines of monarch butterflies may also be attributed to habitat loss that could occur at multiple locations and time periods of the breeding cycle. Reduction in host plants (various milkweed species, *Asclepias*) due to land-use change (mostly urbanization) and agricultural practices, such as the adoption of genetically modified, herbicide-resistant corn and soybean crops, that lower density of host plants in agricultural fields on the breeding grounds (Oberhauser *et al.* 2001; Brower *et al.* 2012; Pleasants & Oberhauser 2013) is predicted to increase competition for food among larvae leading to decreases in immature survival (Flockhart, Martin & Norris 2012).

Given that the conservation of monarch butterflies, like many migratory species, is a responsibility shared by multiple countries (Commission for Environmental Cooperation 2008), a quantitative assessment of year-round population dynamics is critical for guiding effective trans-boundary conservation planning and assessing risk of extinction in the wild. Our objectives were to (i) assess the long-term viability trend and cumulative quasi-extinction probability (<1000 individuals) for monarch butterflies over the next 100 years given projected land-use changes that modify host plant abundance across the breeding grounds and concurrent future climate trends and deforestation rates that alter the frequency of winter mass mortality events on the wintering grounds; (ii) use transient elasticity analysis (the relative sensitivity values which sum to 1) of the projected population to determine which life stage, season and geographical region across the annual cycle are contributing the most to explain population declines of migratory monarch butterflies; (iii) test the three hypotheses of population decline by comparing the singular effects of habitat loss on the breeding ground, habitat loss on the wintering grounds and climate change to a full model where all factors operate concurrently; and (iv) explore the effects of host plant loss on the breeding ground as a result of adoption of genetically modified crops on future monarch butterfly population size and the risk of extinction.

Materials and methods

Our population model required parameter estimates of survival, fecundity and migration throughout the annual cycle (Fig. 1). We considered one overwintering and three breeding regions (Fig. 2a) to parameterize a spatially structured, two-cohort, stochastic and density-dependent periodic projection matrix model (Hunter & Caswell 2005) for monarch butterflies. The model structure (Fig. 1) used a two-cohort approach to differentiate butterflies in diapause that migrate to Mexico from reproductively active butterflies because these cohorts have different physiological and demographic processes (Brower 1995). We therefore had five life stages: an immature stage that included all developmental transitions from egg to eclosion and then first- and second-month or greater (hereafter second month) vital rate estimates for each cohort of adults that captures differences in survival and reproduction (Fig. 1).

POPULATION MODEL

The model took the form $\vec{n}(t+1) = A_t\vec{n}(t)$ where the global transition matrix A at a given month t is used to project the population vector, that is, arranged as the spatial distribution of each

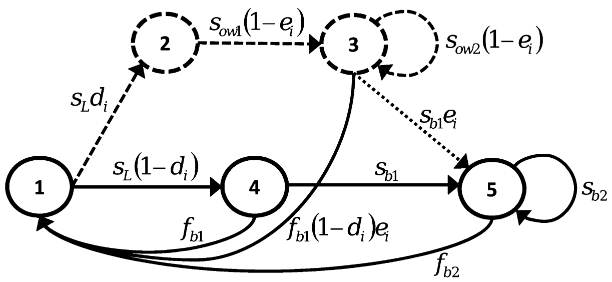

Fig. 1. The life cycle graph of monarch butterflies, characterized by five stages. The immature (1) stage includes egg, larval and pupal development until eclosion. Eclosed butterflies in their first (2) or second or more (3) month of life are in a reproductive diapause (dashed lines). Only eclosed butterflies in their first (4) or second or more (5) month of life in breeding condition (solid lines) produce offspring. The dotted line between (3) and (5) represents overwintered butterflies that emerge from diapause in April and become reproductively active in the South. Descriptions of the variables are provided in Table S1 (Supporting information).

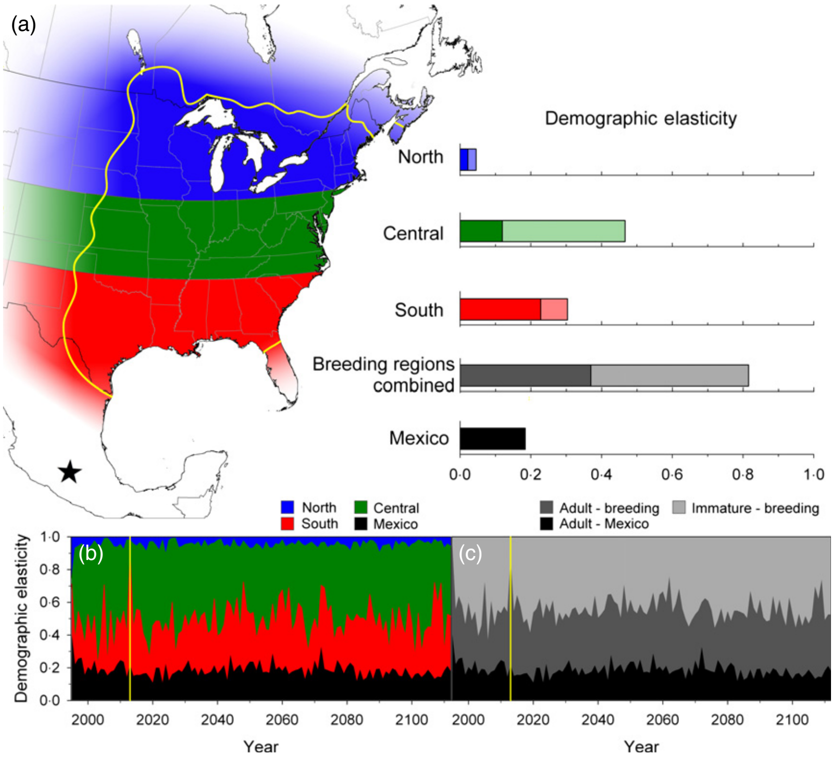

Fig. 2. The geographical regions occupied by monarch butterflies throughout the annual cycle in eastern North America and their associated long-term demographic elasticities between regions, seasons and life stages. (a) Butterflies overwinter in Mexico (black star) and breed in the South (red), Central (green) and North (blue) regions. The yellow outline indicates the monarch breeding habitat study area that was used to quantify milkweed abundance (See Supporting Information). Population abundance was most sensitive to vital rates in the Central region, followed by the South and Mexico, and least sensitive to vital rates in the North. The Central region was most sensitive to perturbation of immature vital rates (light green) compared to adults (dark green), whereas the opposite pattern was found in the South. Population abundance was more sensitive to vital rates on the breeding grounds (South, Central and North regions combined) than the non-breeding grounds (Mexico). On the breeding grounds, sensitivity was almost equal between adult (dark grey) and immature (light grey) life stages. (b) Annual trends of the demographic elasticity of monarch population abundance to perturbation of vital rates among regions and (c) between the breeding and non-breeding portions of the annual cycle. The annual demographic elasticity values vary annually owing to stochastic population processes; however, the sensitivity patterns to the left (historic) and right (future) of the vertical yellow line remain relatively consistent.

stage (Hunter & Caswell 2005), from $n(t)$ to $n(t + 1)$. Within each time step t of 1 month, A_t included both migration among and demography within the four geographical regions i of the five life stages using the block-diagonal formulation and vec-permutation approach (Hunter & Caswell 2005). In this arrangement, butterflies first move between regions before demographic events like reproduction occur, in order to reflect that females are reproductively active during the rapid re-colonization of eastern North America over successive generations (Malcolm, Cockrell & Brower 1993; Flockhart *et al.* 2013). The process is repeated for each of 12 months to project the population over an annual cycle.

The block-diagonal matrix organizes the demographic processes and transitions among life stages within regions (Hunter & Caswell 2005). The demographic vital rates represent survival of immature (s^i_L), overwinter survival for butterflies in their first and second month of diapause (s^i_{ow1}, s^i_{ow2}), survival of adults in their first and second month of breeding (s^i_{b1}, s^i_{b2}), and fecundity of breeding butterflies in their first (f^i_{b1}) and second (f^i_{b2}) months (Fig. 1). The terms d_i and e_i permit the transition of generations between reproductive to diapause life-history stages in autumn (which occurs during immature development; Goehring & Oberhauser 2002) and the emergence from diapause to breeding condition at the end of the winter, respectively. The migration process was structured with the block-diagonal dispersal matrix that accounts for migration of adults between regions. For each adult cohort, migration included both the transition rate among regions (t_{ij}) and survival during migration between these same regions (s_{ij}). The Supporting Information provides details of the model structure.

VITAL RATE ESTIMATION

The population response to the effects of habitat loss and climate change, key environmental factors that are thought to strongly influence population size of monarch butterflies (Brower *et al.* 2012), occurs through changes to vital rates. We present the results of models to estimate milkweed abundance on the breeding grounds and weather-induced mass mortality events in Mexico that were incorporated into estimates of larval survival and adult winter survival probability, respectively. Detailed analysis of each vital rate estimate, as well as the milkweed abundance and weather-induced mass mortality models, is available in the Supporting Information.

Fecundity

We estimated fecundity of first-month and second-month adults (Table S1, Supporting information: f^i_{b1}, f^i_{b2}) using estimated lifetime egg output reported in Oberhauser (1997). We assumed that females laid 75% of their total eggs in the first month and 25% in the second month. Sex ratio of offspring was assumed to be 50:50.

Migration

Migration combines information on migratory connectivity (Webster *et al.* 2002; Norris & Marra 2007) and survival during migration (see below) to estimate the transition probability of adults flying between different regions at each time step. Following the two-cohort structure of the model, we differentiate rates between non-reproductive butterflies that are on fall migration to Mexico and reproductively active butterflies that can move between breeding regions.

The timing of migration of non-breeding butterflies to Mexico follows a relatively predictable pattern by latitude (Taylor 2013). We incorporated these temporal migration patterns in our model by assuming that butterflies depart to Mexico from the north during September, from the central during October and from the south during November. Collectively these butterflies arrived at the overwintering colonies in December where they remained until April when they became reproductively active (Brower 1995).

Reproductive monarch butterflies colonize the breeding grounds over successive generations (Malcolm, Cockrell & Brower 1993; Miller *et al.* 2011, Flockhart *et al.* 2013). We assumed the main cohort of butterflies colonized the south in April, the central in May and the north in June (Cockrell, Malcolm & Brower 1993) and the last breeding generation would occur in August in the north, September in the central and October in the south (Brower 1995; Calvert 1999; Baum & Sharber 2012; Flockhart *et al.* 2013).

We calculated migration rates ($t^t_{i,j}$) of breeding butterflies based on published information in Flockhart *et al.* (2013) who used stable-hydrogen and stable-carbon isotopes to assign a geographical origin of captured butterflies. Using the assigned geographical region as the origin and the capture region as the destination, we cross-tabulated origin and destination regions to produce a contingency table of relative frequency by dividing the number assigned to each origin region by the marginal total of the destination regions. Using this approach, we calculated the migration between the four regions (origin included Mexico for butterflies that overwintered; see Supporting Information) for each month during the year.

Breeding-season survival

First- and second-month adult female survival (Table S1, Supporting information, Fig. 1: s^i_{b1}, s^i_{b2}) estimates came from longevity measures of captured wild female butterflies (Herman & Tatar 2001). Immature survival (s^i_L) was the cumulative survival from egg to eclosion as an adult butterfly and considered the product of a density-dependent survival relationship based on larval competition for milkweed host plants (Flockhart, Martin & Norris 2012), density-independent larval survival (Oberhauser *et al.* 2001) and pupal survival (Oberhauser 2012).

We applied the findings of Flockhart, Martin and Norris (2012) who showed larval survival probability declined as the average number of eggs per milkweed stem increased. Therefore, calculating the density-dependent response required an estimate of milkweed abundance in each region. To estimate the total number of milkweed stems, we multiplied the land area of different land-cover types (e.g. Taylor & Shields 2000) by the proportion of infested area for each land-cover type (e.g. Hartzler & Buhler 2000; Hartzler 2010; Pleasants & Oberhauser 2013) and the number of milkweed stems within infested areas (see Supporting Information). To understand milkweed abundance change over time, we estimated annual rates of land-cover conversion using data from 1982 to 2007 (U.S. Department of Agriculture 2009) and used nonlinear models to estimate the expected changes in adoption of genetically modified, herbicide-resistant corn and soybean crops (Hartzler 2010; Pleasants & Oberhauser 2013). Details of land-cover change and associated dynamic milkweed abundance are presented in the Supporting Information.

We calculated density-independent larval survival from egg to pupation using estimates from Oberhauser *et al.* (2001) who presented counts of 5th instar larvae relative to counts of eggs in non-agricultural areas, agricultural fields and field margins in four geographical regions that spanned the breeding range. Tachinid flies parasitize monarch larvae that results in mortality realized during the pupa stage, so pupal survival was assumed as one minus the marginal parasitism rate of fifth instars based on 11 years of data following Oberhauser (2012). Mortality during the pupal stage was therefore assumed to result solely from tachinid fly parasitism and provides a suitable way to incorporate this important source of immature mortality on monarch population dynamics (Oberhauser *et al.* 2007).

Migration survival

Evidence for Lepidoptera suggests mortality during migration to be low relative to the stationary portions of the annual cycle (Chapman *et al.* 2012; Stefanescu *et al.* 2013), whereas the opposite pattern has been found for vertebrates (Muir *et al.* 2001; Sillett & Holmes 2002). Few data exist to estimate these mortality rates directly and there is currently no published information for monarch butterflies. In the absence of empirical estimates, the opinions of experts can provide valuable information to understand population processes (Martin *et al.* 2012a).

We used an expert elicitation exercise to estimate the survival of monarch butterflies during both spring and fall migration ($s^t_{i,j}$; Table S1, Supporting information). The exercise consisted of independent elicitation of survival estimates, an anonymous review of the group results, and a second round of elicitations where experts were allowed to modify their original responses after having seen the group results (Martin *et al.* 2012a). Each expert provides a worst-case, average-case and best-case estimate of the probability of survival for (i) butterflies migrating to the overwintering colonies during autumn migration, (ii) overwintered adult monarch butterflies that migrate from Mexico to the south and (iii) first- or second-generation breeding butterflies born in the south that re-colonize the rest of the breeding distribution. We calculated the mean and standard deviation for the average-case values between each pairs of regions provided by experts and found that the variation of survival implemented into the matrix model contained both the mean worst-case and best-case estimates provided by experts, suggesting that the estimates

of survival during migration generated during simulations of the model captured a range of expected survival rates (see Supporting Information).

As survival during migration was the only vital rate used in the population model not based on empirical data, we present a sensitivity analysis in the Supporting Information of how well the worst-case, average-case and best-case survival estimates predicted the observed monarch butterfly population decline. The results suggest that both the average-case and best-case scenario estimates better reflect monarch butterfly population dynamics but that the predictions from models that incorporate the average-case scenario more closely reflect the observed population decline (see Supporting Information).

Overwintering survival

The probability of survival for overwintering adult butterflies (s^i_{ow1}, s^i_{ow2}) was a product of a baseline survival in the presence of predators (Brower & Calvert 1985; Glendinning, Alonso Mejia & Brower 1988) and catastrophic mortality events caused by extreme weather phenomena (Brower *et al.* 2004). Birds were estimated to kill about 9% of all butterflies in colonies (Brower & Calvert 1985), whereas mice are predicted to kill about 4% of the population (Glendinning, Alonso Mejia & Brower 1988). To estimate mortality, we divided the estimated number of depredated butterflies from Brower *et al.* (1985) and Glendinning, Alonso Mejia and Brower (1988) by butterfly densities (butterflies/ha) from the Jolly-Seber estimates in Calvert (2004) to correct for potentially biased estimates of population density in the wintering colonies. Assuming that predation by birds and mice is independent, multiplying the product of the two survival estimates yielded the baseline overwinter survival (see Supporting Information).

Stochastic mass mortality events in the overwintering colonies can kill significant numbers of the entire eastern population during a single storm (Brower *et al.* 2004). The magnitude of each mortality event is the interplay between ambient temperature, precipitation and exposure that determine body temperature, and hence freezing risk, of monarch butterflies (Anderson & Brower 1996). We used a logistic function to model the proportion of the total overwintering population that would die from extreme weather. The model included the effects of temperature, precipitation and changes in exposure (see Supporting Information). The addition of an exposure parameter incorporates the 'blanket effects' (Anderson & Brower 1996) offered by high-quality forest habitat that was assumed to be lost at 1·3% per year (Brower *et al.* 2002; Ramírez, Azcárate & Luna 2003; López-García & Alcántara-Ayala 2012; Vidal, López-García & Rendón-Salinas 2014).

Temperatures and rainfall patterns are predicted to change over the next 100 years in Mexico (Sáenz-Romero *et al.* 2010) and these changes are predicted to influence monarch mass mortality events (Oberhauser & Peterson 2003). Using the location and elevation of the monarch colonies (García-Serrano, Lobato Reyes & Mora Alvarez 2004), we extracted monthly (December to March) current and future temperature under the A2 scenario of the CGCM3 (T62 resolution) climate model that assumes high greenhouse gas emissions and a growing human population, presented in Sáenz-Romero *et al.* (2010). For each month, we fit a linear regression of predicted mean minimum temperature using data from the years 2000 (current), 2030, 2060 and 2090 as our predicted climate projection in the overwintering colonies. Variation in daily temperatures was assumed to remain consistent over time and was estimated from daily minimum temperatures from five federal weather stations representative of the overwintering colonies (see Supporting Information). We assumed daily rain events >10 mm would result in butterflies being wetted and making them more vulnerable to freezing risk (Anderson & Brower 1996) and assumed that the probability of a rain event of >10 mm between December and March summarized from the weather station data would remain consistent. The matrix population model randomly selected a daily probability of a large rain event and a minimum temperature to calculate the daily survival between December 1 and March 30. The product of these daily mortality estimates represented the population-level stochastic mortality rate of each year of the model (see Supporting Information).

ANALYSIS

We initiated the population model using the population size observed in 1994 (Rendón-Salinas & Tavera-Alonso 2014) to assess the model fit from the first 19 years of the simulation (1995–2013) and then projected the population for 100 years and calculated the stochastic population growth rate (log λ_s) and 95% confidence interval from 1000 simulations. Model fit was assessed by testing the standard deviates of the population growth rates from observed and projected population sizes (McCarthy *et al.* 2001). The cumulative probability of quasi-extinction was determined using a binomial model that regress the counts of the number of simulations that had gone extinct by a given year. To test between the three hypotheses, we divided the mean population size from a simulation with each effect by the population size of the full model and used linear models to regress differences in population size against year. A slope different from zero indicates that threat alone would cause a larger (in the case of positive slope) future population than the full model that considers all threats simultaneously.

To understand the factors that limit population size of monarch butterflies, we estimated monthly transient elasticities (the relative sensitivity values which sum to 1) of the total species abundance to perturbation of the migration and demographic vital rates (Caswell 2007). To make general predictions of the sensitivity of population growth to changes in vital rates throughout the annual cycle, we summed the demographic transition elasticity values across life stages (immature, adult), life-history events (breeding, non-breeding) or regions (Mexico, South, Central, North). We ran all simulations using Matlab R2009.

Results

POPULATION TREND AND EXTINCTION PROBABILITY

Population size estimates from our model were not significantly different from the observed data ($t = -0{\cdot}4889$, $P = 0{\cdot}63$; Fig. 3a) and predict that, if land-use and climate change continue as expected, population size will decline by an additional 14% within the next 100 years (Fig. 3b). Furthermore, under these conditions, we predict that the cumulative probability of quasi-extinction of <1000 butterflies remaining in the population over 100 years is >5% (Fig. 3b). Overall, the stochastic population growth rate was predicted to be −0·0332 (95% CI: [−0·4028, 0·3364])

(Fig. 3b) which is consistent with the population growth rate observed over the past two decades ($r = -0{\cdot}048$, 95% CI: [−0·186, 0·089]; Brower *et al.* 2012; Rendón-Salinas & Tavera-Alonso 2014).

SENSITIVITY OF POPULATION ABUNDANCE

Population abundance was more sensitive to land-use and climate changes on the breeding grounds (mean 0·816 ± 0·004 SEM) than on the wintering grounds (0·184 ± 0·004; Fig. 2a). Decomposition of these sensitivities showed that larvae (0·446 ± 0·007) were more sensitive compared to adults (0·370 ± 0·007) on the breeding grounds (Fig. 2a). At a regional scale, the total butterfly abundance was more sensitive to land-use and climate change impacts on the vital rates within the Central breeding region (0·446 ± 0·010) than within the South breeding region (0·304 ± 0·010) or Mexico (0·184 ± 0·004), whereas butterfly abundance was least sensitive to impacts in the North breeding region (0·045 ± 0·002; Fig. 2a). Further decomposition between life stages and regions suggests that the patterns in the Central region resulted from sensitivity of perturbation of immature vital rates rather than adults (Fig. 2a). In contrast, in the South, butterfly abundance was more sensitive to disturbance of adult vital rates compared to vital rates of the immature stage (Fig. 2a).

Although annual elasticities varied between years, the historic and future sensitivity patterns were predicted to remain relatively consistent over time. For example, population abundance was about four times more sensitive to changes in vital rates on the breeding grounds than wintering grounds throughout the study (Fig. 2b) despite a reduced probability of mass mortality events in Mexico over time (Fig. S1, Supporting information). Furthermore, changes in butterfly abundance were about 1·3 times more sensitive to changes in vital rates of adults than those of larvae both at the start and end of the study (Fig. 2c) despite a reduction in milkweed abundance across the breeding distribution (Fig. 4).

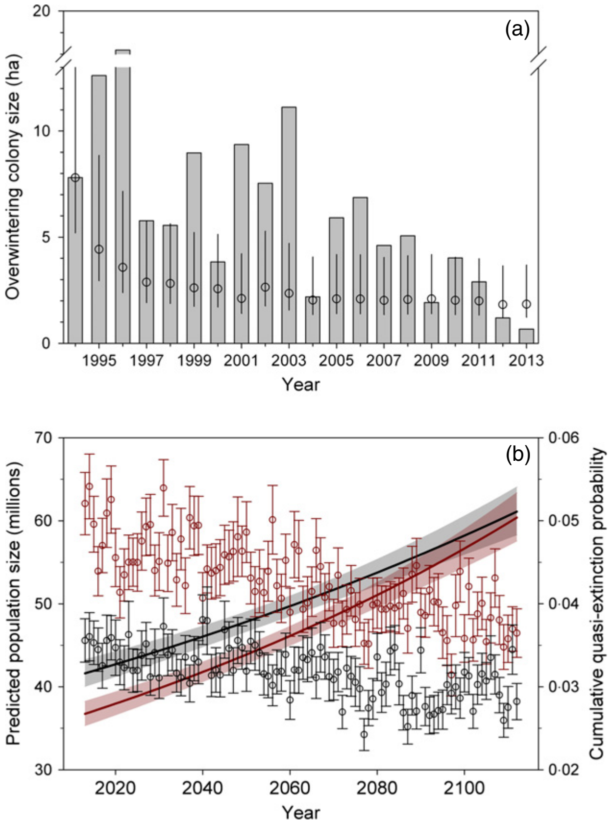

Fig. 3. Monarch butterfly population size is projected to decrease with a corresponding increase in quasi-extinction probability. (a) The model-derived mean predicted overwintering colony size (points) fit the observed monarch butterfly overwintering colony size (bars; Brower *et al.* 2012; Rendón-Salinas & Tavera-Alonso 2014). Overwintering population size is the area (in hectares) occupied by clustering monarch butterflies. For predicted colony size, the points represent the mean density (50 million ha^{-1}), while the upper (25 million ha^{-1}) and lower (75 million ha^{-1}) error bars represent the observed lower and upper population density estimate (Brower *et al.* 2004) assuming a 1 : 1 sex ratio. (b) Projected mean population size (±SE, circles and error bars) and probability (±95% CI, line and shading) of quasi-extinction (<1000 individuals) in eastern North America in December of each year from 2013 to 2112. The full model (black) which includes the effects of genetically modified crops is compared to a simulation with no genetically modified crops (red) and shows the presence of genetically modified crops predict monarch butterfly populations being lower with a higher probability of quasi-extinction over the next half-century. The population values represent the number of females since the model only considered female butterflies.

THREATS TO POPULATION VIABILITY

Under current conditions, the annual probability of a mass mortality event on the wintering grounds was about

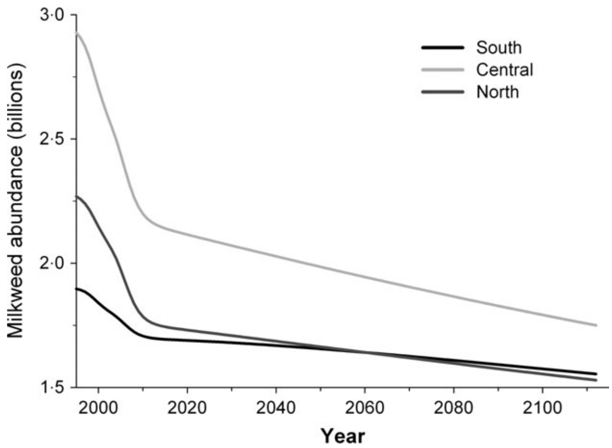

Fig. 4. Predicted changes of milkweed abundance in each breeding region between 1995 and 2112. In each region, milkweed was estimated by multiplying milkweed density by the area of different land-cover types infested with milkweed. Changes in milkweed abundance reflect predicted adoption rates of genetically modified, herbicide-tolerant corn and soybean crops and annual land-use changes.

11% and a reduction in forest cover increased the probability of these events (Fig. S1, Supporting information). Surprisingly, under projected climate change, the chance of butterflies being killed due to severe weather was predicted to decline. For example, winter mortality probabilities of adults under current conditions (11% per year) were eight times higher compared to 2030 (1%), 73 times higher compared to 2060 (<0·2%) and 665 times higher compared to 2090 (<0·02%; Fig. S1, Supporting information). However, over time, the decreasing probability of a mass mortality event caused by rising temperatures trumped any negative effects caused by reduction in forest cover (Fig. S1, Supporting information). Simulations of population dynamics that considered only the effects of forest loss or climate change in Mexico predicted higher population sizes compared to the full model that considered all effects simultaneously (Fig. 5).

Between 1995 and 2013, our model estimated that 1·49 billion individual milkweed stems were lost, representing a 21% decline in milkweed abundance (Fig. 4). Over the past two decades, the Central region, which was the most sensitive to perturbation of vital rates, had the most rapid loss of milkweed (Fig. 4) which resulted from recent widespread adoption of genetically modified, herbicide-resistant corn and soybean crops associated with industrial agriculture. Currently, we estimated there were more than 5·6 billion milkweed stems in the study area with the majority (67%; 3·7 billion stems) occurring in agriculture-intensive landscapes (Table 1). Land held in the public trust for the maintenance of biodiversity (e.g. Conservation Reserve Program lands, road right-of-ways) contained 18% of all milkweed plants. Importantly, road right-of-ways accounted for almost 548 million plants (10% of all milkweeds; Table 1). Our model predicts the rate of milkweed decline to slow into the future with milkweed abundance being 14% lower than current conditions, although this still represents a loss of 770 million milkweed plants over the next 100 years (Fig. 4). Overall, genetically modified, herbicide-resistant crops have increased the current, and predicted future, extinction probability of monarch butterflies in eastern North America (Fig. 3b).

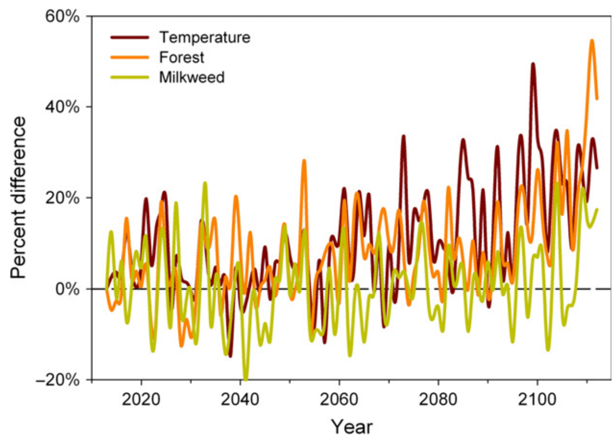

Fig. 5. Reductions in milkweed host plants drive monarch butterfly population decline. The proportional difference in projected mean population size of monarch butterflies over time under the effects of milkweed loss (yellow), forest loss (orange) or changes in temperature (red) relative to the full model that includes all three effects (dashed line). Linear models that regressed population size against year were significant for temperature ($\beta = 0{\cdot}0023$, $P < 0{\cdot}001$) and forest ($\beta = 0{\cdot}0021$, $P < 0{\cdot}001$) but not for milkweed ($\beta = 0{\cdot}0005$, $P = 0{\cdot}09$), indicating no difference in projected population sizes of the full model compared to one that only considered milkweed and hence milkweed is the driving factor of monarch population decline. The models for each effect controls for the others; for example, the milkweed model includes the effects of declines of milkweed host plant abundance on the breeding grounds while controlling for the effects of climate change (no change in temperatures over time) and deforestation (no deforestation over time) in Mexico.

Discussion

Our results suggest both climate change and deforestation had less influence on projected population declines compared to the effects of milkweed declines on the breeding grounds. These results are contrary to the long-held belief that monarch butterflies were most vulnerable to disturbance on the wintering grounds since they congregate in a small area at high densities (Brower *et al.* 2002, 2004). Indeed, this was some of the motivation for multiple Mexican presidential decrees that protected butterfly overwintering habitats (Commission for Environmental Cooperation 2008) and recent successful efforts to curb illegal deforestation activities (Vidal, López-García & Rendón-Salinas 2014). Despite a reduced probability of catastrophic mortality events on the wintering grounds, sensitivity to this life-history stage compared to the breeding season remained relatively fixed because mortality is infrequent, stochastic and density-independent (Brower *et al.* 2004). In other words, even if monarchs adjust their behaviour to deal with changing habitat availability (Sáenz-Romero *et al.* 2012) or experience different future temperature and precipitation regimes (Oberhauser & Peterson 2003; Sáenz-Romero *et al.* 2010), population viability is expected to remain less sensitive to mortality on the wintering grounds than to changes in demographic rates on the breeding grounds.

Overall, observed monarch butterfly population decline and future increased extinction risk are largely driven by conditions on the breeding grounds, particularly in the Corn Belt region of the United States (Oberhauser *et al.* 2001; Brower *et al.* 2012; Pleasants & Oberhauser 2013). Given the demographic importance of the Central region and its direct link to overwintering population size in Mexico (Wassenaar & Hobson 1998; Flockhart *et al.* 2013), the rapid loss of milkweed projected for this region attributable to land-cover changes and shifts in agricultural practices is a large concern (Hartzler 2010; Brower *et al.* 2012; Pleasants & Oberhauser 2013). As monarchs are larval host plant specialists, changes in milkweed abundance directly influence vital rates, first through

Table 1. The proportion of milkweed stems in eastern North America in 2013. Estimates are among breeding regions, landscape protection classification and land-cover types. The total number of estimated milkweed plants was 5 604 106 046

	South		Central		North	
Unprotected	0·84		0·84		0·76	
Crop[a]		0·698		0·880		0·862
Pasture		0·117		0·083		0·108
Rangeland		0·046		0·016		0·024
Wetland		0·139		0·020		0·006
Protected	0·16		0·16		0·24	
Crop[b]		0·177		0·282		0·544
Pasture		0·007		0·009		0·012
Rangeland		0·005		0·004		0·005
Wetland		0·224		0·108		0·006
Right-of-ways		0·587		0·597		0·433
Percentage of total	0·303		0·384		0·313	
Total milkweed	1 696 459 725		2 154 696 122		1 752 950 199	

[a]Includes the effects of genetically modified corn and soybean crops on milkweed abundance, see text for details.
[b]Cropland assumed to have milkweed density of Conservation Reserve Program lands.

intraspecific larval competition (Flockhart, Martin & Norris 2012) or alternatively, by preventing females from laying a full egg complement (Zalucki & Lammers 2010), although the latter has never been empirically demonstrated. Ultimately, understanding the mechanism by which milkweed reduction limits population abundance will have important implications towards conservation planning.

Our results imply that conserving monarch butterflies by addressing the negative impacts of changing land-use and the adoption of genetically modified, herbicide-resistant crops on host plant abundance is the highest conservation priority. These conclusions should not be misconstrued as implying that efforts towards improving the social, economic and environmental conditions on the wintering grounds are not important, but rather, that inaction in one location during a portion of the annual cycle can undermine conservation efforts in other portions of the annual cycle (Myers *et al.* 1987; Martin *et al.* 2007; Sheehy *et al.* 2010; Vidal, López-García & Rendón-Salinas 2014). Specifically, increasing host plant abundance in the South and Central regions of the United States is expected to translate into the largest benefit to species viability. While planting milkweeds in gardens of private citizens and publicly held lands such as road right-of-ways may be the easiest locations to focus immediate conservation efforts given the limited supply of milkweed seeds, overall, these efforts may be insufficient to negate the ongoing annual loss of milkweed plants let alone address the massive habitat losses observed over the last two decades due to industrial agricultural practices (Hartzler 2010; Pleasants & Oberhauser 2013). Furthermore, the spatial arrangement of milkweed may influence population response (e.g. Zalucki & Lammers 2010) highlighting that both recovery efforts and threats are dynamic and spatially explicit (Brower *et al.* 2002, 2012; Commission for Environmental Cooperation 2008); thus, stochastic population dynamics should be incorporated into cost-effective conservation planning options (Baxter *et al.* 2006; Martin *et al.* 2007; Pichancourt *et al.* 2012) to aid monarch butterfly population recovery.

Limited data will affect what we can infer about how ecological relationships interact to influence population dynamics across space and time. In extreme cases, no data exist to estimate vital rates. For example, there are virtually no empirical estimates of survival during migration for any terrestrial migratory animal (for rare exceptions see: Ward *et al.* 1997; Sillett & Holmes 2002; Chapman *et al.* 2012). In such cases, we may be limited to using educated guesses or surveys of experts as to the likely range of empirical values (Martin *et al.* 2012a). Drawing inference from model results based on sparse data must therefore be done cautiously, particularly when the sensitivity of data-limited vital rates is high, but is often necessary when investigating steep population declines of threatened species and where conservation success depends on timely decision-making (Martin *et al.* 2012b). For monarch butterflies, subsequent sensitivity analysis suggests that the values elicited from butterfly experts were robust to observed population dynamics and that true survival during migration is expected to be equal or slightly higher than what was provided by experts.

Population declines among migratory species have generated hypotheses that populations are limited by conditions on the breeding grounds (Robinson *et al.* 1995), the non-breeding grounds (Robbins *et al.* 1989; Sherry & Holmes 1996), during migration (Bolger *et al.* 2008) or a combination of these factors (Kareiva, Marvier & McClure 2000; Brower *et al.* 2012). However, quantifying which environmental and anthropogenic factors drive population dynamics at global extents is a complex issue because it depends on how we integrate migratory connectivity and population processes across the annual cycle (Sherry & Holmes 1996; Kareiva, Marvier & McClure 2000; Faaborg *et al.* 2010) and the quality of the data available.

Overall, the general modelling approach we promote could be applied to any migratory species because it

incorporates recent methods to delineate migratory connectivity (Webster *et al.* 2002), how seasonal interactions influence vital rates via density dependence (Norris & Marra 2007), and established approaches of evaluating spatial population dynamics across the annual cycle (Hunter & Caswell 2005; Caswell 2007). Ultimately, the ability to quantify contributions to population growth rate across the annual cycle provides a tractable way to measure the robustness of international conservation programmes (Bull *et al.* 2013) and has important legal implications for conserving threatened wildlife that migrate between countries that classify and protect species-at-risk differently (Fischman & Hyman 2010).

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Author contributions

D.T.T.F., D.R.N. and T.G.M. designed the research. D.T.T.F. analysed the data. J.-B.P. wrote the code of model. All authors wrote the paper. [Correction added on 28 July 2014, after first online publication: final sentence changed to 'All authors wrote the paper.']

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Appendix S1. Detailed description of methodology.

Fig. S1. The annual probability of a mass mortality event (>1% mortality of total population) under different proportions of habitat forest cover on the wintering grounds over time.

Fig. S2. Daily minimum temperature used to describe temperature patterns at the overwintering colonies in Mexico between December and March.

Table S1. Key to notation used in the spatial periodic matrix model for migratory monarch butterflies (*Danaus plexippus*) in eastern North America.

Table S2. Sample sizes of monarch butterflies captured in each region for assigning migratory connectivity (Flockhart *et al*. 2013).

Table S3. Monthly transition of monarch butterflies between destination region where they were captured and their region of origin based on stable isotopes.

Table S4. Survival of monarch butterflies during migration.

Table S5. Data used in the Geographic Information System used to calculate milkweed abundance in eastern North America.

Table S6. Land-cover classification.

Table S7. Milkweed density (m^2 ha^{-1}) for different land-cover types in eastern North America.

Table S8. Results of models used to explain road and right-of-way widths in eastern North America.

Table S9. The width of roads in eastern North America.

Table S10. The width of road right-of-ways in eastern North America.

Table S11. Transition matrix of annual land-cover change based on data between 1982 and 2007.

Table S12. The proportion of total row crops grown as corn and soybean among the three breeding regions in eastern North America.

Table S13. Parameter estimates used in a logistic regression to predict changes in the adoption rates of genetically modified corn and soybean crops over time.

Table S14. Monthly weather in monarch butterfly overwintering colonies in Mexico.

Table S15. Future monthly mean minimum temperatures in monarch butterfly overwintering colonies in Mexico.

Table S16. Annual rates of winter habitat degradation between 1971 and 2012 in Oyamel fir-pine forest ecosystems, Mexico.

Anexo F

J. Pleasants and K. Oberhauser, *Milkweed Loss in Agricultural Fields Because of Herbicide Use: Effects on the Monarch Butterfly Population,* Insect Conservation and Diversity*,* (March 2012)

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Milkweed loss in agricultural fields because of herbicide use: effect on the monarch butterfly population

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Abstract. 1. The size of the Mexican overwintering population of monarch butterflies has decreased over the last decade. Approximately half of these butterflies come from the U.S. Midwest where larvae feed on common milkweed. There has been a large decline in milkweed in agricultural fields in the Midwest over the last decade. This loss is coincident with the increased use of glyphosate herbicide in conjunction with increased planting of genetically modified (GM) glyphosate-tolerant corn (maize) and soybeans (soya).

2. We investigate whether the decline in the size of the overwintering population can be attributed to a decline in monarch production owing to a loss of milkweeds in agricultural fields in the Midwest. We estimate Midwest annual monarch production using data on the number of monarch eggs per milkweed plant for milkweeds in different habitats, the density of milkweeds in different habitats, and the area occupied by those habitats on the landscape.

3. We estimate that there has been a 58% decline in milkweeds on the Midwest landscape and an 81% decline in monarch production in the Midwest from 1999 to 2010. Monarch production in the Midwest each year was positively correlated with the size of the subsequent overwintering population in Mexico. Taken together, these results strongly suggest that a loss of agricultural milkweeds is a major contributor to the decline in the monarch population.

4. The smaller monarch population size that has become the norm will make the species more vulnerable to other conservation threats.

Key words. Glyphosate, GMO, milkweed, monarch butterfly

Introduction

Monarch butterflies (*Danaus plexippus* L. Lepidoptera: Danainae) in the Eastern North American migratory population undergo a multi-generation annual cycle that includes wintering in central Mexico. In the spring, adults that have overwintered migrate north and reproduce in Texas and states to the north and east. Their offspring move farther north into much of the eastern half of the United States and southern Canada, and two to three more generations are produced (Cockrell *et al*., 1993; Malcolm *et al*., 1993; Prysby & Oberhauser, 2004). Most adults that emerge after mid-August are in a state of reproductive diapause (Herman, 1985; Goehring & Oberhauser, 2002) and migrate from the summer breeding range to their wintering grounds, where they remain until spring (Solensky, 2004).

Annual counts of the size of the overwintering population in Mexico indicate that the monarch population has been declining over the last decade and a half (Rendón-Salinas et al., 2011; Brower *et al*., 2011b). One possible explanation for this decline is that monarch production has been decreasing as a result of a reduction in the availability of the larval host plant. Monarch larvae feed primarily on milkweeds (genus *Asclepias*- Family *Apocynaceae*, subfamily *Asclepiodeae*). On the basis of milkweed cardenolide fingerprints, it has been estimated that 92% of the monarchs wintering in Mexico had fed as larvae on the common milkweed, *Asclepias syriaca* (Malcolm *et al*., 1993). Studies in Iowa found a large reduction in *A. syriaca* in corn (maize, *Zea mays*) and soybean (soya, *Glycine max*) fields from 1999 to 2009 (Hartzler & Buhler, 2000; Hartzler, 2010). It is likely that a similar reduction has occurred throughout the region where corn and soybeans are predominantly grown. Eighty per cent of both

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corn and soybeans are grown in the Midwest (USDA, National Agricultural Statistics Service, 2011c), which is composed of the states of North and South Dakota, Nebraska, Kansas, Missouri, Iowa, Minnesota, Wisconsin, Illinois, Indiana, Michigan, and Ohio. A study in 2000 (Oberhauser *et al*., 2001) found that monarchs heavily used milkweeds in corn and soybean fields. On the basis of stable isotope analysis, Wassenaar and Hobson (1998) estimated that half of the monarchs overwintering in Mexico in 1997 came from the Midwest. Thus, the Midwestern United States is at the epicentre of a reduction in milkweeds in agricultural fields and is also an area that has in recent history contributed a large component of the monarch population. In this study, we estimate the magnitude of this milkweed loss and its consequences for monarch production.

Milkweed in agricultural fields has long been a concern for farmers as its presence reduces yield (Bhowmik, 1994). In the 1970s and 1980s, milkweed infestation in agricultural fields was viewed to be on the increase with 10.5 million ha infested in the north-central states (Martin & Burnside, 1980). Herbicides have been increasingly used to control weeds in row crops. Many of these herbicides produce only moderate control of milkweed, but glyphosate, often referred to as Roundup™ (Monsanto, St. Louis, MO, USA), is more effective (Bhowmik, 1994; Pline *et al*., 2000). However, it also has a detrimental effect on crop plants, so until the development of genetically modified (GM) glyphosate-tolerant (Roundup Ready™, Monsanto) crop plants, herbicides other than glyphosate were used to control weeds. Glyphosate-tolerant soybeans were introduced in 1996 and had reached a 94% adoption level by 2011, and glyphosate-tolerant corn was introduced in 1998 and had reached a 72% adoption level by 2011 (USDA, Economic Research Service, 2011). Glyphosate use in soybeans went from 1.4 million kg in 1994 to 41.7 million kg in 2006 (the last year for which data are available and when adoption of glyphosate-tolerant soybeans was 89%) and glyphosate use in corn went from 1.8 million kg in 2000 to 28.5 million kg in 2010 when the adoption level was 70% (USDA, National Agricultural Statistics Service, 2011a,b).

The time period (1999–2009) over which the Iowa studies found a large reduction in *A. syriaca* in corn and soybean fields (Hartzler & Buhler, 2000; Hartzler, 2010) is coincident with the period when use of glyphosate herbicide increased in conjunction with the increased adoption of glyphosate-tolerant corn and soybeans. It is very probable that a similar milkweed reduction has occurred throughout the Midwest because adoption levels of herbicide-tolerant crops are similar throughout this region (USDA, Economic Research Service, 2011). How much milkweed loss does this represent on a landscape scale? To address this question, we need information on the density of milkweeds in different habitats and the landscape area covered by those habitats. Common milkweed tends to be found in habitats with a moderate degree of disturbance, including roadsides, pastures, old fields, prairies and agricultural fields (Bhowmik, 1994). Multiple data sets provide information on the density of milkweeds in different habitats over the last decade. The studies by Hartzler and Buhler (2000) and Hartzler (2010) surveyed a number of milkweed habitats in Iowa, including agricultural fields. Additionally, a number of Midwest volunteers in the Monarch Larva Monitoring Project (2011), hereafter referred to as MLMP, measured milkweed density in their non-agricultural observation patches over several consecutive years. Milkweed density data can be combined with published statewide land-use data to estimate the number of milkweeds in different habitats. Some of the data sets we use come from Iowa because for some parameters only Iowa data are available. However, we use data from the Midwest as a whole whenever possible and make the case that the resulting estimates of monarch production are representative of the Midwest.

What is the significance of the loss of milkweeds in agricultural fields for monarchs? To address this issue, we need to estimate annual monarch production in the Midwest over the last decade to determine whether there has been a significant downward trend. Obtaining data to estimate production is difficult, despite the fact that the monarch butterfly is such a well-studied species. One approach would be to use the number of migrants that come out of the Midwest at the end of the summer as a measure of production. A monarch tagging programme begun 20 years ago (Monarch Watch, 2011) has been tracking migrating butterflies. The number of monarchs tagged shows a decline from 2004 to 2010 (Brower *et al*., 2011a). However, it is difficult to obtain accurate measures of production from this tagging programme because of the variability among the years in the number of person-hours involved in capture and tagging, the fall conditions when tagging occured and the locations where tagging occured. Alternatively, one could use counts of the number of migrating monarchs passing particular locations where they tend to be funnelled because of passage over water or geography. Such counts have been made for over a decade in upper Michigan and New Jersey (Davis, 2011) but these sites do not monitor monarchs from the Midwest.

Rather than trying to count adults, another approach to estimating Midwest monarch production is to focus on the number of eggs and larvae found on milkweed plants. This requires monitoring many patches of milkweed in different habitats, including agricultural fields. Production can then be estimated from the average number of monarchs per plant in each habitat and the number of milkweeds in each habitat on the landscape. We have combined several existing data sets that provide this information. The MLMP (2011), which has been operational for over a decade, provides data on egg and larva density on milkweeds. MLMP volunteers are located throughout the monarch breeding range and monitor sites of their choosing weekly over the summer months, reporting the number of plants (stems) monitored and the number of eggs and larvae observed. They learn the procedures of the project through workshops, by reading directions on the project website (MLMP, 2011) and via communication with the project managers (Prysby & Oberhauser, 2004). The sites they monitor, however, are not in agricultural fields. But one of us (Pleasants) has monitored eggs and larvae on milkweeds in both agricultural fields and non-agricultural habitats for several years in central Iowa and a study with larger spatial scale quantified monarch density in both agricultural and non-agricultural habitats in 2000 (Oberhauser *et al*., 2001). We will make the case that the relative use of milkweeds in agricultural and non-agricultural habitats observed over those years can be extrapolated to provide

data on monarch use of agricultural milkweeds in years where only MLMP data exist. There is a question of what aspect of production to use to estimate monarch population changes. The latest stage for which we have density data, and thus which is closest to *actual* production of adult monarchs, is the fifth instar (L5, the last larval instar). However, there are many factors that can affect survivorship from egg to L5 that have nothing to do with milkweed availability, such as predation and weather. Our goal was to examine the effect of milkweed resource limitation on monarch production. Consequently, we chose to focus on eggs per plant that represents *potential* production.

Methods

Data sources for milkweed density

Habitats in which milkweeds are found include primarily roadsides, corn fields, soybean fields, pastures, old fields, and land set aside from farming and enrolled in the Conservation Reserve Program (CRP). CRP land is typically planted to a variety of cover plants including grasses and forbs. To estimate milkweed densities in these habitats, we used data from several sources: Iowa censuses carried out in 1999 and 2009 (Hartzler & Buhler, 2000; Hartzler, 2010), and data from some MLMP volunteers who measured milkweed density at their sites in several Midwest states. To calculate monarch production for each year, it is necessary to know how milkweed densities have changed over the last decade in non-agricultural and agricultural habitats.

Non-agricultural habitats. For roadsides, there was little observed change in milkweed density in Iowa between 1999 and 2009 (Hartzler, 2010) so we have assumed that milkweed density did not change in that habitat over the entire period of the analysis. Hartzler (2010) measured milkweed densities for CRP land and pastures in 1999 but not in 2009 so any change that may have occurred could not be determined from the Iowa data. However, a subset of MLMP volunteers (n = 16) measured milkweed density at their sites (which included natural areas, CRP land, pastures and old fields) for at least 4 years over this period (97 total observations). Measurements by individual MLMP volunteers did not cover the entire period but there were sufficiently long and overlapping sequences to provide a complete picture. Volunteers either measured the area of their site and did a complete count of milkweed stems, or used a modified belt transect to sample milkweed density in 100 1 × 1 m plots. We have used those data to estimate the change in milkweed density in CRP land and pasture land over the last decade.

For the data from the MLMP volunteers, we used log of milkweed density as the variate and used an SAS mixed model and restricted maximum likelihood estimation with fixed effects being 'habitat', 'year' and 'habitat by year'. We did not find a 'habitat by year' effect so we reran the analysis with this removed. There was a significant 'year' effect ($F_{1,85}$ = 9.35, P = 0.003). The slope of the regression (on a log scale) was −0.0536, which corresponds to a decline in density of 5.2% per year. We found no 'habitat' effect so we applied the same rate of decline to both CRP land and pastures (Fig. 1).

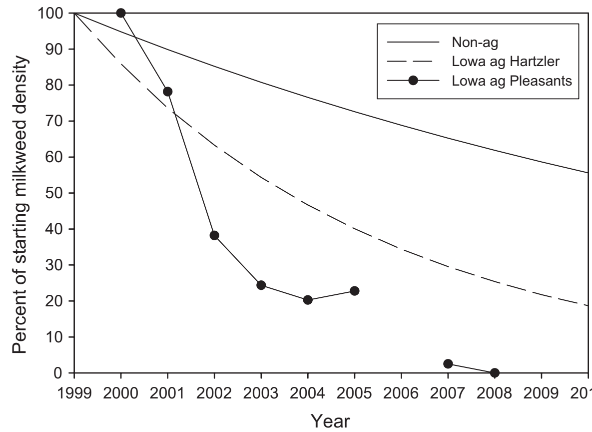

Fig. 1. Decline of milkweeds in agricultural and non-agricultural habitats. The line depicting the decline in non-agricultural habitats is based on a regression using data from MLMP volunteers. The line depicting the decline in agricultural habitats is based on an exponential decay function connecting the 1999 and 2009 values from the Iowa surveys (see Methods). Also shown is the proportional change in the number of milkweed stems in all monitored plots in seven agricultural fields in Iowa starting with 998 stems in 2000. The increase in milkweed stems observed in the agricultural sites in 2005 was attributed to the influence of fields where corn was planted 2 years in a row. Some agricultural fields received glyphosate herbicide treatment and others non-glyphosate treatment. No observations were made in 2006.

Agricultural habitats. We have values for milkweed density in Iowa agricultural fields for 1999 and 2009 (Hartzler & Buhler, 2000; Hartzler, 2010). To calculate milkweed density in fields for the intervening years, we have to make an assumption about the shape of the decline. Pleasants observed the change in the number of milkweeds in plots in seven agricultural fields in Iowa from 2000 to 2008 (Fig. 1). The observed decline is best described by an exponential decay function. Such a function is also consistent with more acres of glyphosate-tolerant corn and soybeans being planted each year over the last decade (USDA, Economic Research Service, 2011). We have therefore assumed that milkweed density in fields decreased as an exponential decay function from its 1999 value to its 2009 value (see Table 1). This corresponds to a 14.2% decline per year (Fig. 1). Other decline functions, ranging from a linear decline to a more precipitous exponential decay, had no significant effect on the overall results.

Data sources for land use

We obtained data on the acres occupied by roadsides and pastures on the Iowa landscape in 2002 from Lubowski *et al.* (2006) and, because no more recent data exist, we have assumed the

Table 1. Estimates of the amount of milkweed in non-agricultural habitats, agricultural fields and total milkweeds in Iowa from 1999 to 2010.

Year	Milkweeds in non-agricultural habitats				
Year	CRP hectares*	CRP mlkwds†	Pasture mlkwds‡	Roadside mlkwds§	Total non-ag mlkwds¶
1999	601	127.4	19.8	38.2	185.4
2000	647	130.1	18.8	38.2	187.1
2001	729	139.0	17.8	38.2	195.0
2002	755	136.4	16.9	38.2	191.5
2003	762	130.5	16.0	38.2	184.7
2004	767	124.5	15.2	38.2	177.9
2005	776	119.5	14.4	38.2	172.0
2006	793	115.7	13.6	38.2	167.5
2007	797	110.3	12.9	38.2	161.4
2008	733	96.2	12.3	38.2	146.6
2009	690	85.8	11.6	38.2	135.7
2010	663	78.2	11.0	38.2	127.4
Year	Milkweeds in agricultural fields				
	Total ag hectares**	Mlkwd density††	Total ag mlkwds‡‡		Total milkweeds§§
1999	9267	23.00	213.2		398.5
2000	9308	19.75	183.8		370.9
2001	9186	16.92	155.4		350.4
2002	9166	14.55	133.4		324.8
2003	9267	12.49	115.8		300.4
2004	9267	10.73	99.4		277.3
2005	9247	9.21	85.2		257.2
2006	9207	7.91	72.8		240.3
2007	9247	6.79	62.8		224.2
2008	9328	5.83	54.4		201.0
2009	9389	5.00	46.9		182.6
2010	9389	4.29	40.3		167.6

*×1000; from USDA Conservation Programs (2010).
†m^2 × 1000; CRP ha × 212 m^2 ha^{-1} (milkweed density from H&B, 2000) × 0.948^x (where $x = 0$ for 1999).
‡m^2 × 1000; 1416 ha (Lubowski *et al*., 2006) × 14 m^2 ha^{-1} (milkweed density from H&B, 2000) × 0.948^x (where $x = 0$ for 1999).
§m^2 × 1000; 386 ha (Lubowski *et al*., 2006) × 99 m^2 ha^{-1} (average milkweed density from H&B, 2000 and H, 2010).
¶m^2 × 1000; Conservation Reserve Program (CRP) milkweeds + Pasture milkweeds + Roadside milkweeds.
** ×1000; from Iowa State Ag. Statistics (2010).
††m^2 ha^{-1}; 1999 value from H&B (2000), 2009 value from H (2010); others = 1999 value × 0.858^x, where $x = 0$ for 1999.
‡‡m^2 × 1000; Ag ha × Milkweed density.
§§m^2 × 1000.

acres in roadside and pasture have not changed substantially over the last decade. Data on the acres planted to corn or soybeans by year were obtained from Iowa State Agricultural Statistics (2010) and the amount of Iowa CRP land from the USDA Conservation Programs (2010).

Estimating monarch use of non-agricultural milkweeds

To estimate monarch use of non-agricultural milkweeds, we used data on the number of monarch eggs per milkweed stem from the MLMP. We examined MLMP data from 1999 to 2010 for sampling localities within the Midwest (eastern Kansas, eastern Nebraska, eastern North and South Dakota, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana and western Ohio). Sites were excluded in any given year if the average number of milkweeds monitored was < 25 and if there were fewer than five sampling events in July and August. We also excluded garden sites because they represent a minor component of milkweeds on the landscape. Sites were excluded if volunteers observed more larvae than eggs because these volunteers may not have been able to discern monarch eggs accurately. We initially divided sites into two groups based on the habitats in which the milkweeds were found: 'natural areas' (prairies or nature preserves) and 'other' (pastures, old fields, roadsides and CRP land); there were no sites in agricultural fields. However, 'natural areas' and 'other' were not significantly different from each other in egg density and were combined in the analysis into a single 'non-agricultural' category.

For any site, the number of eggs per plant varies over the course of the season. However, there is a population build-up during July and August when the second/third generation

occurs (MLMP, 2011). We used egg density at the peak of this build-up as a metric of annual production. For each year, our estimate of production was based on the average maximum egg density over all MLMP sites. This metric does not include all of the annual production but does allow us to examine the relative differences in production among years.

Monarch use of milkweeds in agricultural fields

Pleasants monitored milkweed populations and monarch activity in agricultural fields and non-agricultural habitats in Iowa from 2000 to 2003. Initially six study sites were selected. Each site included a field planted to soybeans, another field adjacent or nearby that was planted to corn and a nearby non-agricultural habitat. Non-agricultural habitats included natural areas, pastures, old fields and roadsides. CRP land was not explicitly included as a habitat type but the non-agricultural habitats selected are similar in vegetative characteristics to CRP land. Sites were all located within a 10 km radius of Ames, Iowa, except for one site located 40 km south of Ames. Over the years of study, a few sites were removed from monitoring for logistical reasons and a few others added but in all years, both agricultural and non-agricultural plots were examined. Within each site, patches of milkweeds were marked (milkweed plots). These patches were relatively discrete units that ranged in area from 3×3 to 6×10 m and contained 10–150 milkweed stems. In each field, approximately 10 milkweed plots were chosen and mapped using a global positioning system device so they could be relocated in subsequent years. Sites were visited at weekly intervals: in 2000 from late May to late August; in 2001 from early July through late August; and in 2002 and 2003 from early June to late August. During each visit, every milkweed stem in each milkweed plot was inspected for monarch eggs and larvae.

As described above, we used the maximum number of eggs per stem observed during the weekly censuses from July through August as the measure of production. Egg densities in different non-agricultural habitat types were not statistically different, so they were combined into one category. Egg densities on milkweed in corn and soybean fields in any year were not statistically different from each other and were combined into a single category. The results are shown in Table 2. Egg densities on milkweeds in agricultural fields were significantly higher than on milkweeds in non-agricultural habitats in each year by an average factor of 3.89.

Estimating potential monarch production

Potential monarch production for any year is equal to the sum of egg production from two sources: non-agricultural and agricultural milkweeds. To calculate production from non-agricultural milkweeds, we first determined the number of milkweeds in non-agricultural habitats. This is equal to the area occupied by each habitat type (CRP land, pasture and roadside) multiplied by the density of milkweeds in that habitat (see Table 1).We then multiplied the total number of non-agricultural milkweeds by the average number of eggs per non-agricultural milkweed plant for that year from the MLMP data (see Table 3). To calculate production from agricultural fields, we first determined the number of milkweeds in fields. This is equal to the area occupied by agricultural land multiplied by the milkweed density in fields (see Table 1). The number of agricultural milkweeds in each year was multiplied by the eggs per agricultural milkweed plant. For the years 2000–2003, we used Iowa data for the eggs per agricultural milkweed (from Table 2). For each of the other years, the egg density on agricultural milkweeds was taken to be 3.89 times the MLMP value for that year (see Table 3).

Results

Estimates of milkweed numbers on the Iowa landscape (Table 1) show that milkweeds declined in both agricultural fields and non-agricultural habitats from 1999 to 2010. There was a 31% decline for non-agricultural milkweeds and an 81% decline for agricultural milkweeds with a 58% overall decline for total milkweeds. In 1999, milkweeds in agricultural fields constituted 53% of total milkweeds, but by 2010 were only 24% of the total. The 58% loss of milkweeds on the landscape actually underestimates the loss of resource for monarchs, because most

Table 2. Maximum eggs per milkweed stem July through August for agricultural and non-agricultural sites in Iowa where '*n*' is the number of fields examined. Egg densities on milkweeds in agricultural fields were significantly higher than on milkweeds in non-agricultural habitats in each year (2000: $t = 3.97$, d.f. = 11; 2001: $t = 2.90$, d.f. = 4; 2002: $t = 3.35$, d.f. = 4: $t = 4.54$, d.f. = 5; all P-values < 0.02).

	Maximum eggs per milkweed						
	Agricultural			Non-agricultural			
Year	Avg.	SE	*n*	Avg.	SE	*n*	Ratio ag/non-ag
2000	0.796	0.140	10	0.197	0.049	8	4.05
2001	1.661	0.459	5	0.329	0.021	3	5.05
2002	0.659	0.123	4	0.205	0.056	4	3.21
2003	1.125	0.108	5	0.345	0.133	3	3.26
						Average ratio	3.89

Table 3. Estimate of egg production in the Midwest from 1999 to 2010. Note that values in the final three columns are relative; egg densities are in eggs/stem whereas milkweed densities are not in stems ha^{-1} but m^2 ha^{-1}.

Year	Total non-ag milkweeds*	Total ag milkweeds*	Eggs/ plant-non-ag†	Eggs/ plant-ag‡	Production non-ag§	Production ag¶	Total production**
1999	185.4	213.2	0.243	0.945	45.0	201.4	246.5
2000	187.1	183.8	0.144	0.796	26.9	146.3	173.2
2001	195.0	155.4	0.299	1.661	58.3	258.2	316.5
2002	191.5	133.4	0.197	0.659	37.6	87.9	125.5
2003	184.7	115.8	0.173	1.125	31.9	130.2	162.1
2004	177.9	99.4	0.102	0.395	18.1	39.3	57.4
2005	172.0	85.2	0.205	0.796	35.2	67.8	103.0
2006	167.5	72.8	0.277	1.077	46.4	78.5	124.9
2007	161.4	62.8	0.274	1.066	44.2	66.9	111.1
2008	146.6	54.4	0.154	0.599	22.6	32.6	55.2
2009	135.7	46.9	0.120	0.465	16.2	21.8	38.0
2010	127.4	40.3	0.311	1.210	39.6	48.7	88.4

*$m^2 \times 1000$; from Table 1.
†from MLMP.
‡Non-ag eggs/plant × 3.89 (ratio of ag to non-ag, see Table 2), except for 2000–2003 from Table 2.
§Total non-ag milkweeds × Eggs/plant non-ag.
¶Total ag milkweeds × Eggs/plant ag.
**Production non-ag. + Production ag.

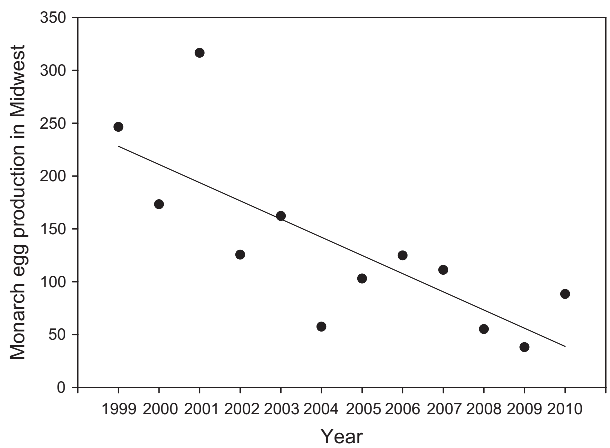

Fig. 2. Estimate of monarch production from the Midwest by year. Linear regression $F_{1,11} = 13.7$; $P = 0.004$; $r^2 = 0.58$.

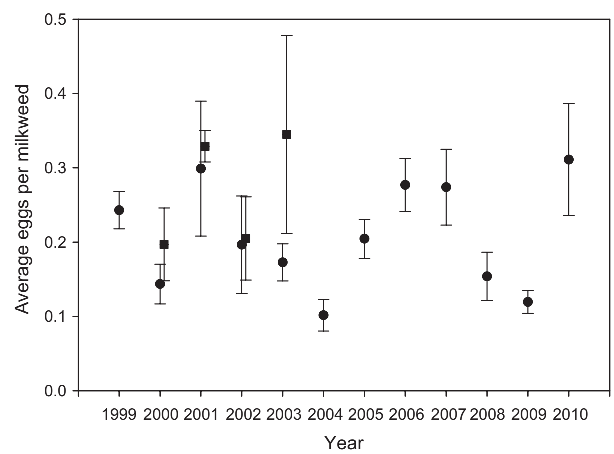

Fig. 3. Average maximum egg density (eggs per milkweed stem ± 1 SE) for July through August for non-agricultural milkweeds at sites throughout the Midwest (from MLMP). Number of sites: 1999, 16; 2000, 41; 2001, 13; 2002, 25; 2003, 41; 2004, 46; 2005, 49; 2006, 57; 2007, 29; 2008, 29; 2009, 30; 2010, 21. Square symbols indicate the average value (±1 SE) for non-agricultural sites in Iowa (from Table 2). The Iowa value for each year was not significantly different from the MLMP value.

of the loss was in agricultural fields and each agricultural milkweed represents 3.89 times more monarch eggs than a non-agricultural milkweed (Table 2). If the numbers of agricultural milkweeds in Table 1 are multiplied by 3.89 to convert them to their resource potential, the decline in the milkweed resource base is 72%. Of this potential resource lost, 92% comes from agricultural fields and 8% from non-agricultural habitats. Table 3 shows the conversion of yearly milkweed numbers into monarch production. The relative contribution of agricultural milkweeds to total monarch production went from 82% in 1999 to 55% in 2010.

There has been a significant decline in monarch egg production over the last decade (Fig. 2 – linear regression $F_{1,11} = 13.7$, $P = 0.004$, $r^2 = 0.58$). On the basis of regression equation for this decline ($y = 254.4 - 17.21x$, where $x = 1$ when the year is 1999), we estimate that between 1999 and 2010 monarch egg production in the Midwest was reduced 81%. This decline in production would not have occurred if monarchs had increased their use of the remaining milkweeds as agricultural milkweeds declined. However, egg density on non-agricultural milkweeds from the MLMP data did not show a significant change over the years (Fig. 3) (because of non-normality, a Poisson regression was used; Wald $\chi^2 = 0.15$; d.f. $= 1$; $n = 398$, NS). We

also compared our estimate of potential monarch production in each summer with the size of the population that subsequently overwintered in Mexico (Fig. 4). Yearly production values were positively correlated with the size of the overwintering population (linear regression $F_{1,11} = 8.97$, $P = 0.01$, $r^2 = 0.47$).

Discussion

Our estimate of monarch production decline in the Midwest was based in part on Iowa data. To what extent do Iowa data reflect the Midwest as a whole? We used Iowa data to estimate (i) the proportion of milkweed in various habitats, (ii) the density of milkweeds in each habitat, (iii) the decline in milkweeds in agricultural fields and (iv) the relatively higher egg density on agricultural milkweeds compared to non-agricultural milkweeds. We examine each of these aspects of the data. (i) Data on land use for the Midwestern states (Lubowski *et al.*, 2006) show that of the potential milkweed habitat 73% was in crop production and 27% in non-agricultural habitats (6% in CRP land, 6% in cropland pastures, 11% in grassland and range pastures, and 4% in roadsides). This is similar to the 79% in crop production for the state of Iowa and 21% in non-agricultural habitats (6% in CRP land, 5% in cropland pastures, 7% in grassland and range pastures and 3% in roadsides). Note that these values do not include forested land as this is not milkweed habitat. This comparison excluded the Northern Plains states (Kansas, Nebraska, N. and S. Dakota), which have extensive grasslands and rangeland in the western sections. If those states are included, the per cent of Midwest land in crops falls to 60% with 40% of land non-agricultural. (ii) Iowa data were used to estimate milkweed densities for agricultural and roadside habitats; the change in milkweed density in other non-agricultural habitats was based on Midwest MLMP data. There has not been a long-term study of milkweed density in agricultural habitats

Fig. 4. Estimate of monarch production in the Midwest by year (from Table 3) compared with the size of the subsequent overwintering population in that year (from Rendón-Salinas et al., 2011). The size of the overwintering population is measured in hectares covered by butterflies. Linear regression $F_{1,11} = 8.97$; $P = 0.01$; $r^2 = 0.47$.

outside of Iowa so the similarity between Iowa and the Midwest in this aspect can only be assumed. (iii) Other Midwest areas have seen a decline in milkweed density in agricultural fields over the past decade. Two of the Wisconsin fields originally surveyed by Oberhauser in 2000 (Oberhauser *et al.*, 2001) were resurveyed in subsequent years. In 2000, these sites had an average of 0.28 milkweed stems m^{-2}, and in 2002–2006, after the growers began to use glyphosate-tolerant soybeans in 2001, no milkweeds were found. (iv) Higher egg densities on agricultural milkweeds were also observed in other states in the Midwest in 2000 (Oberhauser *et al.*, 2001).

Further evidence suggesting that our approach, which combines data from Iowa and Midwest sources, does reflect production for the Midwest as a whole comes from the significant positive correlation between the annual estimate of monarch production and the size of the subsequent overwintering population (Fig. 4). Because the Midwest contributes about half of the individuals to the overwintering population (Wassenaar & Hobson, 1998), we would expect such a correlation if Midwest production were accurately estimated. We note, however, that the estimate of the Midwest contribution to the overwintering population was made before significant glyphosate use in row crops and only represents 1 year of data.

Although our estimates of annual Midwest monarch production were highly correlated with the size of the subsequent overwintering population, these estimates explained only 47% of the variation in the size of the overwintering population. In particular, our production value for 2003 underestimated the overwintering population size and our value for 2000 overestimated it. We suggest four possible reasons for such deviations. (i) Deviations may be due to the fact that we have used egg density as our measure of production, which is a measure of potential production, while actual production is adult butterflies. The relationship between potential and actual production will depend on survivorship from egg to adult, which may vary among years (J. M. Pleasants & K. S. Oberhauser, unpubl. data). (ii) The relative contribution of the Midwest to the population as a whole is likely to vary from year to year (K. S. Oberhauser, unpubl. data). (iii) The amount of mortality during the fall migration is likely to vary among years depending on conditions along the migratory route including nectar availability, temperature, weather events, drought conditions and wind conditions. (iv) We used a factor of 3.89, the average of 4 years of Iowa data, to convert agricultural milkweeds into their monarch egg production. The factor varies among years, as seen in Table 2, and may be somewhat different in other areas of the Midwest.

The differences between years in egg density per stem seen in the MLMP data (Fig. 3) are likely to be caused by factors in addition to the effect of resource availability. The MLMP egg densities we used came from the second and third generation of monarchs. The size of each generation will depend on the size of the previous generation, each of which will be influenced by the prevailing weather conditions during egg laying and larval development (Zalucki & Rochester, 2004). Although the overwintering population begins this sequence, we found no correlation between the size of the overwintering population and monarch production the following summer. This indicates that other factors, principally temperature and weather conditions, can erase

the influence of the starting population. But environmental conditions alone do not govern population size. Even if favourable conditions exist, the potential production of the monarch population is dampened by the loss of milkweeds.

As previously mentioned, the loss of milkweeds in agricultural fields would not have affected total monarch production if monarch use of the remaining milkweeds, both agricultural and non-agricultural, had increased sufficiently. We do not have data on the use of agricultural milkweeds over the last decade but data from the MLMP indicate that there was no increase in use of non-agricultural milkweeds over this period (Fig. 3). In a modelling study, Zalucki and Lammers (2010) found that removing small patches of milkweed from the matrix (the area between larger patches of milkweed) made it harder for monarch females to achieve their egg production potential because of increased search time. In their model, a decrease in milkweed availability in the agricultural crop matrix, such as what would result from herbicide use, could significantly reduce the lifetime number of eggs laid by individual females.

Davis (2011) has suggested that there has been no downward trend in monarch production, based on monitoring data at two sites at which monarchs congregate during the fall migration. The monarchs that appear at these two sites, Peninsula Point in Upper Michigan and Cape May in New Jersey, are migrants from the Upper Peninsula of Michigan and south central Canada, and the Eastern United States, respectively. However, the isotope analysis of (Wassenaar and Hobson (1998) indicates that monarchs from these areas constitute a much smaller portion of the total monarch population than monarchs from the Midwest. Consequently, the lack of decline Davis observed will not reflect the population as a whole. Similar points have also been argued by Brower *et al.* (2011a).

The lack of decline in migrating Eastern monarchs, noted by Davis, further illustrates the connection between glyphosate use in corn and soybean fields and monarch decline. Monarchs from the Northeast and Canada may not be experiencing a decline because they come from areas with less corn and soybean agriculture and thus less milkweed loss because of herbicide use. In 2010, there were 25.1 million soybean hectares and 25.5 million corn hectares in the Midwest but only 0.4 million soybean hectares and 0.7 corn hectares in the Northeast (USDA, National Agricultural Statistics Service, 2011c).

We estimated that monarch production in the Midwest had declined 81% from 1999 to 2010. For comparison, there was a 65% decline in the size of the overwintering population over this same period (Brower *et al.*, 2011b). The similarity of these percentages, and the fact that our estimate of Midwest production is strongly correlated with the size of the overwintering population, clearly show the dominance of Midwest production for the population as a whole. However, the fact that the size of the overwintering population has declined less than the population contribution from the Midwest reflects the mitigating effect of portions of the range of the species that are not dominated by corn and soybean agriculture and have not been impacted by milkweed loss. As the monarch production contribution from the Midwest declines, the relative contribution from other parts of the range increases. A reassessment of the production contribution of the Midwest and other parts of the range, such as that performed earlier by Wassenaar and Hobson (1998), would be useful.

The loss of milkweeds in agricultural fields is particularly devastating for the monarch population because agricultural milkweeds are more heavily used than non-agricultural milkweeds (Table 2). This difference in egg density could result if females that find patches of milkweeds in agricultural fields lay more eggs per stem or if more females find patches of agricultural milkweeds. Patch size is typically smaller in agricultural fields than in non-agricultural habitats (J. M. Pleasants & K. S. Oberhauser, pers. obs.), and higher egg densities per stem are observed in smaller milkweed patches (Zalucki & Suzuki, 1987). Monarch females may seek out smaller patches and oviposit more heavily there, perhaps because small patches tend to support greater larval success (Zalucki, 1981; Zalucki & Kitching, 1982). Greater oviposition by individual females may also be due to their perception of agricultural milkweeds as being of higher quality. Agricultural milkweed leaves have higher nitrogen content (J. M. Pleasants, unpubl. data) and tend to be in better condition. Finally, the milkweed chemical signal that attracts monarch females may be more apparent against the monoculture background of agricultural fields making it easier for females to find milkweeds in this habitat.

One unexpected finding in this study was the decline in milkweed density in non-agricultural habitats based on measurements by MLMP volunteers. These patches were not chosen at random, and it is possible that this decline is not representative of milkweeds in non-agricultural habitats across the landscape. Milkweed is a disturbance species and as such we would expect colonisation of disturbed areas followed by a population increase for a number of years and then a population decline as milkweed is outcompeted by later successional species. Monitored patches were chosen because they contained high milkweed densities. Thus, they may represent populations that had already experienced some growth and were now in the declining phase. A more thorough survey of milkweed densities in randomly chosen non-agricultural habitats over time is needed. If milkweed densities in non-agricultural habitats are not declining, then the loss of monarch production is not as large as we have estimated. We reran our calculations assuming no decline, and the estimated loss of monarch production from 1999 to 2010 was 76%, somewhat lower than the 81% decline estimated using decreasing milkweed densities in non-agricultural habitats.

Given the disappearance of milkweeds in agricultural fields, milkweeds present in other habitats become more important for monarch populations. Table 1 indicates that the habitat of greatest importance is CRP land. However, the amount of CRP land is also declining; in 2010, the number of CRP hectares for the Midwestern states had declined by 0.5 million from its high in 2007 of 3.8 million hectares (USDA, Conservation Programs, 2010). Farmers have a number of options with regard to what types of vegetation to use as cover on CRP land, with grasses predominating. Adding forbs, including milkweeds, to planting mixes would provide nectar sources that could benefit many insect species and provide host plants for monarchs. While persuading farmers to include milkweed seed in the mix may be difficult, milkweed is capable of colonising such habitats on its own

and education efforts about the value of milkweed and the many non-weedy milkweed species available are underway (Monarch Joint Venture, 2011). Further research needs to be undertaken on CRP land to see how different types of cover vegetation and land management practices affect milkweeds and monarchs.

Roadsides can provide important milkweed habitat; in 2010, 20% of the milkweeds were in roadsides (Table 1), and this value will increase as the remaining agricultural milkweeds disappear. The treatment of roadsides by departments of transportation could influence their value to monarchs. Roadsides are often mowed and sprayed with herbicides to eliminate forbs but roadside management plans compatible with monarch conservation could be developed. Many states are implementing programmes to plant native species along roadsides; such programmes could consider adding milkweeds.

We have not yet seen the full impact that the use of glyphosate herbicides and the consequent reduction in milkweed resources will have on the monarch population. At present, some milkweeds still remain in agricultural fields. Given the established dominance of glyphosate-tolerant crop plants and widespread use of glyphosate herbicide, the virtual disappearance of milkweeds from agricultural fields is inevitable. Thus, the resource base for monarchs in the Midwest will be permanently reduced. This will set a new, lower ceiling for monarch population size. A lower population size could lead to greater vulnerability of the population to deforestation on the overwintering sites and to extreme weather events or climate changes on the overwintering sites, in breeding areas and along migratory routes (Brower *et al*., 2011b).

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Author contributions

J.P. performed field studies in Iowa, analysed the data and was primarily responsible for writing the article. K.O. supervised the collection and collation of the data from the MLMP and participated in the writing of the article.

Competing financial interests

The authors declare no competing financial interests.

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