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BIODIVERSITY RESEARCH

Future land use threats to range-restricted fish species in the United States

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ABSTRACT

Aim Land use change is one major threat to freshwater biodiversity, and land use change scenarios can help to assess threats from future land use change, thereby guiding proactive conservation decisions. Our goal was to identify which range-restricted freshwater fish species are most likely to be affected by land use change and to determine where threats to these species from future land use change in the conterminous United States are most pronounced.

Location United States of America.

Methods We focused on range-restricted freshwater fish species, identified which of these species are considered threatened based on either the International Union for the Conservation of Nature (IUCN)'s Red List or the Endangered Species Act (ESA), and compared their distributions to patterns of future land use changes by 2051 under three scenarios.

Results We found that 14% of the range-restricted species had >30% of their distribution area occupied by intensive land use in 2001, and this number increased from 27 to 58% by 2051 depending on the land use scenario. Among the 57 species most likely to be strongly affected by intensive land use, only 26% of these species are currently listed as threatened on the IUCN Red List, and 12% are listed as threatened under the ESA.

Main conclusions Our approach demonstrates the value of considering future land use change scenarios in extinction risk assessment frameworks and offers guidelines for how this could be achieved for future assessments.

Keywords
biodiversity indicators, Endangered Species Act, extinction risk, global change, IUCN Red List, scenario planning.

INTRODUCTION

Land use change remains one of the greatest threats to biodiversity. In recent decades, land use change and associated infrastructure, such as dams and roads, have led to substantial range contractions and species extinctions in many aquatic ecosystems. For example, urbanization and row crop agriculture have replaced natural vegetation in many places, resulting in decreased stream bank stability, increased run-off and nutrient loading (Allan, 2004). Consequently, freshwater biodiversity is under pressure (Dudgeon *et al.*, 2006; Vörösmarty *et al.*, 2010). Given the importance of land use change for freshwater biodiversity, it is important to evaluate the implications of future land use change on species that are threatened with extinction or range restriction. Similar analyses for terrestrial species suggest looming threats to biodiversity (Jetz *et al.*, 2007), and projected changes in land use in places with high aquatic biodiversity suggest that there may be a similarly high risk for freshwater species (Martinuzzi *et al.*, 2014).

Range-restricted species are intrinsically vulnerable, and a conservation priority whether they are already recognized as threatened or not (Jenkins *et al.*, 2015). At the global scale, the International Union for the Conservation of Nature (IUCN) Red List is the primary assessment framework for assessing, categorizing and monitoring species extinction risk (Rondinini *et al.*, 2014). National and international policies and conservation investments often focus on species listed as

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threatened (i.e. Vulnerable, Endangered or Critically Endangered) on the IUCN Red List (Butchart *et al.*, 2010). In addition to the IUCN Red List, which is global, many countries have national-level lists of threatened species. In the United States, the primary extinction risk assessment framework is the Endangered Species Act (ESA). While future threats are to some extent included in both IUCN Red List and ESA species assessments, the impact of future disturbances, such as land use change, on the conservation status of most species, remains largely unknown (Bomhard *et al.*, 2005).

Scenarios of future land use change can inform conservation and allow decision-makers to evaluate how policy changes might influence land use and biodiversity (Polasky *et al.*, 2011). Such scenarios are particularly relevant when they are coupled with data on species distributions to estimate how many species are likely to be affected by future land use, and where (Visconti *et al.*, 2015). In the southeast United States, roughly half of all reptiles and 20% of amphibians are expected to see >10% habitat loss due to future land use changes, and those numbers can be higher under future increases in crop commodity prices (Martinuzzi *et al.*, 2014). Across the globe, there remains an opportunity to explore how broad-scale land use changes are likely to influence freshwater-dependent taxa such as fishes.

Here, we evaluated the potential consequences of future expansion of urban and agricultural land use on native freshwater fish species in the conterminous United States based on one measure of intrinsic vulnerability (range-restricted) and two measures of species imperilment (based on species designations on the IUCN Red List or ESA). We assessed projections of land use change for 2001–2051 under three different scenarios reflecting potential conservation policies and changes in crop market prices. We had two objectives. Our first objective was to determine which freshwater fish species are range-restricted, which of these range-restricted species are considered to be threatened, and where these species are distributed within the conterminous United States. Our second objective was to evaluate the percentage of each range-restricted species' distribution occupied by intensive land use (urban and row crop agriculture), both currently and in the future, and to determine where in the United States this is most common and whether there is spatial congruence of this pattern with that of threatened species based on the IUCN Red List or ESA.

METHODS

Our analysis focused on freshwater fish species distributed within the conterminous United States. We represented species' distributions with data available from NatureServe for 799 freshwater fish species (NatureServe 2010). NatureServe data are the most complete source of freshwater fish species' distributions for the conterminous United States and are increasingly used in ecological and conservation studies (Muneepeerakul *et al.*, 2008). Approximating extent of occurrence (EOO), NatureServe's species' distribution data are mapped to 2111 hydrologic units (based on HUC8 level units delineated in the United States' Geological Survey's Watershed Boundary Dataset; U.S. Geological Survey, 2010). The mapped EOO for each species is based on the hydrologic units that encompass the species' known occurrences. For the purposes of this study, species' distributions are synonymous with EOO and are represented as the total *current* hydrologic unit area that a species occupies. In this way, we did not include *historical* distributions, because we were concerned only with existing distributions. Consequently, any species identified as extinct prior to the creation of the NatureServe data were not included in our assessment because only *historical* distributions were available for these species. We calculated the total area of each of the 799 fish species' EOO and determined range-restricted fishes based on the IUCN Red List criteria B threshold for designating a species as Vulnerable (i.e. species with distribution areas <20,000 km^2). We then determined which of the range-restricted species were threatened based on the IUCN Red List (Vulnerable, Endangered, Critically Endangered or Extinct) or ESA (Threatened or Endangered) designation (accessed from IUCN 2015 and USFWS, 2014). To do this, we drew on the most up-to-date database from the IUCN Red List, accounting for the recently completed assessment of freshwater fishes in the United States.

We represented land use with 100-m resolution models developed by Lawler *et al.* (2014). Lawler *et al.* (2014) based current land use on the US National Land Cover Database 2001 (Homer *et al.*, 2004) and subsequently projected land use to 2051 under three different land use change scenarios including *Business As Usual*, *High Crop Demand* and *Urban Containment*. The three land use projections were based on an econometric model that predicts changes in land use during that 50-year period under alternative conservation policies and crop market conditions, at 100-m resolution, and based on past observation on economic return to land uses (from the 1990s), soil characteristics and land cover (Radeloff *et al.*, 2012; Lawler *et al.*, 2014). In our land use projections, only private lands are allowed to change in land use between 2001 and 2051; public lands and wetlands are assumed to stay in the same land use over the study period. The model quantifies changes in urban, row crop agriculture, forest, rangeland and pasture, but we focused here on urban and row crop agriculture (i.e. intensive land uses) due to their relevance for freshwater quality assessment. These projections have been used to evaluate the potential consequences of land use changes between 2001 and 2051 for protected areas, wildlife species and freshwater ecosystems in the United States (Martinuzzi *et al.*, 2014). The *Business As Usual* scenario projects land use changes between 2001 and 2051 following 1990s trends. The *High Crop Demand* scenario reflects an increase in agricultural demands and mimics a recent period (2007–2012) of high crop prices and crop cover expansion. Finally, the *Urban Containment* scenario allows urban expansion only in metropolitan counties and reflects a potential 'smart growth' scenario. Returns from agriculture in the *Urban Containment* scenario were the same as in *Business As Usual*. We determined the percentage of each species' distribution area occupied by intensive land use in 2001 and in 2051 under the three land use scenarios. Similar to previous studies (e.g. Jetz *et al.*, 2007), we assumed stationary EOO for all species.

Allan (2004) demonstrated that catchments with >10% urban cover or >50% row crop cover show marked declines in habitat quality, having adverse impacts on riverine biodiversity. Consequently, we assumed that increases in intensive land use result in declines in fish habitat quality and availability. Following Allan (2004), we considered the extent and quality of habitat to be impacted >30% of a species EOO was occupied by intensive land use. Using this threshold, we compared the proportion of threatened and non-threatened range-restricted species whose habitat is, or is projected to be, affected by land use. We then determined which species have, or are projected to have, >30% of their distribution area under intensive land use in the four land use scenarios, and considered these species as those most likely to be strongly affected by intensive land use (sensu Visconti et al., 2011). Finally, using the hydrologic units as our unit of analysis, we determined the geographical distribution of species most likely to be strongly affected by intensive land use and used Pearson's correlation coefficient to assess spatial congruence between the geographical patterns of future risk and current geographical distribution of species listed as threatened on the IUCN Red List or ESA. We carried out all spatial analyses in ArcGIS 10.2 (ESRI 2013).

RESULTS

We found that 51% (407) of native freshwater fish species in the conterminous United States are range-restricted (see Table S1 in Supporting Information for complete list of species) and 31% of hydrologic units support at least a single range-restricted species. Hydrologic units with the highest percentages of range-restricted species occurred in the west, particularly in the south-west and along the Oregon coast, while those without range-restricted species primarily occurred in the Upper Midwest (Fig. 1a). We found that 34% of range-restricted species are listed as threatened on the IUCN Red List (the majority listed as Vulnerable; Table 1), and 20% are listed as threatened by ESA (Table 1). We also found notable differences in the spatial patterns of threatened species based on the IUCN Red List and ESA (Fig. 1b,c). Hydrologic units in the south-east supported between 6% and 25% more threatened species on the IUCN Red List than the ESA, and those along the west coast support between 19% and 35% more threatened species by ESA than the IUCN Red List (see Fig. S1).

In 2001, 14% of range-restricted species had >30% of their EOO with intensive land use, and this increased by 2051 regardless of the future scenario considered (Fig. 2). There were notable differences among land use scenarios in the amount of intensive land use projected to occur within species' EOO in future. Under the *Business As Usual* and *High Crop Demand* scenarios, 27% and 43% of range-restricted species are projected to have more than 30% of their EOO with intensive land use, while under the *Urban Containment* scenario, there is a lower projected increase in species (17%) with intensive land use in >30% of their EOO (Fig. 2).

Regardless of the assessment framework (i.e. IUCN Red List or ESA), non-threatened species were less likely to have their habitat affected by land use in 2001 than those that were threatened (IUCN Red List: 12% non-threatened species vs. 16% of threatened (Fig. 3a,b); ESA: 9% of non-threatened vs. 16% of threatened species (Fig. 3c,d)). By 2051, this pattern is projected to change greatly under the *High*

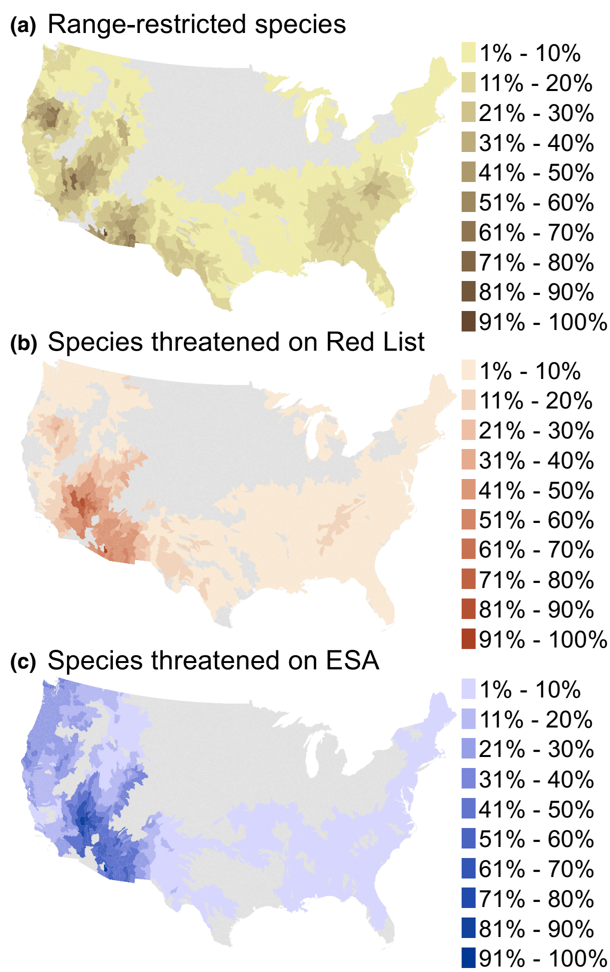

Figure 1 Geographical summaries of range-restricted freshwater fish species currently considered threatened based on the International Union for the Conservation of Nature's (IUCN) Red List or Endangered Species Act (ESA) within hydrologic units in the conterminous United States. Summaries represent the percentages of: (a) range-restricted species, (b) range-restricted species listed as threatened on the IUCN Red List and (c) range-restricted species listed as threatened on the ESA.

Table 1 Summary of the number and percentages of range-restricted freshwater fish species (n = 407) in the conterminous United States that are currently listed as threatened (Extinct, Critically Endangered, Endangered or Vulnerable) or not threatened (Data Deficient, Near Threatened, Least Concern) on the International Union for the Conservation of Nature (IUCN)'s Red List or threatened (Threatened or Endangered) or not by the Endangered Species Act (ESA). Species not evaluated by IUCN were categorized as not threatened because their status is unknown.

	Count	Percentage
Threatened – IUCN		
Extinct	1	0.2
Critically Endangered	16	4
Endangered	53	13
Vulnerable	69	17
Threatened – ESA		
Threatened	48	12
Endangered	32	8
Not threatened – IUCN		
Data Deficient	6	1
Near Threatened	43	11
Least Concern	194	48
Not evaluated	25	6
Not threatened – ESA		
	327	80

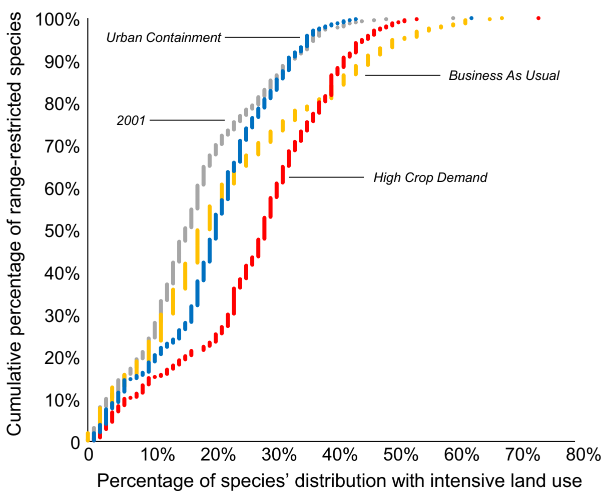

Figure 2 Cumulative proportion of range-restricted freshwater fish species with increasing proportion of intensive land use (urban and row crop agriculture) within their distribution area in the conterminous United States. The proportion of intensive land use within species' distributions is presented for 2001 and three land use scenarios for 2051: *Business As Usual*, *High Crop Demand* and *Urban Containment*.

Crop Demand scenario: 44% of range-restricted species not listed on the IUCN Red or ESA are projected to be affected by intensive land use, exceeding the figure for counterparts that are already recognized as threatened (42% of species). Thus, regardless of their current threat designation, the number of range-restricted species affected by intensive land use in 2051 is expected to nearly triple under the *High Crop Demand* (Fig. 3, red circles) scenario compared to 2001 (Fig. 3, grey circles).

We identified 57 species most likely to be strongly affected by intensive land use, that is those that had >30% of their EOO occupied by intensive land use both currently and under all three future land use scenarios (Table 2). Of those species, 26% are currently listed as threatened on the IUCN Red List, and 12% are listed as threatened under the ESA, with seven species shared by both assessment frameworks (Table 2). Of the species most likely to become strongly affected by intensive land use in the future, species that are not currently designated as threatened are projected to have slightly lower increases in the percentage of intensive land use within their distribution area than those listed on the IUCN Red List, ESA or both (35% vs. 38%). Indeed, two species, *Nocomis asper* and *Pogonichthys macrolepidotus*, with some of the highest percentages of intensive land use in their EOO, both currently and under future scenarios, are not listed as threatened under either assessment framework (Table 2).

Fifty-nine per cent of the fish species we identified as being most likely to be strongly affected by intensive land use (i.e. >30% of their EOO occupied by intensive land use in all four scenarios) are projected to have stable or increasing intensive land use within their EOO under all three future scenarios (Table 2). Within these species' distributions, intensive land use is projected to increase the most under the *Business As Usual* scenario (>7% increase in intensive land use; Table 2). In contrast, the *Urban Containment* scenario is projected to lead the highest percentages of species experiencing reductions in intensive land use by 2051 (1% to 10% reduction in intensive land use within species' distributions, Table 2).

Within a single hydrologic unit, the maximum percentage of species most likely to be strongly affected by land use was 25% (Fig. 4). We found moderately strong spatial congruence between hydrologic units supporting high percentages of species most likely to be strongly affected by intensive land use and species currently listed as threatened on the IUCN Red List (r = 0.58) and ESA (r = 0.57). Units supporting higher percentages of species most likely to be strongly affected by intensive land use primarily occur in the south-west and western United States (Fig. 4), where high percentages of species were also listed as threatened on both the IUCN Red List and ESA (Fig. 1).

DISCUSSION

Our results demonstrate that future land use scenarios can provide valuable information for extinction risk assessments. Based on our approach, range-restricted freshwater fish species in the United States are projected to see 3% to 44% increases in intensive land use within their distribution area between 2001 and 2051. Our results identify where range-restricted

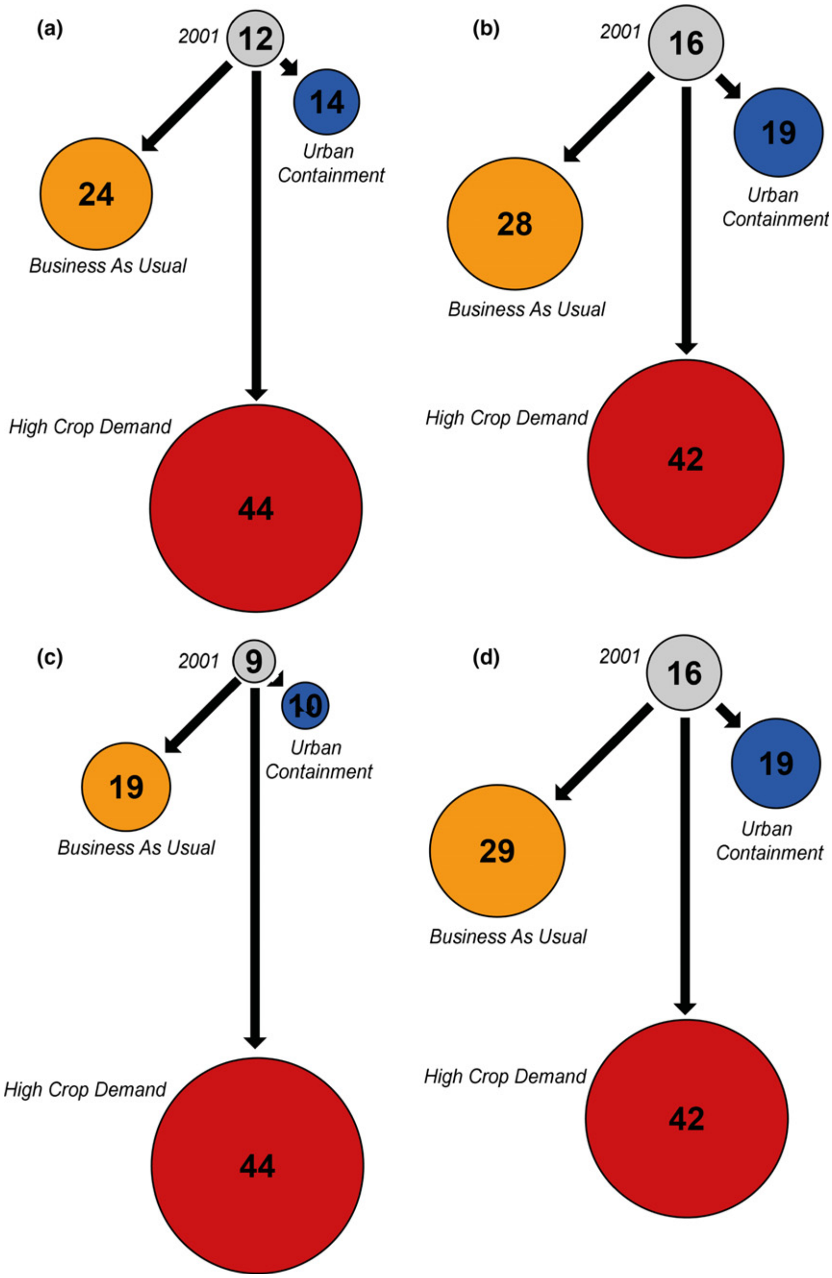

Figure 3 Percentages of range-restricted species with >30% of their distribution in the conterminous United States occupied by intensive land use (urban and row crop agriculture), based on land cover in 2001 and under three scenarios for 2051: *Business As Usual*, *High Crop Demand* and *Urban Containment*. Percentages of species with >30% of their distributional area occupied by intensive land use under different scenarios are presented based on: (a) range-restricted species not threatened on the International Union for the Conservation of Nature's (IUCN) Red List, (b) range-restricted species threatened on the IUCN Red List, (c) range-restricted species not threatened on the Endangered Species Act (ESA) and (d) range-restricted species threatened on the ESA.

freshwater fish species will potentially be affected by changes in intensive land use, and how these changes could affect the extinction risk of both currently threatened and non-threatened range-restricted freshwater fish species.

We found that the majority of range-restricted species that are most likely to be strongly affected by intensive land use in future are not currently listed as threatened by either the IUCN Red List or ESA. Given this mismatch, our findings have the following practical applications. First, our results provide an early warning system to flag those species that are most likely to become threatened with extinction by intensive land use in the future. Second, our results could be used to prioritize species for (re)assessment of current conservation status, because range-restricted species with consistently high predicted increases in intensive land use across future scenarios are possibly more likely to shift in conservation status than other species.

We found that higher percentages of range-restricted freshwater fish species are listed as threatened on the IUCN Red List than by ESA. Our findings echo those of Harris *et al.* (2012) who found that the ESA under-represents IUCN-listed birds, mammals, amphibians, gastropods, crustaceans and insects. Given the history and objectives of these two assessment frameworks, it is not surprising that the ESA has fewer threatened species (Harris *et al.*, 2012). The ESA, unlike the IUCN Red List, legally protects species, and the implementation of the ESA requires resources and responsibility and is vulnerable to political influences. Because of

Table 2 Range-restricted freshwater fish species, in the conterminous United States, identified as most likely to be strongly affected by intensive land use because they had >30% urban and row crop agriculture cover within their distribution in 2001 and in three land use scenarios for 2051: *Business As Usual*, *High Crop Demand* and *Urban Containment*. The percentage of intensive land use within each species distribution area in 2001 and 2051 (for each of the three scenarios) as well as whether (1) or not (0) each species is listed as threatened on International Union for the Conservation of Nature (IUCN)'s Red List or the Endangered Species Act (ESA) is shown. A species is categorized as threatened if listed as Extinct, Critically Endangered, Endangered or Vulnerable, or not threatened if they were listed as Data Deficient, Near Threatened or Least Concern on the IUCN Red List, and considered threatened if listed as Threatened or Endangered, and otherwise considered as not threatened, by ESA.

Species	2001	*Business As Usual*	*High Crop Demand*	*Urban Containment*	Threatened IUCN	Threatened ESA
Cottus marginatus	0.31	0.42	0.42	0.33	0	0
Fundulus escambiae	0.31	0.44	0.42	0.33	0	0
Etheostoma baileyi	0.31	0.46	0.40	0.31	0	0
Ctenogobius pseudofasciatus	0.31	0.46	0.40	0.31	0	0
Moxostoma rupiscartes	0.31	0.46	0.41	0.32	0	0
Notropis rupestris	0.32	0.40	0.40	0.32	0	0
Ptychocheilus umpquae	0.32	0.42	0.40	0.33	0	0
Catostomus warnerensis	0.32	0.42	0.41	0.33	1	1
Coregonus kiyi	0.32	0.44	0.40	0.32	1	0
Fundulus bifax	0.32	0.44	0.42	0.32	0	0
Cyprinella xaenura	0.32	0.44	0.43	0.33	0	0
Pteronotropis metallicus	0.32	0.46	0.41	0.33	0	0
Etheostoma nigripinne	0.33	0.40	0.42	0.34	0	0
Percina cymatotaenia	0.33	0.42	0.42	0.33	1	0
Moxostoma austrinum	0.33	0.44	0.43	0.33	0	0
Coregonus nipigon	0.33	0.46	0.42	0.33	0	0
Fundulus luciae	0.33	0.48	0.41	0.33	0	0
Cottus leiopomus	0.33	0.50	0.40	0.32	0	0
Cottus pitensis	0.34	0.42	0.43	0.35	0	0
Cyprinodon salinus	0.34	0.46	0.44	0.34	1	0
Cottus caeruleomentum	0.34	0.46	0.44	0.35	0	0
Percina roanoka	0.34	0.48	0.44	0.34	0	0
Cottus girardi	0.34	0.50	0.42	0.33	0	0
Hybopsis hypsinotus	0.35	0.44	0.42	0.35	0	0
Etheostoma etowahae	0.35	0.44	0.48	0.33	1	1
Etheostoma duryi	0.35	0.48	0.44	0.35	0	0
Percina burtoni	0.35	0.54	0.44	0.34	1	0
Macrhybopsis tetranema	0.36	0.46	0.44	0.36	1	0
Lythrurus ardens	0.36	0.48	0.40	0.31	0	0
Percina nasuta	0.36	0.48	0.45	0.36	0	0
Hybopsis lineapunctata	0.36	0.48	0.46	0.36	0	0
Gobiomorus dormitor	0.36	0.50	0.44	0.36	0	0
Etheostoma blennius	0.36	0.50	0.45	0.36	0	0
Ameiurus serracanthus	0.36	0.50	0.46	0.36	0	0
Gila boraxobius	0.37	0.48	0.45	0.37	1	1
Etheostoma barbouri	0.37	0.50	0.44	0.36	0	0
Oncorhynchus gilae	0.37	0.50	0.46	0.35	1	1
Percina uranidea	0.37	0.52	0.47	0.37	0	0
Dionda nigrotaeniata	0.37	0.54	0.44	0.36	0	0
Fundulus stellifer	0.38	0.54	0.43	0.34	0	0
Ambloplites cavifrons	0.38	0.54	0.46	0.36	0	0
Notropis cahabae	0.38	0.54	0.47	0.37	1	1
Percina squamata	0.38	0.54	0.49	0.39	0	0
Awaous banana	0.38	0.56	0.47	0.37	0	0
Etheostoma cinereum	0.38	0.56	0.48	0.38	1	0
Micropterus cataractae	0.39	0.52	0.47	0.37	0	0
Ammocrypta meridiana	0.39	0.56	0.44	0.36	0	0
Micropterus notius	0.41	0.60	0.47	0.38	0	0

Table 2 Continued.

Species	2001	*Business As Usual*	*High Crop Demand*	*Urban Containment*	Threatened IUCN	Threatened ESA
Gila alvordensis	0.42	0.58	0.49	0.40	0	0
Noturus munitus	0.42	0.58	0.50	0.41	1	0
Fundulus rubrifrons	0.42	0.60	0.50	0.40	0	0
Noturus baileyi	0.43	0.62	0.51	0.42	1	1
Etheostoma microlepidum	0.44	0.62	0.52	0.42	0	0
Etheostoma chienense	0.45	0.62	0.52	0.43	1	1
Pogonichthys macrolepidotus	0.47	0.66	0.54	0.44	0	0
Nocomis asper	0.49	0.62	0.50	0.39	0	0
Coregonus zenithicus	0.60	0.68	0.74	0.63	1	0

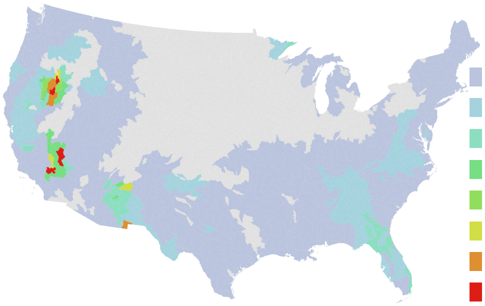

Figure 4 Geographical summaries, within hydrologic units, of the percentage of range-restricted freshwater fish species most likely affected by intensive land use within their distribution area. Species likely to be affected by land use were distinguished based on having >30% of their distribution under intensive land use across four scenarios: 2001 and *Business As Usual*, *High Crop Demand* and *Urban Containment* scenarios for 2051.

these differences, it is unlikely that all species listed on the IUCN Red List will be protected under the ESA (Harris *et al.*, 2012). However, organizations, such as IUCN or the United States Fish and Wildlife Service (USFWS), who are responsible for assessing and monitoring species extinction risk status, could cross-reference the two lists and explicitly evaluate why a species is listed as threatened on one and not the other. Our approach could also act as a first pass to identify species and inform listing decisions for the ESA in the immediate future. For example, repeating the steps we used here, organizations such as USFWS can 1) identify range-restricted species; 2) incorporate a measure of likelihood that a species could be strongly affected by land use; and then 3) within this subset of species identify which species are not yet considered threatened on ESA, but are listed as threatened on the Red List. For example, looking at the range-restricted species in our analysis, there are 15 species listed as threatened by the IUCN Red List, but only half of these species are also listed as threatened on ESA (e.g. *Coregonus zenithicus*, *Noturus munitus*, *Etheostoma cinereum*, and see Table 2 for complete list). This suggests an opportunity exists to use our approach to flag species as potentially imperilled, and as requiring more thorough investigations and consideration for the ESA (*sensu* Harris *et al.*, 2012).

In addition to our individual species assessments, we evaluated geographical patterns of hydrologic units supporting range-restricted species likely to be affected by land use and those supporting IUCN Red List or ESA-threatened species, and found moderately strong spatial congruence. This finding indicates areas of opportunity (e.g. south-west and south-east United States) where landscape-scale conservation initiatives in support of currently threatened freshwater fish species could also benefit other species that are likely to be impacted by human land use now, and in the future. Such areas of opportunity are highly relevant to USFWS decision-making, because the agency is responsible for managing ESA-threatened species and has established the Landscape Conservation Collaborations to foster effective multispecies conservation (see http://www.fws.gov/landscape-conservation). A reasonable next step from our analysis could be to undertake a spatially explicit prioritization considering all freshwater fish species to identify areas of conservation priority for freshwater fishes, giving explicit consideration to species' extinction risk and current and future land use. Similar to previous assessments undertaken for aquatic biodiversity in Australia (Bush *et al.*, 2014), such a prioritization could identify where conservation actions could be taken at the national level to maximize benefit for freshwater fish species now and in future.

Our analyses were designed to elucidate potential patterns of intensive land use changes in relation to range-restricted species, and should not be interpreted as a comprehensive assessment of species extinction risk. Our approach also has several limitations. First, we assumed that fishes have constant distribution areas. If this is not the case, then we may have overestimated the impact of intensive land use on these range-restricted species (Jetz *et al.*, 2007), but it is not possible to estimate species' distribution shifts from the coarse available spatial data on freshwater fish distributions. Second, our assessment is based on species distributions within the conterminous United States, and in a few cases, it is possible that the ranges of species included in our analyses extend beyond the United States. Therefore, our assessment only informs the potential implications of land use change in the United States. Third, urban and row crop agriculture are only two of many disturbances threatening freshwater biodiversity in North America, and other threats include fragmentation and fishing pressure (Dudgeon *et al.*, 2006). Unfortunately, most other human disturbances do not lend themselves to scenario analysis of future conditions as readily as intensive land use. However, when available, additional factors should be taken into account to more fully estimate human impacts on individual species. We were also unable to account for climate change here, but considering interactions between climate and land use change would be an interesting next step from our study. Fourth, given the broad-scale of our study, we used a single threshold, based on Allan (2004), as an indicator of potential decline in habitat quality and species persistence (30% of species' distribution area). Future studies could further explore a range of thresholds, evaluating sensitivity on a species-by-species basis to identify individual species' specific sensitivities to land use within their ranges.

Our approach offers a simple and repeatable set of criteria, drawing on both published and commonly used thresholds (i.e. the IUCN Red List threshold for range-restricted designation; 30% intensive land use threshold derived from Allan (2004)), and it could be applied to other taxonomic groups whose biogeography is well described. Where similar predictions of future intensive land use are available, our approach could also be extended to other regions. Indeed, our land use projections were based on a single approach, econometric modelling, but there are other model approaches (rule-based, cellular automata, etc.) that could be used to project land use changes. Finally, our approach brings the focus of scenarios to the species level, allowing us to evaluate and comment on the potential implications of future land use on species' extinction risk. Indeed, impacts from human land use and other human disturbances affect the condition of biodiversity and are increasingly being shown as drivers of reductions in species ranges as well as species extinctions (Di Marco & Santini, 2015). Drawing on data, like those presented here, future research is needed to identify how species traits and life history (currently the key considerations in extinction risk assessments) and human disturbances interact to influence species' extinction risk (*sensu* Davidson *et al.*, 2012; Bland *et al.*, 2015). The development and application of such approaches is especially needed for data-limited taxa such as fishes, for which trait, life history information and data on stressors are often poorly understood or for which data do not exist (*sensu* Comeros-Raynal *et al.*, 2012). While the development of machine learning modelling methods, to explain species' extinction risk, is a growing area of study (see Bland *et al.*, 2015), we see the consideration of future disturbances, such as land use change, in such modelling frameworks as an important step towards informing and guiding proactive conservation decision-making.

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SUPPORTING INFORMATION

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

Table S1 Range-restricted fish species' in the United States with or without >30% of their distribution with intensive land use. Each species conservation status is also indicated.

Figure S1 Differences in the percentages of range-restricted species listed as threatened on the International Union for the Conservation of Nature's Red List (increasing shade of red) compared to Endangered Species Act (increasing shade of blue). Hydrologic units that do not support any species with restricted ranges are depicted in grey.

BIOSKETCH

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