The biodiversity value of groundwater-dependent ecosystems: A cataloguing of United States federally listed species that depend on groundwater

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Background

Water flowing underground in aquifers discharges to the surface at discrete points where it meets surface waters and forms groundwater-dependent ecosystems (GDEs), including springs, wetlands, rivers, and lakes (Brown et al. 2011). These ecosystems often have unusual hydrologic and chemical properties that differ from nearby surface water-driven aquatic ecosystems. The geochemistry reflects the geology of the aquifer; for example groundwater may have high concentrations of specific minerals. Groundwater hydrology is characterized by discharge that is generally steady and does not show a distinct seasonal pattern; it often flows into ecosystems at rates much lower than surface water-fed streams. Finally, groundwater temperature is relatively static; compared to surface water, it is cooler in the summer and warmer in the winter (Anderson 2005). Alternatively, geothermal conditions can produce hot springs which also have unique hydrologic and temperature characteristics.

This combination of geochemistry and hydrogeology creates ecosystem conditions that often are distinct from surrounding aquatic ecosystems. Because points of groundwater discharge can be quite small, the ecosystems themselves may be smaller than surface water-driven ecosystems. All of these factors influence the plant and animal species composition, and often include rare and endemic species (Bedford and Godwin 2003). Below are three examples of this important relationship:

- The California pitcher plant (*Darlingtonia californica*) is found almost exclusively in highly basic serpentine fens rich in Mg^{+}, which are groundwater-dependent.
- In many western streams, salmon species congregate around areas of cool groundwater discharge into streams and lakes in the summertime, when

warm water temperatures are physiologically stressful.

- The Oregon spotted frog (*Rana pretiosa*) and the yellow rail (*Coturnicops noveboracensis*) both select nesting habitat adjacent to springs in Oregon's Upper Klamath basin, where water levels are more constant during the breeding season.

Despite this general understanding of the relationships between groundwater and the species that inhabit groundwater-dependent ecosystems, the extent of rare and endemic species' reliance on groundwater has not been quantified. To address this gap, we surveyed the habitat requirements of all species with status under the U.S. Endangered Species Act, to identify those species that rely on groundwater for all or some part of their life cycle.

Obligate	Facultative
discharge	bog
fen	cienega
gaining reach	cypress dome
GDE	floodplain
geyser	kettle hole
groundwater	lake
hot spring	marsh
karst	peatland
seep	playa
sink	pocosin
spring	pond
subterranean	prairie pothole
thermal	riparian
	swamp
	vernal pool
	wet meadow
	wet prairie
	wetland

Table 1: Search terms to determine groundwater dependence of USESA (federally) listed, proposed, implied, and candidate species

Methods

The NatureServe Explorer (NatureServe 2010) database was accessed on 2/3/2011, and a database search was conducted for all species with status under the US Endangered Species Act, including listed, proposed, implied, and candidate species. For the purposes of this study, "species" refers to biological species as well as documented populations, varieties, or subspecies. The search was limited to vertebrate, invertebrate and tunicate animals, as well as fungi, lichen, non-vascular and vascular plants. Data were downloaded and then queried specifically for information pertaining to the species' scientific name, common name, USESA status, and habitat information. This information corresponds to NatureServe data under the columns "other status", "status value", "status description", "implied status", "habitat description", and "habitat comments", respectively.

Species in this data set were evaluated for their groundwater dependence based on several criteria. First, a list of groundwater-dependent species developed for the state of Oregon (Appendix C in Brown et al. 2009) was consulted, and species within our data set that were listed as groundwater-dependent in the previous study were identified. Next, a list of search terms indicative of potential groundwater dependence (Table 1) was established and used to query habitat information for the remaining species in our data set. Search terms were divided into two categories: obligate and facultative. Habitats listed under each column are considered representative, though not comprehensive, of ecosystems dependent on groundwater. When species were identified using "facultative" search terms, habitat descriptions also were scanned for explicit reference to the source of water to determine if species should be retained. Thus, if a species was identified using the search term "marsh," the species was not included as groundwater dependent if the description did not indicate the marsh was fed by groundwater.

For those species lacking habitat information, searches were conducted using documents associated with the species' listing procedure as provided on the US Fish and Wildlife Service website. No additional information was available for several populations, varieties, and subspecies. These populations, varieties, and subspecies were therefore identified as groundwater-dependent if the species as a whole was considered groundwater-dependent. For example, both *Oncorhynchus nerka* population 1 and population 2 are identified as groundwater-dependent,

even though no habitat information was available for population 2. We note that species indirectly groundwater-dependent (those whose habitat description indicated a dependence on a host plant that may or may not itself be dependent on groundwater) were not included if the species' habitat information did not include these search terms. Habitat descriptions for species not considered groundwater-dependent also were checked for accuracy.

Findings

Based on ESA criteria, we downloaded NatureServe data for a total of 1,753 species. Of these, 325 were invertebrates, 490 were vertebrates, 936 were vascular plants, and 2 were lichen. No fungi, nonvascular plants, or tunicates met these initial criteria (i.e., no U.S. federal status). Using this subset of species, our search methods identified 291 federally listed, implied, or proposed species obligately, facultatively, or indirectly dependent on groundwater (for link to table, see Appendix), of which 47 were identified based on the results of Brown et al. (2009). We summarize the data as follows. Of the total 291 groundwater-dependent species, 84 were invertebrates, 113 were vertebrates, and 94 were vascular plants (summarized in Table 2). Neither species of lichen was found to be groundwater dependent. Of the 244 species identified using search terms, 203 species inhabit obligate groundwater-dependent habitat, and 41 inhabit facultative groundwater dependent habitat. Of the 203, 19 were identified based on habitat descriptions not identified *a priori* but that were

	LE	IS:LE	PS:LE	LT	IS:LT	PS:LT	C	IS:C	PS:C	Total
Invertebrates	42	2	1	6	0	0	32	1	0	84
Vertebrates	44	6	3	33	9	4	13	0	1	113
Vascular Plants	53	3	0	27	1	0	10	0	0	94
Total	139	11	4	66	10	4	55	1	1	291

Table 2. Summarized results for groundwater dependent invertebrates, vertebrates, and vascular plants by their USESA listed, implied, and proposed status. Status indicated as endangered (LE), implied endangered (IS:LE), proposed endangered (PS:LE), threatened (LT), implied threatened (IS:LT), proposed threatened (PS:LT), candidate (C), implied candidate (IS:C), and proposed candidate (PS:C).

still indicative of groundwater dependent ecosystems. These include habitats described as caves, limestone, or simply underground, with some mention of water. Search terms most commonly identified for obligate groundwater dependent species include spring (n = 97) and seep (n = 42), with fen, groundwater, hot spring, karst, sink, and subterranean also contributing (n = 45). The search term that most commonly identified facultative groundwater dependent species was bog (n = 37), with cienega (n = 3) and marsh (n = 1) also contributing.

Significance

Our findings highlight the importance of sustainable groundwater management on species of conservation concern. Indeed, 26% of invertebrates, 23% of vertebrates, and 10% of vascular plants with federal listing were deemed groundwater-dependent in some way, with 17% overall (Table 3). In particular, cave ecosystems appear to provide important habitat for listed, groundwater-dependent species, as 13% of these species and 39% of these invertebrate species are cave-dependent. Additionally, several states such as California, Texas, Oregon, and Nevada appear to have higher numbers of groundwater-dependent species (Figure 1), suggesting targeted conservation of groundwater in particular states may have a disproportionate benefit to listed species.

	# of listed species	# of listed species that depend on groundwater	% of listed species that depend on groundwater
Inverte-brates	325	84	26%
Vertebrates	490	113	23%
Vascular Plants	936	94	10%
Lichen	2	0	0%
Total	1753	291	17%

Table 3. Summarized results for groundwater dependendent species by type (invertebrates, vertebrates, vascular plants, and lichen)

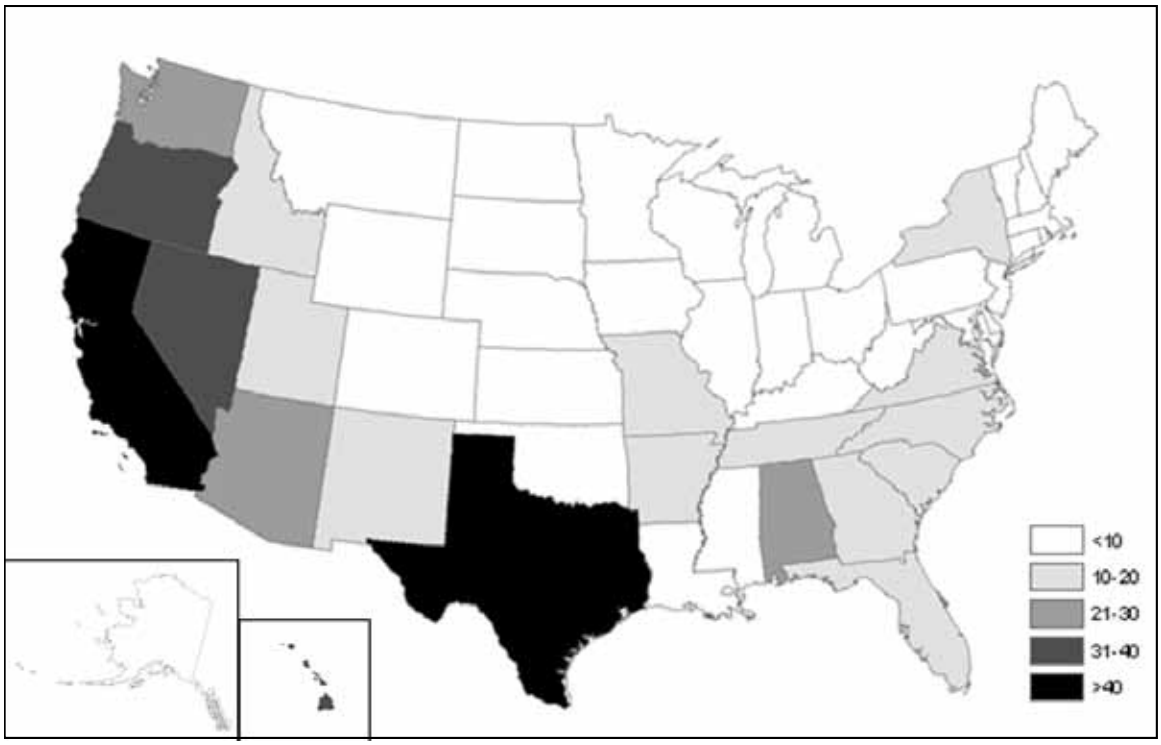

Figure 1. Number of federally-listed, groundwater-dependent species by state.

These results point to the need to protect these unique habitats and the groundwater feeding them due to their tremendous value in supporting biological diversity. We present these results at a time when surface waters in many watersheds are fully appropriated, and when water users are increasingly turning to groundwater to meet the needs of municipalities, industries, and irrigators. Despite these competing uses of groundwater, there are still opportunities to identify the groundwater requirements of all species reliant on this water source and implement means to ensure an adequate supply of groundwater to support them.

References

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Appendix

Table 1, containing the full list of USESA (federally) listed, proposed, implied, and candidate species associated with groundwater-dependent habitats may be found at: http://tinyurl.com/groundwater-species