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Exploring the potential of habitat banking in preserving freshwater biodiversity and imperiled species

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ABSTRACT

Habitat banking, a conservation approach to offset habitat loss, has been widely accepted and implemented in the United States, especially for the protection of freshwater ecosystems. The potential adequacy of the habitat banking approach has, however, not yet been formally quantified in the context of its underlying framework and policies. Using a gap analysis approach, we test the current adequacy and future potential of habitat banking for 2313 approved and 552 pending banks in the United States. In the analysis, we consider water stress due to projected climate change, freshwater diversity, imperiled species, and human population growth, among other factors. The results show that the highest conservation urgency was assigned to states in the Southwest with high levels of species imperilment and large increases in anticipated water stress. The banking network covers most of the freshwater biodiversity hotspots in the East and Southeast. Land ownership is a potential driver for the low bank density in western states, with large proportions of land being owned and managed through federal agencies and only 58 banks situated on federal land. While the banking network in the United States is one of the most developed on a global level, gaps and priority areas can be clearly identified to strengthen the current network and its role in preserving freshwater habitat and diversity.

1. Introduction

Freshwater resources provide valuable ecosystem services, providing economic as well as social and cultural value and support high species biodiversity while occupying <1 % of the earth's surface (e.g., Geist, 2011; Strayer and Dudgeon, 2010). Threats to freshwater biodiversity have been increasing significantly over the past decades, with biodiversity declines surpassing those of terrestrial systems due to pollution, invasive species, habitat degradation, and overharvest as well as climate change and several less obvious stressors (Reid et al., 2019). An additional complication is that development, monitoring, and enforcement of conservation policies is difficult for freshwater ecosystems, with unintended consequences of mitigation and restoration efforts being common (e.g., Kemp, 2016; Pastorino et al., 2019). Planning processes for residential and industrial development in most countries involve frameworks that mitigate negative impacts on ecosystems. Most frameworks follow a mitigation hierarchy from most to least preferred (1) to avoid impacts by choosing a different location, (2) to minimize impacts through best practices, (3) rehabilitation through impact removal after project completion, and (4) to offset any residual negative impacts (Arlidge et al., 2018). Offsets compensate for the unavoidable loss of ecosystem function or habitat area using enhancement, restoration, or creation measures. Offsets can be constructed in a like-for-like (i.e., replace what was lost) or like-for-unlike (i.e., replace what was lost with something else), either on- or off- site, depending on agency requirements and project impacts (Hayes and Morrison-Saunders, 2007).

Habitat banking poses an alternative mechanism to provide offsets. Banking allows the proponent to offset approved negative impacts through the purchase of credits from a bank. These accreditation systems replace the traditional offset as the last step of the mitigation hierarchy and each credit responds to a habitat area held by the bank and its associated ecological value. Banks can be situated on private or

Abbreviations: TBIS, Total Bank Indicator Score; TEDIS, Total Environment and Diversity Indicator Score; TEDIL, Total Environmental and Diversity Indicator Level; TBIL, Total Bank Indicator Level.

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public lands and operated by a government agency, corporation, non-profit organization, or other entity or ownership form (EPA, 1995; Pidot, 2020) Regulatory agencies approve banks and assign the mentioned ecological value through environmental assessments, which translate to a certain credit amount to be offered in transactions with a proponent. While facing similar pitfalls as traditional offsetting (e.g., inappropriate offsetting metrics, transparency of assessment and approval criteria, long-term administrative consistency, and funding) banking has been widely adopted as an offsetting mechanism, mainly due to it the advantage of moving administrative and assessment responsibilities away from the proponent toward the bank as a third party (e.g., Bull et al., 2013; Maron et al., 2016). Ecological benefits of banking range from the ability to protect larger areas, increasing connectivity and reducing potential edge effects of smaller habitat patches, over staggered credit release linked to ecological performance criteria, to credit transfer and transboundary agreements and collaboration, which is becoming more and more important considering migratory species (e.g., BenDor et al., 2009; Doka et al., 2022; Reiss et al., 2009). The United States banking framework is based on two different legislations leading to the establishment of mitigation (wetlands and streams under the Clean Water Act Section 404, RIBITS, 2021) and conservation banks (listed species under the Endangered Species Act, USFWS (U.S. Fish and Wildlife Service), 2021).

Regarding the preservation of freshwater ecosystems and imperiled aquatic species (i.e., endangered, threatened or of concern), banking has several key advantages that makes it a promising approach. First, conservation banks are areas of land approved by the designated regulator to sell offsetting credits for either threatened or endangered species or habitats (Fox and Nino-Murcia, 2005). Second, considering listed freshwater species, conservation banks are especially suited for imperiled species, being susceptible to threats due to unique life history or habitat requirements and are limited in range or distribution (Fox and Nino-Murcia, 2005; Poudel et al., 2019). Third, the same approach applies to threat intensity and biodiversity of a particular region, with conservation banks being well suited to preserve a diverse freshwater ecosystem with high threat exposure (Fig. A1).

Mitigation banks refer to banks selling credits used to offset negative impacts on streams or wetlands (Tallis, 2016). These banks are appropriate for less diverse systems and less susceptible species and overall lower threat intensity, as they are used for larger development, agriculture, or land-use projects (Fig. A1). The evaluation criteria of mitigation banks are based on area ratios, basic ecological success criteria, financial assurances, and administrative benchmarks (Reiss et al., 2009; Tallis, 2016). Proponents also have the option to pay money into compensation funds managed by non-profit or government In-Lieu Fee programs (ILF), using these resources for offsetting activities. Finally, Umbrella Banks (UMBs) are established to run multiple offsetting sites on a regional level under single institution funding. This top-down multi-area management approach offers the opportunity to preserve and manage larger areas, especially securing connectivity, and minimum viable ecosystem size (Bayon et al., 2012).

Conserving biodiversity hotspots for freshwater species is a well-recognized objective, but no research has examined whether the current banking network covers hotspots and freshwater areas and species that could benefit from bank establishment (e.g., Howard et al., 2018; Kareiva and Marvier, 2003; Linke et al., 2019; Nel et al., 2009). Furthermore, there is no research available on whether banking follows the issue of hotspot over-prioritization (e.g., Kareiva and Marvier, 2003; Linke et al., 2019). Conservation practitioners, policy makers and mangers have been trying to address this issue of how to conserve biodiversity and move toward a process-based conservation prioritization approach for freshwater ecosystems (e.g., Kareiva and Marvier, 2003; Linke et al., 2019). Finding more appropriate priority indicators for identifying urgent freshwater species and ecosystems will become even more crucial when considering current and predicted water stress, land-use change and climate change (e.g., Doka et al., 2022; Du Plessis, 2018; Howard et al., 2018; Sabater et al., 2018; Schwabe et al., 2020). Similar advances are being made toward applying mitigation options and offsetting for public lands in the United States which are often managed under different approaches through government agencies but have the legislative and logistic framework in place to use offsetting and consequently banking (Pidot, 2020).

This study contributes an evaluation of the adequacy of habitat banking for preserving freshwater biodiversity and imperiled species in the United States, based on arguably the largest and best documented banking system in the world (Poudel et al., 2019). Using a gap analysis approach, we consider a wide variety of factors, including considerations of how threats may evolve due to climate change and human population growth. Specifically, we test (1) whether the current bank distribution in the United States adequately covers freshwater biodiversity and imperiled species, (2) whether priority indicators can be identified to direct future banking efforts and banking types to strengthen the current network and its role in preserving freshwater habitat and diversity.

2. Methods

2.1. Banking, biodiversity, and environmental data

Data for this study were extracted from the United States Regulatory In-Lieu Fee and Banking Information Tracking System (RIBITS; R 4.1.0 - rake). For this study, we reviewed 3771 banks and ILF sites listed for the United States. We define banks as Conservation, Mitigation, and Umbrella banks since they all state the end goal to satisfy compensatory mitigation through preservation, establishment, and restoration or enhancement measures, including the bank site, bank agreement, and a service area within which a bank is allowed to sell credits (RIBITS, 2021). To investigate current banking practices, we only included banks and ILF sites in the conterminous United States and its 48 States in the analysis to match water stress and species data (unavailable for Hawaii, Alaska, District of DC, Guam, Puerto Rico). Pending banks were used to predict short to mid-term future developments in their designated target and service areas as the average bank in the United States takes around 10 years to be fully operational (Theis and Poesch, 2022). We also only considered banks established after the United States Army Corps of Engineers (USACE) guidelines of 1995 were put into place to have banks with a uniform reporting and approval system. The previous criteria led to the inclusion of 2313 (1593 with listed service areas) approved and 552 pending banks (150 with listed service areas) for analysis (RIBITS, 2021).

Freshwater biodiversity data was acquired through NatureServe in the form of GIS layers containing 865 species for the conterminous United States and its 48 States, on a minor basin scale (8-digit hydrologic units (HUC 8, NatureServe, 2010 - Version 3.0). All species present in the GIS layers were extracted by name and filtered by their status (excluding species under review) according to the United States Fish and Wildlife Service (USFWS - Endangered Species Act status). The initial 865 fish species were separated into the imperilment categories of *Endangered* (n = 77), *Threatened* (n = 46) or *Species of Concern* (n = 93, USFWS (U.S. Fish and Wildlife Service), 2021). The database we compiled from public sources contains 12,984 entries for 485 watersheds in 49 states and is publicly available via the open access repository http://figshare.org/75eg7w745.

Anticipated water stress, defined as change from the current baseline to 2040 was available through the World Resource Institute and their aqueduct tools (WRI, 2021, HUC 8, Table A3). Their baseline water stress was calculated as the ratio of total water withdrawal over available renewable surface and groundwater, with withdrawals being domestic, industrial, agricultural and irrigation, and non-consumptive uses. Water supplies take upstream consumptive use and damming and their effects on downstream water supplies into account (Hofste et al., 2019; WRI, 2021).

2.2. Gaps in the United States banking network

Objective (1) 'Does the current bank distribution in the United States adequately covers freshwater biodiversity and imperiled species?', was addressed by a gap analysis. Gap analysis uses spatial data from protected areas and determines whether their distribution and extent meet the stated conservation targets for landscape, administrative, or ecological units. These assessments are a helpful way to identify representation (presence of ecosystem or species in a protected area), ecological (ecological condition of system or species met, e.g., accounting for movement), or management gaps (management systems fail to meet security requirements for certain species or ecosystems, e.g., Dudley and Parish, 2006; Higgins and Esselman, 2006). Here, we investigate representation gaps of biodiverse areas, as well as ecological management gaps using the following steps: Identify target (freshwater biodiversity and imperiled species), map targets (GIS mapping of freshwater species), map protected areas (GIS mapping of banks and service areas), map additional factors (GIS mapping of water stress), identify gaps (areas not covered by banks either showing high biodiversity or imperiled species presence, Fig. 1). We follow well-established gap analysis methodology detailed for example by Dudley and Parish (2006) or Higgins and Esselman (2006). Spatial datasets used for GIS-based gap analysis were obtained from NatureServe (NatureServe, 2010 - Version 3.0), the Regulatory In-Lieu Fee and Banking Information Tracking System (RIBITS, 2021, banking shapefiles) and water stress shapefiles from the World Resource Institute (WRI, 2021).

2.3. Indicators for banking opportunities and environmental urgency

Objective (2) 'Can we use priority indicators to identify gaps and direct future banking efforts and banking types to strengthen the current network and its role in preserving freshwater habitat and diversity?', was addressed by developing environmental indicators pertaining to environmental urgency and banking indicators, signalling banking opportunities in each state (Fig. 1). We chose to develop priority indicators (*Banking indicators* n = 10, *Environmental and diversity indicators* n = 10) on where to direct current and future banking efforts based on a state level to keep the adequate spatial resolution and take legislative differences in banking and conservation policies between states into account. The goal of these indicators was to translate the visually identified gaps based on 10 representative banking and environmental and diversity metrics. Indicator metrics were obtained from the United States Census Bureau, NatureServe, RIBITS, WRI, USFWS, Natural Resource Council (NRC) or through analyses and calculations done in

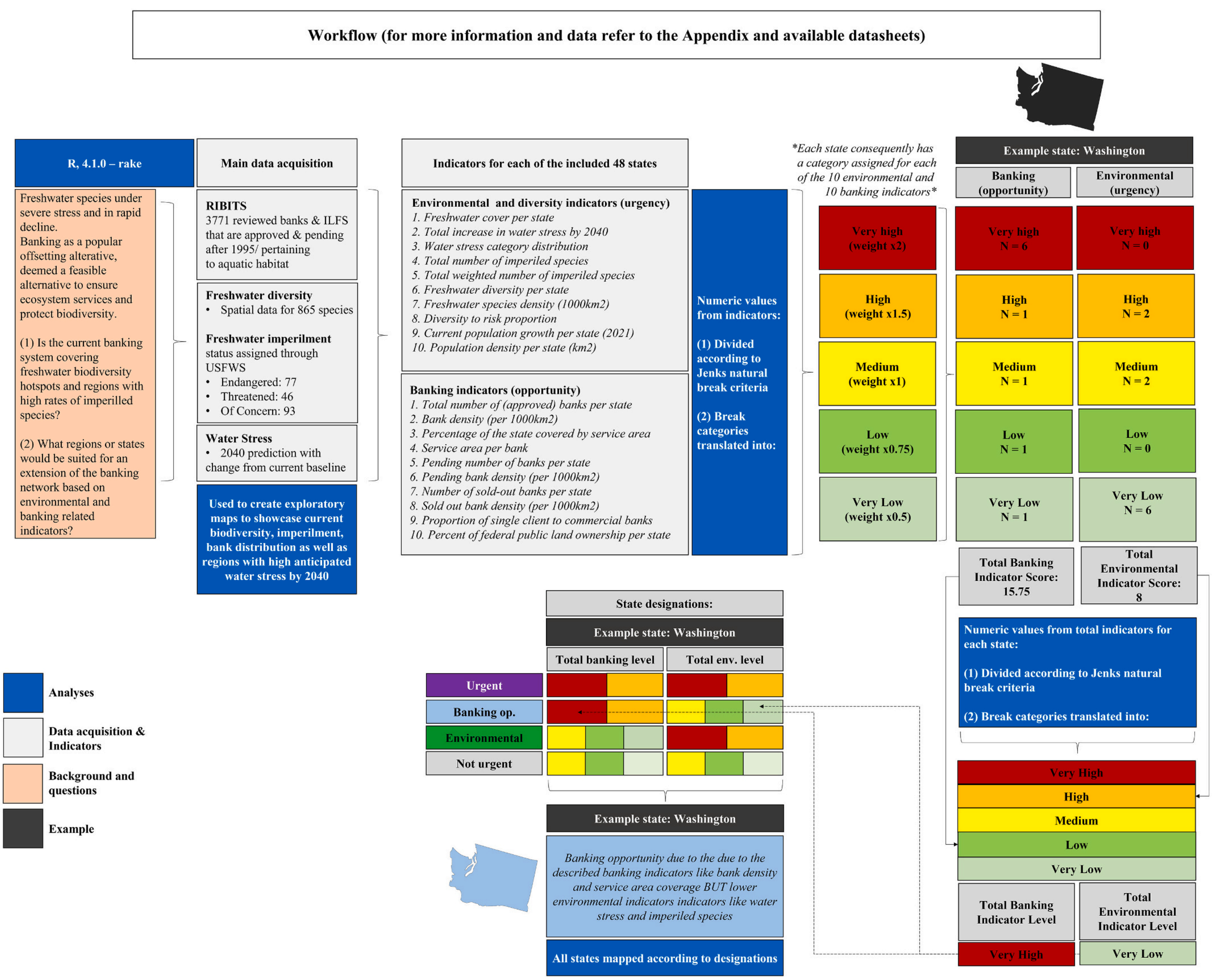

Fig. 1. Workflow and analytical steps. Transformative and analytical steps taken. Steps are divided into data acquisition, indicator formation based on numeric values and Jenks natural breaks, and state designation assignment through total environmental urgency and banking opportunity levels.

GIS (Dataset SI 1). We here present only a summary of the steps used to form priority indicators, see Table A1 and Fig. 1 for more details. Numeric values from each indicator were divided according to Jenks natural break criteria (Dataset S1). Break categories were labeled as very high, high, medium, low, and very low. Categories correspond to each individual indicator (e.g., low number of pending banks in a state result in high to very high banking indicators, since indicating banking opportunity).

2.4. Combined indicator scores and state designations

Each states *Banking indicators* and *Environmental and diversity indicators* categorical scores were weighted and summed (very high x2, high x1.5, medium x1, low x0.75, very low x0.5, Fig. 1). For instance, California scored very high = 2, high = 1, medium = 4, low = 2 and very low = 1 time for *Banking indicators* which resulted in a *Total Banking Indicator Score (TBIS)* of 11.5 through the weighing process. The same was done for *Environmental and diversity indicators* leading to *Total Environmental and Diversity Indicator Score (TEDIS)* on a state level. These state level total scores were divided according to Jenks natural break criteria (Dataset S1) into very low to very high categories representing *Total Bank Indicator Level* (*TBIL)* and *Total Environmental and Diversity Indicator Level* (*TEDIL)*. For example, California's *TBIS* of 11.5 translates to a low *TBIL* (Fig. 1). TBIS and TBL determined the final state designation according to: (1) *Banking opportunity*, (2) *Environmental and diversity priority*, both (3 *Urgent*) or none (4 *Not urgent*). *Urgent* was assigned to states with both total indicators being high, or very high. *Environmental and diversity urgency* was a designation for states with medium to very low *TBIL* but high to very high *TEDIL*. States with overall low total indicators (medium to very low in both groups) were labeled as (4) No*t urgent*. A detailed breakdown by state is provided as Table A1 and Dataset S1. All states were mapped according to their designations to inform what regions or states would be suited for an extension of the banking network based on environmental and banking related indicators going beyond the initially identified broad gaps.

3. Results

3.1. Biodiversity, imperiled species, and bank coverage

Freshwater biodiversity for the conterminous United States was clearly centered around the Midwest and Southeast, with high diversity states exceeding 101 different species on a minor basin level like Kentucky, Tennessee, or Alabama (Fig. 2A). While these states also had several imperiled species, the areas of highest species imperilment were in the Southwest, including Nevada, New Mexico, and California with an overall lower freshwater biodiversity on a minor basin level, often <25 species (Fig. 2C). A detailed breakdown by state is provided in the dataset S1.

Mapped anticipated water stress exceeding two-fold increases were recorded the western and southwestern United States with individual minor basins predicted to experience extreme water stress covering California, Nevada, South Dakota, Wyoming, Arizona, Utah, Colorado, Oklahoma, Idaho, Nebraska, New Mexico, and Texas (Fig. 2B). Minor basins expected to experience extreme water stress had overall low freshwater biodiversity but high imperilment numbers on a state level. For instance, Nevada's affected minor basins had biodiversity of 1 to 10 species on average with a state-level imperilment of 18 species of concern, 24 threatened species, and 6 endangered species (Fig. 2B, C).

In contrast, bank distribution and service area coverage for the conterminous United States varied between states (Fig. 3). Most banks were in the Midwest, Northeast, and Southeast or West Coast, with small numbers in the Southwest and Northwest (Fig. 3B). Service areas showed visual gaps in the western parts of the United States (e.g., New Mexico, Nevada <10 %) and Northeast (e.g., Maine, Vermont, or Massachusetts <10 %, Fig. 3A). Notably, Michigan had the lowest service area coverage in the Midwest, with no banks listed. States with high service area coverage and bank numbers were for instance Louisiana, Mississippi, Georgia, South Carolina, Virginia, Wisconsin, and Minnesota (91 to 100 % service area coverage and 100+ banks per state, Fig. 3).

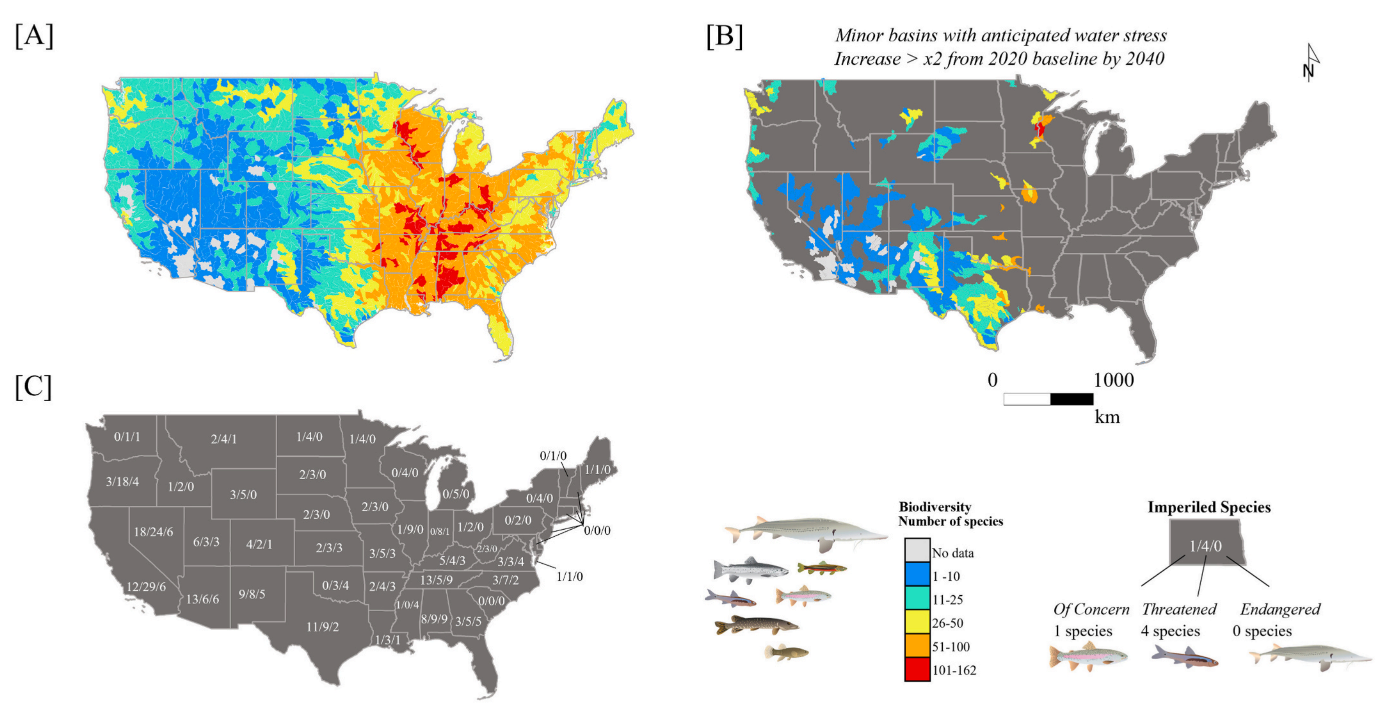

Fig. 2. Freshwater biodiversity, water-stress, and imperiled species in the United States. Freshwater biodiversity on a minor basin level (HUC 8, A), highlighting the basins expected to exceed an increase in water stress by x2 by 2040 and corresponding basin biodiversity (B) and imperiled species on a state level (species of concern, endangered, threatened) for the conterminous United States (C, based on NatureServe data, Version 3.0, WRI, 2021).

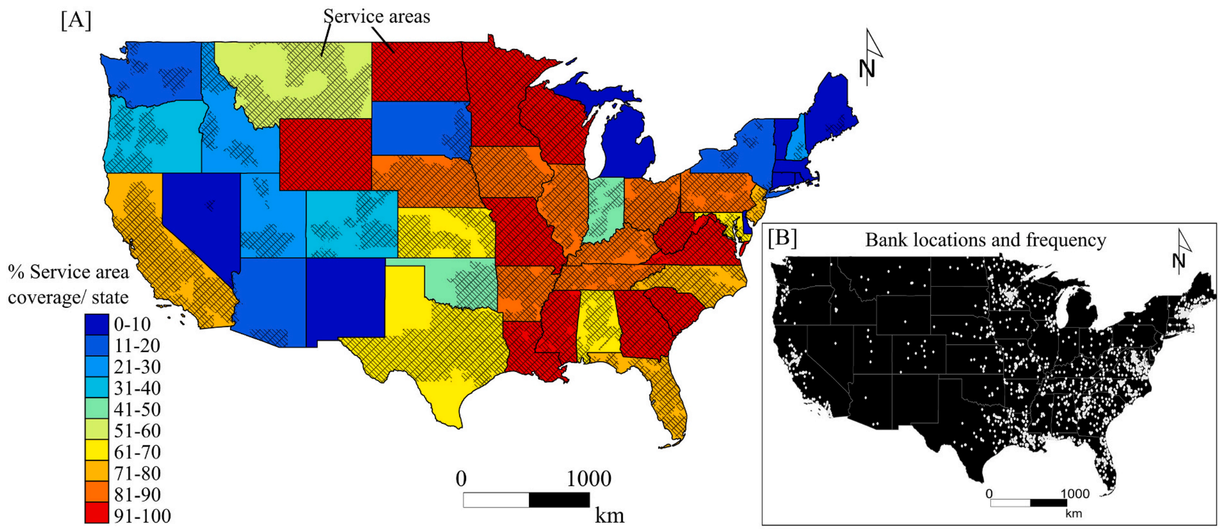

Fig. 3. Bank service area coverage across states. The extent of service area per bank and state area covered by service area in % (A) as well as individual bank location in the conterminous United States (B) (based on RIBITS data 2021, bank number = 2313 (1593 with service area)).

3.2. Banking indicator scores by designation and state

3.2.1. Banking opportunity

States in the *Banking opportunity* designation (n = 18) were predominantly located in the Midwest (Michigan, North Dakota, South Dakota, Kansas, Nebraska, Wyoming) and Northeast (New York, Pennsylvania, Massachusetts, Connecticut, Delaware, Rhode Island, Vermont, Maryland, New Jersey) of the United States (Fig. 4A, B; Table A2). These states were characterized by high to very high TBIS (15.99 ± 0.99) paired with medium to very low TEDIS (8.75 ± 0.86; Fig. 4 A, B; Table A2). The primary drivers for high TBIS values in terms of indicators were small numbers of *Total number of (approved) banks per state* (13.9 ± 11.0) and *Bank density (*0.16 ± 0.20) *as* well as *Pending number of banks per state* (3.04 ± 3.45), *Pending bank density* (0.05 ± 0.09)*, Number of sold-out banks per state* (1.04 ± 1.54) and *Sold-out density* (0.01 ± 0.02). *Service area per bank* was high (50,939.75 ± 14,945.79 km^2/bank) lead by Wyoming (253,279.53 km^2/bank).

Total Environment & Diversity Indicator levels were medium to very low as per designation requirements. However, two individual *Environmental and diversity indicators, Population density per state* (104.80 ± 136.69/km^2, noticeably New Jersey, Rhode Island, and Massachusetts >300/km^2) and *Freshwater diversity per state* (99.16 ± 53.59, noticeably Arkansas (203), Indiana (189), Illinois (188), Oklahoma (171), Pennsylvania (163), New York (159)) had high mean values.

3.2.2. Environmental and diversity urgency

States in the *Environmental and diversity urgency* designation (n = 2) were California and Georgia (Fig. 4A, B, Table A2). These states were characterized by high to very high TEDIS (11.75 ± 1.06) and medium to very low TBIS (11.13 ± 0.53, Fig. 4A, B, Table A2). The important drivers for high TEDIS in terms of indicators were high values for *Total number of imperiled species* for California (48.0 %) and *Total weighted number of imperiled species* (79.0 %) and *Diversity to risk proportion* (77.42 %*)*, while high overall *Freshwater diversity per state* (250) was the main TEDIS driver for Georgia as well as current population growth (3.03 %).

Banking opportunity levels were medium to very low as per designation. However, one individual *Banking indicator, Percent of federal public land ownership per state for* Georgia, was low (<5 %), indicating high banking opportunities (Fig. 4A, C; Dataset SI 1).

3.2.3. Urgent

The10 States in the *Urgent* designation were in the South (Texas, Alabama, New Mexico, Arizona, Tennessee) and the Western United States (Utah, Nevada, Fig. 4A, B, Table A2). These states were characterized by high to very high TEDIS (13.14 ± 1.41) and high to very high TBIS (15.96 ± 1.60, Fig. 4A, B, Table A2). Key drivers for TEDIS were high values for all three water stress indicators, *Freshwater cover per state* (1.83 ± 1.37 %), *Total increase in water stress by 2040* (1.64 ± 0.38× increase by 2040), *Water stress category distribution* (~37 % of minor basin area to experience a 1.6 to 2.5× increase and ~ 7.5 % >2.5 increase in water stress by 2040), along with imperilment indicators, *Total number of imperiled species* (25.86 ± 10.91 per state)*, Total weighted number of imperiled species* (53.86 ± 19.40 per state) and *Diversity to risk proportion* (43.40 ± 37.88 %). *Current population growth per state* (3.32 ± 1.98 %) was another influential factor for TEDIS in the *Urgent* designation.

Primary TBIS drivers for states in the *Urgent* designation were small numbers of *Total number of (approved) banks per state* (27.43 ± 31.78, noticeably: Nevada, New Mexico (both 1), Arizona (3), Utah (6)) and *Bank density* (0.16 ± 0.24/1000 km^2), *Pending number of banks per state* (5.29 ± 11.03), *Pending bank density* (0.04 ± 0.10)*, Number of sold-out banks per state* (2.29 ± 2.98) *Sold out density* (0.016 ± 0.024) as well as *Percentage of the state covered by service area* (37.0 ± 35.29 %, especially: New Mexico (<1 %), Nevada (1.9 %), Arizona (11.5 %)). Other less influential drivers were *Service area per bank* (5330.22 ± 4445.52 km^2/bank). *Percent of federal public land ownership per state* (31.48 ± 32.95 %), noticeably: Nevada (81 %) and New Mexico (~40 %, Fig. 4C) and *Proportion of single client to commercial banks (*21.97 ± 35.41 %).

3.2.4. Not urgent

The remaining 14 States were assigned the *Not urgent* designation mainly located in the Midwest (Minnesota, Wisconsin, Ohio, Kentucky) Northeast (Maine, New Hampshire) and Southeast (Virginia, West Virginia, Florida, Louisiana, Mississippi, Missouri, North Carolina and South Carolina, Fig. 4A, B, Table A2). These states were characterized by medium to very low TEDIS (8.35 ± 1.20) and medium to very low TBIS (11.31 ± 2.02) indicating low priority for both areas (Fig. 4A, B, Table A2). Low TEDIS and TBIS scores were driven by low predicted *Total increase in water stress* by 2040 (1.14 ± 0.07× increase by 2040) and *Total number of imperiled species* (5.50 ± 4.15 per state), paired with high numbers of *Total number of (approved) banks per state* (107.36 ± 94.96).

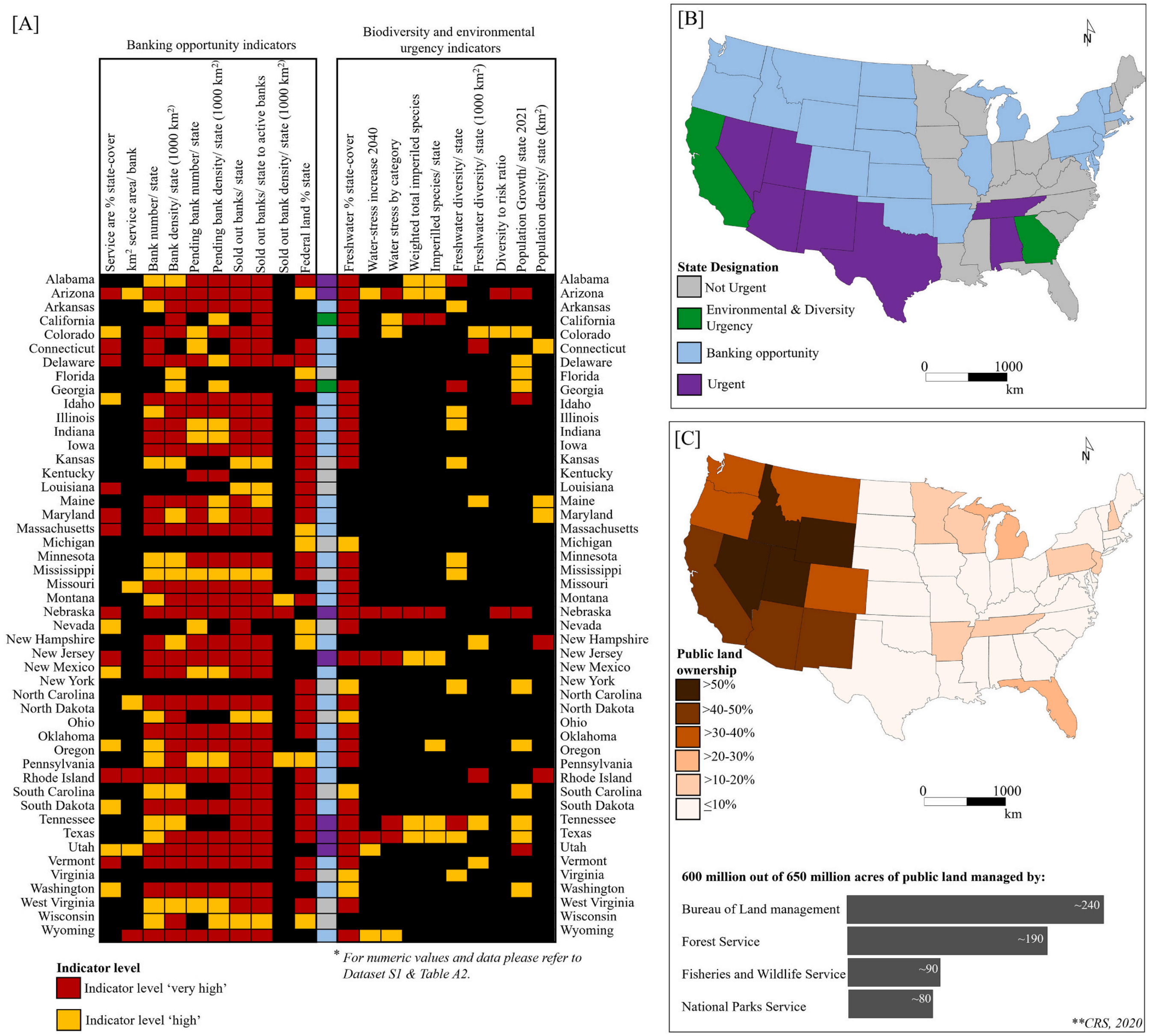

Fig. 4. State-level environmental and banking designations. Indicators level distribution (A) and the corresponding four designations across the United States on a state level (B). Designations, divided into *Urgent*, *Not urgent*, *Banking opportunity,* and *Environmental and biodiversity urgency,* are based on Total Bank Indicator Score (TBIS) and Total Environment and Diversity Indicator Score (TEDIS) converted into corresponding categories of Total Environmental and Diversity Indicator Level (TEDIL) and Total Bank Indicator Level (TBIL). *Urgent*: TBIL and TEDIL high to very high, *Not urgent*: TBIL and TEDIL medium to very low, *Banking opportunity*: TBIL high to very high and TEDIL medium to very low, *Environmental and biodiversity urgency:* TBIL medium to very low and TEDIL high to very high (Table A2). Public land ownership is managed through federal and state-level agencies and bodies (C; CRS, 2020). For detailed indicator scores for each state, refer to Dataset S1.

4. Discussion

4.1. Gaps in the current banking network

Our results demonstrate that regional gaps in the current banking network of the United States exist in the West and Southwest and in certain Northwestern and Midwestern states characterized by regions with low bank density and low service area coverage. These findings are contrary to our expectations as there have been substantial efforts, especially in the past 2 decades, to advance banking policy and incentivize investors (Poudel et al., 2019; Reiss et al., 2009).

High bank coverage was observed in the Southeast and Midwest, in accordance with other studies (Poudel et al., 2019; Reiss et al., 2009). While missing demand for mitigation should be seen as a positive finding, land ownership remains the biggest distinguishing factor besides ecoregion between *Urgent* and other designations and could limit the establishment of a banking network in the Southwest. Our results showed that almost no habitat banks can be found on public federal land while mitigation and offsetting options are available. Most land in the West and Southwest is federal public land with a majority management regime under the Bureau of Land Management and the United States Forest Service (Congressional Research Service CRS, 2020; Fig. 4C). Federal land management has often contributed to harmful impacts on aquatic ecosystems that have been slowly rectified over time, but long-term effects persist (e.g., Roper et al., 2019). This constellation of currently low mitigation demand and land managed through federal agencies could become an issue when adding water stress and imperiled species to the equation. Water stress by 2040 is predicted to affect many watersheds in the conterminous United States, with the biggest increases predicted in the Southwest, especially the Texas-Gulf, Rio Grande, Colorado, and Arkansas Red White watersheds. The Southwest also has the highest environmental and biodiversity urgency for banks to protect a high proportion of imperiled and specialist freshwater species, facing high anticipated water stress (e.g., Budy et al., 2015; Schwabe et al., 2020; Wilcove et al., 1998). Current and future trends indicate that a need for a strong banking network in these areas is likely, especially with water stress amplifying anthropogenic impacts (Harte, 2007; Lade et al., 2019; Schwabe et al., 2020). Ultimately, this decision will be up to the federal government to decide whether to incorporate banking more strongly in these regions in the future as an alternative mitigation and preservation approach as seen in other states.

Demographic changes, especially considering recent acceleration in growth trends, need to be monitored and incorporated into priority indicators, as shown, to identify and counter future increases in human footprint and urbanization early on (Schwabe et al., 2020). High population density states and areas such as the metropolitan areas on the East-coast will likely experience further pressure from ongoing urbanization and linked habitat degradation (e.g., Oertli and Parris, 2019; Surasinghe et al., 2019). Population dense areas provide their challenges when it comes to habitat banking, mostly due to the involvement of different stakeholders, area and land availability, and the need for civic participation and partnerships (Gorissen et al., 2020). Urbanized areas and regions also rely more on single client banks, designated for immediate development projects like road construction (Poudel et al., 2019). While advances in urban restoration projects have been made recently, urbanized areas could still face increased issues in how to best integrate conservation and mitigation projects like banks into an urban landscape, often struggling with fragmented habitats and spatial limitations (Booth, 2005; Jackson and Pringle, 2010).

Overall, regional gaps related to land ownership need to be accounted for, since current alternative federal management practices in these areas might reach its limitations in the near future while the demand for mitigation efforts in the Southwest is likely to increase in future climate, land-use change and water stress scenarios.

4.2. *Strategies to strengthen the banking network*

Each of the mentioned four bank types, UMBs, ILFs, Conservation, and Mitigation banks can provide essential conservation benefits for the four designations to potentially address the gaps and stressors.

Urbanized states listed under *Banking opportunities* should use strategic land-planning as well as using UMBs and ILFs or specialized conservation banks to explore alternative conservation gains or the role of anthropogenic and urban habitats and increase habitat connectivity between patchy habitats or smaller scale banks (e.g., Oertli and Parris, 2019; Sousa et al., 2021). Non-urban states, especially in the Midwest and West, often have lower freshwater diversity or proportion of imperiled species should follow a precautionary approach since the immediate environmental and diversity urgency is currently not present but could change rapidly (Coulter et al., 2015; (Höök et al., 2019)). A strongly developed banking network in terms of service area coverage, bank density, covered vulnerable species and target ecosystems and available area could help mitigate further agricultural land-use development and climate stress as well as meet banking demand (e.g., Bourque et al., 2019; Lind et al., 2019; Theis and Poesch, 2022). Given large land availability and ownership in non-urban states, large-scale stream and wetland mitigation banks would be an appropriate approach and could be modeled after the Southeast or Minnesota, which both have a comparable land situation and have a well-established and working banking network (Lave et al., 2008; Spieles, 2005).

Efforts to strengthen the banking network for states in the *Urgent* designation will have to overcome jurisdictional overlap and fragmentation as well as the often-limited agency capacities along with underestimated conservation costs in the United States leading to inadequate budgets to achieve conservation goals (Nolte, 2020; Scarlett and Boyd, 2015). Many endangered and threatened species in the *Urgent* designation states tend to be small-bodied resident species limited to few and often isolated habitats (e.g., Railroad Valley Springfish (*Crenichthys nevadae*), Cucherousset and Olden, 2011; Meffe et al., 1983; Williams and Williams, 1989). These restricted specialist species are particularly prone to extinction through habitat loss, pollutants, and invasive species. Conservation banks could prove essential in preserving habitat in these cases (Deák et al., 2020; Hermoso et al., 2016; Theis and Poesch, 2022). Banks could also be used toprovide climate refugees for Cold-water species, like Bull Trout (*Salvelinus confluentus*) (Al-Chokhachy et al., 2016). *Urgent* states with low federal land ownership, high biodiversity, and good service area coverage, not necessarily facing water stress, should expand their existing banking network where possible. High service area coverage might pose a challenge and will likely require extensive agency collaboration and public stakeholder involvement. Especially fostering a balance between land use and stewardship to alleviate ecosystem pressure and find conservation alternatives that are not necessarily banks could be crucial in these states. Examples here are the changes in recreational fishing regimes like observed for Lake Sturgeon (*Acipenser fulvescens)* fisheries in Michigan or riparian lease incentive programs in Texas, already being very effective for the Gulf Coastal Plains (Birdsong et al., 2020; Briggs et al., 2020).

States in the *Environmental and biodiversity urgency* designation will require targeted banking approaches if they want to add to the already well-developed banking market and network on a state level (Flather et al., 1998). Conservation banks adopting adaptive management approaches, anticipating species listing under the ESA and stronger stakeholder involvement, addressing underlying conflicts and strengthening ties with state-level and the federal government could help increase resilience for species facing environmental as well as economic and policy-related threats like winter-run Chinook Salmon (*Oncorhynchus tshawytscha*) and Longfin Smelt (*Spirinchus thaleichthys*) (e.g., Moyle et al., 2018; Young et al., 2013). The cases of California and Tennessee serve as an example of states facing major threats to freshwater diversity exerted through invasive and non-native species (e.g., Panlasigui et al., 2018; Thieme et al., 2016). Bank ownership and stewardship often come with requirements to reduce or prevent the spread of invasive species (Fox and Nino-Murcia, 2005). Conservation banks designated to preserving and protecting listed species and ecosystems should be the preferred bank type for these states (e.g., Bunn et al., 2014; Fox and Nino-Murcia, 2005).

States from the *Not Urgent* designation are often hotspots for freshwater biodiversity, covered by extensive banking networks. That said, these states still face similar threats to other states, such as land-use change, pollution, habitat degradation, and invasion pressure. The key difference here will be to adapt and improve banking practices and long-term management requirements to appropriately respond to these evolving threats. For instance, Florida with its large-scale banking network faces high invasive species pressure, being addressed by partnerships between scientists, government, landowners, and the public sector to identify high-risk areas and provide funds where needed. Habitat banks, especially UMBs or ILFs, could provide essential support and funds in these partnerships (Funk et al., 2013; Panlasigui et al., 2018).

Finally, states with well-developed and functioning banking systems will become increasingly important in the future and should be relied upon for guidance to validate current practices and to help anticipate administrative and ecological issues (Box, 2013; Wilcove and Lee, 2004). Our study shows that the banking network in the United States is well established, covering many urban centers and biodiversity hotspots for freshwater species. Our discussion showcases strategies for each designation and corresponding states on how to strengthen and support the respective banking networks. States in the *Urgent* designation could benefit from stronger incorporation into the current banking system considering future land-use changes, population growth and anticipated water stress. Land ownership by the federal government will become a key deciding factor on when and to what extent that could happen.

4.3. Limitations of gap analyses and indicator scores

This study has potential limitations pertaining to its coarse spatial resolution and use of combined indicators. Species imperilment data was only available on a state level which did not allow for an equivalent comparison to minor basin level water stress and biodiversity. Further, combined indicator scores do not allow an easy assessment of what individual parameters drives their values. However, the overall goal for this analysis was to identify spatial gaps that could benefit from habitat bank establishment, especially considering water stress, imperiled freshwater fish species and biodiversity which can be adequately done. Hence, our results should be seen as a broad spatial baseline analysis, with an emphasis on region-specific gaps and opportunities, using indicator scores as an overall measure for opportunity and urgency. We further provide data for in-depth state level analyses looking at specific drivers (https://figshare.com/articles/dataset/19312526). Future studies should build on the identified gaps on a region-specific level as well as with additional geospatial and life-history data to potentially identify key basins or species that could be protected though banks and increased stakeholder and manager involvement.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2022.109700.

Availability of data and material

Data is available through the supplemental material (Dataset S1), through the listed sources in the method section (Table A1) and available through a direct request through the authors and figshare: https://doi.org/10.6084/m9.figshare.19312526. Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2022.109700.

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CRediT authorship contribution statement

S. Theis: Conceptualization; Methodology; Software; Validation; Formal analysis; Investigation; Data Curation; Writing - Original Draft; Writing - Review & Editing; Visualization; Project administration.

D. Castellanos-Acuña: Conceptualization; Methodology; Software; Validation; Formal analysis; Investigation; Data Curation; Writing - Review & Editing; Visualization.

A. Hamann: Conceptualization; Methodology; Resources; Writing - Review & Editing; Supervision.

M.S. Poesch: Conceptualization; Methodology; Resources; Writing - Review & Editing; Supervision; Funding acquisition.

Declaration of competing interest

The Author(s) declare(s) that there is no conflict of interest.

Data availability

Link to data/ datasets is included with the manuscript as well as links to the original data sources shared.

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Glossary

Conservation bank: Permanently protected sites managed for endangered species, threatened species, or species at risk. The aim is to offset adverse impacts to the protected species occurring off-site. Permits managed by USFWS.

ILF (In-lieu fee program): Rehabilitation, establishment, enhancement, and/or preservation of habitat area or ecosystem function through funds paid to a governmental or non-profit natural resources management organization. The operation and use of an in-lieu fee program are governed by an in-lieu fee program instrument thus differing from mitigation banks as well as allowing out of kind mitigation.

Mitigation bank: A site where wetlands, streams, or riparian areas are established, rehabilitated, enhanced, or preserved to offset authorized by the Department of Army permits.

Mitigation hierarchy: Allowing a harmful activity or project and compensating said impacts through offsetting is only permitted after following the previous steps in the mitigation hierarchy, avoidance, minimization, and restoration or rehabilitation.

No Net Loss (NNL): Providing mitigation or compensation measures that are equal to or outweigh the harmful impact exerted by a development project or anthropogenic activity.

Offset: Physical area or measures meant to mitigate and compensate for approved negative impacts. Offset gains can be "in-kind", meaning similar to what is lost or "out-of-kind".

RIBITS: Regulatory In-Lieu Fee and Banking Information Tracking System where bank reports and credit transactions are uploaded and stored in a centralized database for the United States covering mitigation, conservation, and umbrella banks as well as ILFs.

Service area: Area in which the bank can legally sell their credits that are used as offset requirements for development projects.

Umbrella bank: One banking instrument that dictates general requirements for an array of current and future sites (e.g., management and oversight of individual site plans to add future sites to the program). Can be mitigation or conservation banks.

Water stress: Ratio of total withdrawals to total renewable supply in a watershed based on water use and competition.