Recovery Potential Metrics
Summary Form

Indicator Name: INVASIVE SPECIES RISK

Type: Stressor Exposure

Rationale/Relevance to Recovery Potential: Non-indigenous species (NIS) invasions are widely known to disrupt aquatic system function and inhibit recovery of altered systems. The rapid colonization typical of NIS may act to subvert expected succession pathways and thereby disrupt restoration planning. Altered structure due to aquatic or riparian NIS can reduce shade, inhibit native riparian vegetation cover, and increase sedimentation. Aquatic invaders may compete directly or prey upon key native species, reduce numbers or species diversity, and markedly alter food webs and ecological structure. Presence of aquatic or riparian NIS may actually be the impairment cause for listing, and recovery in such cases depends on eradication or control. Particularly relevant to recovery potential screening is the fact that some NIS, once established, cannot currently be controlled or eradicated by any known methods. See literature excerpts below for more effects.

How Measured: In recovery potential screening, this metric may consider existing invasions or the risk of future invasions, or both. Many options for scoring can be developed, based on the state. An example quantile scoring process is:

- 0 – no established NIS of concern, no immediate risk
- 1 – no established NIS of concern, risk due to proximity or other vulnerability
- 2 -- established NIS of concern exists, control or eradication feasible
- 3 – established NIS of concern exists, control or eradication infeasible

This scoring approach can be customized for NIS species-specific rankings, direct influence on prospects of reattaining the unmet water quality standard, or to consider multiple NIS problems per waterbody. If detailed data are limited, simple presence/absence of NIS can be used.

Geo-Spatial Data Source: Data availability may be through waterbody-specific monitoring information on occurrence, such as the USGS Non-Indigenous Aquatic Species Information Resource (See: http://nas.er.usgs.gov/default.aspx) or through Non-Indigenous Species Database Network range maps by species (See: http://www.nisbase.org/nisbase/index.jsp) which include a variety of participating databases. The USDA National Invasive Species Information Center also contains links to several databases (See: http://www.invasivespeciesinfo.gov/resources/databases.shtml). Availability of either is highly variable and difficult to update under rapid changes.

Indicator Status (check one or more)

_______ Developmental concept.
___x__ Plausible relationship to recovery.
_______ Single documentation in literature or practice.
___x__ Multiple documentation in literature or practice.
_______ Quantification.

Comments: Operational but frequently data-limited by not having sufficient data for all waters being compared. Even with partial datasets, knowledge of the extremes (no NIS, established NIS with no known control) can be strong drivers of recovery potential and particularly important for evaluating good or bad restoration prospects. Nationally applicable to all water types, although highly variable geographically with regard to NIS species of concern and type of risks. Needs to be tailored to single-state or potentially sub-state scales for effective use.

Supporting Literature (abbrev. citations and points made):

- (Lake et al., 2007)Threats to successful restoration from exotic species may require the introduction of barriers to segregate and protect native species thereby reducing longitudinal connectivity (601).
- (Lake, et al. 2007) Human-induced disturbances, such as riparian clearing, nutrient enrichment or the introduction of non-native species all have the ability to change food web structure and thus modify community composition (602).
- (Lake et al., 2007) An additional factor potentially affecting trajectories of recovery in many restoration projects is the impact of invasive species, which may act to subvert expected succession pathways. For example, in southern Australia, succession of riparian vegetation may be blocked by fast-growing invaders, such as blackberries (Rubus spp.) and Reed Sweetgrass [Glyceria maxima (Hartm.) Holmb.], the latter of which may act as an ecosystem engineer by creating major changes in sedimentation in addition to nutrient dynamics (Clarke, Lake & O'Dowd, 2004). In south-western U.S.A., saltcedar (Tamarix ramosissima Ledeb) is an active invader that reduces native riparian cover (Busch & Smith, 1995) and thus alters stream ecosystem processes such as organic matter breakdown (Kennedy & Hobbie, 2004). Similarly, 'swampers' (space monopolisers) such as the New Zealand mud snail (Potamopyrgus antipodarum Gray; Schreiber, Quinn & Lake, 2003) or the zebra mussel (Dreissena polymorpha Pallas; Strayer et al., 1999) may result in a benthic community in 'restored' streams being very different from that made up of the original native species. The impact of invasive species on restoration need not be a passive one. For example, up until quite recently in Australia, with the aim of 'restoring' riparian zones, non-native willows (Salix sp.) were actively planted within riparian zones, with a variety of detrimental impacts on riparian and instream ecosystem processes (Read & Barmuta, 1999; Greenwood, O'Dowd & Lake, 2004) (606).
- (Poiani et al., 2000) For purposes of biodiversity conservation, functionality or integrity of a conservation area can perhaps best be judged by the extent to which the composition and structure of the focal ecosystems and species are within their natural ranges of variability. Even for conservation areas with intact or nearly intact ecological processes, conservationists should not assume that focal ecosystems and species are compositionally and structurally intact. For example, invasive non-native species can displace natives, completely altering ecosystem composition, while general ecological processes such as fire and flood are still maintained. In addition, preliminary evidence shows that compositional and structural integrity may be critical in maintaining internal stability, productivity, and resilience of the ecosystem itself (e.g. Johnson et al. 1996, Naeem 1998) (138).
- (Rahel 2007) One consequence of human-aided breaching of biogeographic barriers has been the spread of noxious species that have altered aquatic ecosystems and fisheries in ways that are undesirable to humans (696).
- (Rahel 2007) Another consequence of human-aided breaching of biogeographic barriers has been the homogenization of aquatic biotas. Homogenization occurs when a few cosmopolitan species come to dominate communities at the expense of unique native species (696).
- (Rahel 2007) The circumvention of biogeographic barriers promotes homogenization of aquatic biota. Homogenization refers to the increased similarity of biota over time and is typically the result of displacement of native species by a small set of non-indigenous species that have been widely introduced through human actions (Rahel, 2004). These cosmopolitan species bring sameness to faunas that were historically unique because of biogeographic isolation (McKinney & Lockwood, 1999) (701).
- (Light and Marchetti 2007) Many of California's native populations of freshwater fish are in serious decline, as are freshwater faunas worldwide. Habitat loss and alteration, hydrologic modification, water pollution, and invasions have been identified as major drivers of these losses (434).

- (Light and Marchetti 2007) Hydrologic modification (impoundments and diversions), invasions, and proportion of developed land were all predictive of the number of extinct and at-risk native fishes in California watersheds in the AIC analysis (434).
- (Light and Marchetti 2007) Our results suggest that, for California freshwater fishes, invasions are the primary direct driver of extinctions and population declines, whereas the most damaging effect of habitat alteration is the tendency of altered habitats to support nonindigenous fishes (434).
- (Light and Marchetti 2007) Nonindigenous species invasions are commonly cited as the number two cause, after habitat alteration, of biodiversity loss (e.g., Vitousek et al. 1996; Mack et al. 2000; Ricciardi 2004). This one–two ranking of habitat alteration and invasions has been repeated so often that it has entered the abbreviated canon of conservation biology taught in introductory biology and environmental science classes (e.g., Wright 2005; Campbell & Reece 2005) (435).
- (Light and Marchetti 2007) In a survey of fishes considered extinct, declining, or endangered in California, Moyle and Williams (1990) identified water diversions as the principal cause, followed closely by introduced species and other forms of habitat modification and more distantly by pollution and overexploitation. Similarly, habitat alteration is the most commonly cited cause of fish extinctions throughout North America (73%), followed by introductions (68%) (Miller et al. 1989) (435).
- (Light and Marchetti 2007) Fish species richness and species composition in California watersheds have been markedly altered over the last 150 years by both invasions and extinctions, and these alterations were associated with many forms of watershed alteration, including development, agriculture, and hydrologic alteration (Table 2) (439).
- (Light and Marchetti 2007) Diversity loss among California freshwater fishes was strongly associated with the extent of invasions, hydrologic modification, and land-use disturbance (442).
- (Light and Marchetti 2007) The regression analysis gave nearly equal importance to hydrologic modifications (as a group) and invasions as predictors. In contrast, the path analysis identified invasions as the key direct driver of native fish declines and extinctions (442).
- (Light and Marchetti 2007) The most parsimonious path model was the driver model, which included no direct effect of either hydrologic modification or land disturbance on native fish declines. Instead, it indicated that the overall association of both variables with native fish declines was due to indirect effects via fish invasions and other correlated factors, such as watershed area and native diversity (442).
- (Light and Marchetti 2007) Some particularly well-documented cases in California support the idea that modified habitats frequently continue to support native species in the absence of invasions. For example, many mid-elevation reservoirs of the Central Valley contained abundant native Sacramento suckers (Catostomus occidentalis), Sacramento pikeminnow(Ptychocheilus grandis), and hardhead (Mylopharodon concephalus) for the first few years after filling. As non-native fishes, especially centrarchid basses, were introduced and became abundant, recruitment of pikeminnowand hardhead declined, and theywere eventually extirpated (though typically they have maintained populations in streams where these are not too altered by reservoir operations) (442).
- (Light and Marchetti 2007) Nevertheless, the more common pattern, at least in California, is the dominance of altered habitats by introduced fishes—including large predators such as the black basses (Micropterus spp.), intermediate predators such as sunfishes (Lepomis spp.) and crappies (Pomoxis spp.), and introduced forage fishes such as golden shiner (Notemigonus crysoleucas) and threadfin shad (Dorosoma petenense)—and the subsequent limitation of native fishes to less-altered stream reaches (when these remain), where few introduced fishes can maintain large populations (Baltz & Moyle 1993; Moyle 2002) (442-443).
- (Light and Marchetti 2007) Although these losses have had major ecological and economic impacts, they are dwarfed in sheer numbers by declines and extinctions that are associated at least in part with invasions (Moyle 2002; this analysis) (443).

- (Light and Marchetti 2007) According to the surveys of resource managers and other experts, exotic invasions top the list of threats to western aquatic species, whereas eastern species are most threatened by altered sediment loads and nutrient pollution, threats that were rarely mentioned forwestern species (Richter et al. 1997) (443).
- (Light and Marchetti 2007) Where restoration alone cannot reduce populations of invasive species, serious consideration should be given to aggressive eradication efforts, coupled with education and legislation designed to prevent or at least slow the rate of new introductions. Eradicating established nonindigenous species, however, is generally feasible only at the earliest invasion stages and/or over a small geographic area (Drake & Naiman 2000; Saunders et al. 2002; Simberloff 2003). In aquatic systems eradication attempts have typically used nonselective poisons, particularly the piscicide rotenone, which is increasingly running afoul of public concerns about impacts on drinking water safety, nontarget biodiversity issues, conservation values, and managed sport fisheries (e.g., eradication efforts for northern pike [*Esox lucius*] in California, Moyle 2002). The generally low success, high expense, and unpopularity of eradication efforts suggest that preventing further invasions should be a high priority to conservation (Saunders et al. 2002). Analyses that have considered the economic costs of invasions versus the cost of prevention have also made this point (e.g., Mack et al. 2000; Leung et al. 2002) (444).
- (Gregory et al., 2002) Projections of geomorphic and hydrologic changes are not simple and will vary greatly based on local landscapes and climate. Ecological interactions are complex because of the interactions between adjacent terrestrial and aquatic ecosystems, predator–prey interactions, competition, succession, and dispersal of aquatic and terrestrial organisms. Even more complex is the array of social actions in river systems that dictate ecological responses, such as hydrologic alteration, water diversion, bank hardening, land use conversion, exotic species introductions, and water quality impairment (721).
- (Han et al., 2008) The invasion of non-native fish species has led to the decline of native fish populations, the extinction of native fish species, and the so-called biotic homogenization, i.e., the replacement of endemic native species with widespread exotic species (Gido & Brown 1999; Olden & Poff 2004; Marchetti et al. 2006; McKinney 2006; Smith 2006; Light & Marchetti 2007) (1).
- (Paul and Meyer 2001) Introduced fish species are also a common feature of urban streams. As a result of channelization, other river transportation modifications, and voluntary fisheries efforts in the Seine around Paris, 19 exotic species have been introduced, while 7 of 27 native species have been extirpated (Boet et al. 1999). The red shiner (*Cyprinella lutrensis*), a Mississippi drainage species commonly used as a bait fish, has invaded urban tributaries of the Chattahoochee River in Atlanta, Georgia where it has displaced native species and now comprises up to 90% of the fish community (DeVivo 1995) (353).
- (Light and Marchetti 2007) The path analysis revealed strong and significant direct effects only of native richness and nonindigenous richness on fishes of conservation concern (Figs. 1a & 1c; Table 5) (441).
- (Light and Marchetti 2007) In the analysis of variable importance, native richness was the most important single predictor of number of fishes of conservation concern in a watershed, entering every highly ranked model. The variable nonindigenous richness was next in importance, followed by the variables aqueduct density and dams (Table 3). In the analysis of category importance, the cumulative rank of all models including water development variables (0.919) was the highest, followed closely by models including nonindigenous richness (0.811) and more distantly by models including land-use variables (0.187) (441).
- (Han et al., 2008) Although stocking reservoirs with alien or translocated fish species for recreational fishing has long been a pervasive human activity (Allan & Flecker 1993), lower reaches of rivers and streams below dams have also been invaded by a large number of nonnative fishes, especially in systems with high levels of human disturbance (Moyle & Light 1996). In such cases, dams, weirs and waterfalls can serve as barriers to

prevent the downstream non-native species from invading upstream reaches to protect endangered native species there (Townsend & Crowl 1991; Novinger & Rahel 2003). The possible linkage between dams and fish invasions can therefore be complex depending on fish species and mechanisms in the invasion process (2).

- (Morita and Yamamoto 2002) Exotic fishes approach just below the dams, turning dammed-off habitats into refuges for native fishes in some rivers (e.g. Takami et al. 2002). Therefore, managers should consider this potential benefit of dams before fish ladders are installed (1322).
- (Filipe et al., 2004) Once reserve areas have been selected, they must be integrated within a basin management approach to harmonize development opportunities and exploitation of aquatic resources (Meffe 2002). There is also a need for ecologists, conservationists, social scientists, and stakeholders to negotiate use rights (Cullen et al. 1999). In multinational water bodies, such as the Guadiana River basin, international collaboration is needed and all social, economic, and political constraints should be considered. Additionally, the establishment of discrete reserves is not enough to protect freshwater fishes (Angermeier 2000; Meffe 2002). Interventions upstream or downstream must be considered in the management of reserves because these activities could have implications for the species for which the reserve is designed (Cowx & Collares-Pereira 2002). In particular, the construction of a dam outside of the reserve network has implications for the recolonization of each reserve area because it may disrupt migration pathways. Similarly, the introduction of alien species elsewhere in the watershed may have long-term implications if the introduced species is able to disperse into the reserves. In our case study, the Alqueva and Pedrogao reservoirs will create unsuitable habitats for native fishes by affecting their movement and enhancing the populations of exotic species. In addition, the lack of facilities for fish passage around Alqueva has permanently isolated the populations upstream and downstream of the dam (197).
- (Palmer et al., 2005) We propose that the first step in river restoration should be articulation of a guiding image that describes the dynamic, ecologically healthy river that could exist at a given site. This image may be influenced by irrevocable changes to catchment hydrology and geomorphology, by permanent infrastructure on the floodplain and banks, or by introduced non-native species that cannot be removed. Rather than attempt to recreate unachievable or even unknown historical conditions, we argue for a more pragmatic approach in which the restoration goal should be to move the river towards the least degraded and most ecologically dynamic state possible, given the regional context (Middleton 1999; Choi 2004; Palmer *et al*. 2004; Suding, Gross & Housman 2004) (210).
- (Stanley and Doyle 2003) Because taking out dams creates “new” habitat, and because sediments are amenable to plant growth, dam removal may be a valuable tool for riparian restoration (Shafroth *et al*. 2002). However, widely available and often nutrient-rich sediment also represents prime habitat for invasion of weedy and exotic species that are generally considered undesirable (Shafroth *et al*. 2002). Observations of plant communities at several Wisconsin dam-removal sites show that species such as stinging nettle (*Urtica diocia*) and the invasive reed canary grass (*Phalaris arundinaceae*) are often abundant (CH Orr pers comm; Figure 5) (17).