British Columbia's Freshwater Fish, Species, and Ecosystems Are More at Risk and Less Protected

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ABSTRACT

Freshwater fish, other freshwater aquatic species, and freshwater ecosystems are not getting equal representation in conservation efforts in British Columbia compared to terrestrial species and ecosystems. They are much more often listed as at risk and Forest Dependent (FD) than any other taxonomic group and biogeographic or habitat type. This risk discrepancy is not addressed by protection under the British Columbia Forest Practices Code (FPC) or the British Columbia Protected Areas Strategy (PAS). Fish compose the highest proportion (one-third) of Red-listed (threatened or endangered) taxa, and 25% of these do not have proper taxonomic nomenclature. Sixty-seven percent of Red-listed fish have a global distribution of a single British Columbia water body, and a further 24% of Blue-listed (vulnerable or sensitive) and Red-listed fish are peripheral isolates. No commercial salmonid or other stocks are listed. Fish also have the highest percentage (82%) of taxa designated FD, which includes 35% of Red-listed fish. In contrast, less than 1% of FD fish taxa receive designated protection as Managed Identified Wildlife (MIW) under the FPC. Similarly, fish represent 25% of all vertebrates designated FD, but compose only 2% of the MIW listings for vertebrates. This protection presently amounts to a single fish species (bull trout), which is still likely inadequately covered by the standard MIW protective measure of a Wildlife Habitat Area (WHA), due to the inherent interconnectivity of watersheds. Without even considering commercial salmonids and fishes, there are at least 10 additional fish taxa strongly deserving forestry consideration. The PAS protects only (and often incidentally) 15% of Red-listed, 9% of Blue-listed, and 4% of FD fish taxa. About 14% of fish biodiversity "hotspots" are also protected. The PAS is based on conserving species through protection of the representative biogeoclimatic ecosections they live in. Ecosections (and WHAs) are a terrestrial concept and can have limited correspondence to the distribution of fish and aquatic biodiversity or their drainage basins. Fish and aquatic biodiversity are also uniquely composed of strong within-species variability resulting from both historical and ecological factors. Among fish, non-commercial or non-sport taxa are particularly poorly understood, with even basic taxonomic, ecological, and life-history information often not available. The management and conservation implications, which are substantial and immediate, are discussed in this paper. Equitable coordination of overall conservation is needed between aquatic and terrestrial biologists.

Key words: aquatic ecosystems, fish, Forest Practices Code, freshwater, Protected Areas Strategy, taxonomy.

The general public, and often even scientific, perception is that fish and aquatic species and ecosystems are receiving enough, or even too much, of the overall conservation effort and protection (McPhail 1993, Slaney et al. 1996, Haas 1998). This paper demonstrates that this is not the case, why it is not, and what might still be done about it. These points and the differences inherent to fish and aquatic ecosystem are analyzed through comparison to the other vertebrate taxonomic groups. The comparisons are based on:

1. Taxa Red-listed as threatened or endangered and Blue-listed as vulnerable or sensitive by the British Columbia Conservation Data Centre (CDC; Cannings and Ptolemy 1998, Smith 1998), and their global and provincial distributions in terms of limited occurrence.
2. Taxa designated as Forest Dependent (FD; Smith 1998), and other taxa worthy of consideration in terms of resource utilization impacts (e.g., Haas 1997*a*-*c*, 1998).
3. Protection under the British Columbia Protected Areas Strategy (PAS; Land Use Coordination Office 1999), Ecological Reserve System (B.C. MELP 1999*a*), and British Columbia Forest Practices Code (FPC; Forest Practices Code 1995, Haas 1998, B.C. MELP 1999*b*).
4. A preliminary examination from an aquatic perspective of

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the utility of the biogeoclimatic terrestrial ecoprovinces and ecosections, which form the basis of the PAS (Land Use Coordination Office 1999). This is done in light of major drainage connections, their composite watershed groupings, aquatic biodiversity "hotspots," and the connectivity of aquatic systems.

5. A related examination of the unique patterns and magnitude of within-species variability in fish and aquatic species and ecosystems. In aquatic species, this variability is formed both by historical features largely corresponding to the last glacial period (10,000–15,000 years ago) and by ecological factors since then (McPhail and Carveth 1993*a*, Haas 1998).
6. Fundamental conservation and management knowledge about taxonomy, identification, ecology, and life-history (McPhail and Carveth 1993*a*, Haas 1998). This is also briefly examined from the viewpoint of commercial/sport versus non-commercial/non-sport fish taxa.
7. Recommendations for addressing these disparities, and for the conservation and management of fish and aquatic species and ecosystems, as well as general conservation and management (McPhail and Carveth 1993*a*, Haas 1998).

METHODS AND STUDY AREA

Overview analyses of the state of conservation, protection, and protected areas for freshwater fish, other freshwater aquatic species, and freshwater ecosystems throughout British Columbia were largely based on the latest data from Haas (1998) and that appreciatively made available in Cannings and Ptolemy (1998) and Smith (1998). The updated PAS and Ecological Reserve System information kindly came from D. Biffard (Parks Branch, B.C. Ministry of Environment, Lands and Parks). Additional information on these data are available at the web sites of the British Columbia Land Use Coordination Office (http://www.luco.gov.bc.ca), and the British Columbia Ministries of Environment, Lands and Parks (http://www.env.gov.bc.ca.), Fisheries (http://www.fisheries.gov.bc.ca), and Forests (http://www.for.gov.bc.ca.). All interpretation of this data and responsibility for it are nonetheless my own.

These data and analyses are specific to freshwater and anadromous fish in British Columbia. However, the interpretations and implications extend to freshwater fish, species, and ecosystems in at least the Pacific regions of western North America (e.g., Waples 1995, Allendorf et al. 1997), particularly in jurisdictions where parallels exist to the factors discussed here for British Columbia. These factors include poor or incomplete taxonomy and inventory, protected areas based on terrestrial ecosection or biogeoclimatic zone, and strong commercial- or sport-fish species biases and databases.

RESULTS

RISKS

Red-listed Species

Of the vertebrate taxonomic groups designated and tracked by the Conservation Data Centre, fish compose the highest proportion of Red-listed taxa. Approximately one-third (32%) of freshwater fish taxa in British Columbia are Red-listed (Fig. 1). This ratio is about 10% higher than for reptiles (23%) or amphibians (22%), which constitute the taxonomic groups with the next highest proportions of Red-listed taxa. The combined total for all Red-listed non-fish vertebrates is only 9%. Fish also have proportionately more Red-listed taxa than non-vertebrate organisms such as plants. The term "taxa" is used as a species surrogate throughout this paper due to incomplete taxonomies and to remain consistent with its use in these listings by the CDC (Cannings and Ptolemy 1998) .

Forest Dependency

Forest Dependent taxa are defined as those with a high to medium dependence on forests (full definitions and listings in Smith 1998). Fish compose the highest percentage (82%) of taxa that are officially designated as FD (Fig. 2; Smith 1998), and, of the taxonomic groups designated by the CDC, have the highest proportion of Red-listed taxa that are FD. Thirty-five percent of the Red-listed freshwater fish in British Columbia are FD. This ratio is 20% higher than for amphibians, which are the taxonomic group with the next highest proportion of FD Red-listed taxa (15%). The combined total for all non-fish vertebrates is only 7%, with all other taxonomic groups at similar percentage levels. For animals, only vertebrate taxa could be examined since to my knowledge there are no good overall data on invertebrates (but for an examination see Scudder 1996). Plants could not be included in this analytical comparison since the numbers summarized here and by Smith (1998) were for vertebrates only.

PROTECTION

Forest Practices Code

The percentage of Forest Dependent fish taxa (Smith 1998) that receive particular protection under the FPC as Managed Identified Wildlife (MIW; B.C. MELP 1999*b*) is <1% (Fig. 3). This protection is for a single fish species, bull trout (*Salvelinus confluentus*). Only 2% of the total number of vertebrates listed as MIW are fish. Yet, 25% of all the vertebrate taxa officially designated as FD are fish. There are also more fish taxa listed as FD (69) than the total number of vertebrates listed as MIW (43).

Reptiles and amphibians are the only taxonomic categories that have more FD taxa listed as MIW under the Forest Practices Code than their proportional composition in the total number of vertebrates listed by the CDC (Cannings and Ptolemy 1998, Smith 1998, Cannings et al. 1999): 9% of all

CDC-listed vertebrates are reptiles and 2% are amphibians, yet the proportion of FD taxa listed as MIW is 100% for reptiles and 8% for amphibians.

Reptiles and amphibians also have more taxa designated as MIW than their proportions of the total FD vertebrate taxa. One percent of the total number of FD vertebrate taxa are reptiles and 5% are amphibians.

The other 2 non-fish vertebrate taxonomic groups, mammals and birds, also have high proportions of taxa designated as MIW in comparison to their proportions of the total FD vertebrate taxa. Mammalian taxa compose 22%, and bird taxa 47%, of all FD vertebrate taxa, yet 37% of mammals and 49% of birds are designated as MIW. Mammals also have somewhat more FD taxa listed as MIW under the FPC (26%) than their proportional composition of the total number of FD vertebrates (22%).

The combined non-fish vertebrate taxa compose 75% of FD vertebrate taxa, but 98% of all vertebrate taxa listed as MIW are non-fish vertebrates. Nevertheless, only 20% of all non-fish vertebrate taxa designated as FD are listed as MIW in the FPC. This percentage demonstrates another recurring theme, which is that no vertebrate groups except reptiles are receiving MIW protection under the FPC that is concomitant with their respective numbers of FD taxa. This situation and disproportion are worst in fish and in aquatic species and ecosystems.

Protected Areas Strategy

The Protected Areas Strategy for British Columbia incorporates populations of about 15% of Red-listed fish taxa at some level (Fig. 4). Only 9% of the Blue-listed fish taxa and 4% of the Forest Dependent fish taxa are in these areas. Fourteen percent of particular "hotspots" for fish and aquatic biodiversity (Haas 1998) are covered by protected areas at least in some way. Most of the incorporation of fish and aquatic biodiversity in these cases is incidental (Haas unpubl. data).

The PAS is based on a biogeoclimatic concept called ecosections (Demarchi 1995, also see Smith 1998, Land Use Coordination Office 1999). The ecosections are ecologically defined terrestrial regions with borders delineated by climate and physiographic features (Figs. 6–7). These ecosections can have limited correspondence to the distribution of fish and aquatic biodiversity in terms of their "hotspots," Red- and Blue-listed taxa (Fig. 4), or occupied drainages (Fig. 5). Many of the actual protected areas (Fig. 4) and the ecosections with more area protected (Fig. 6) are at higher

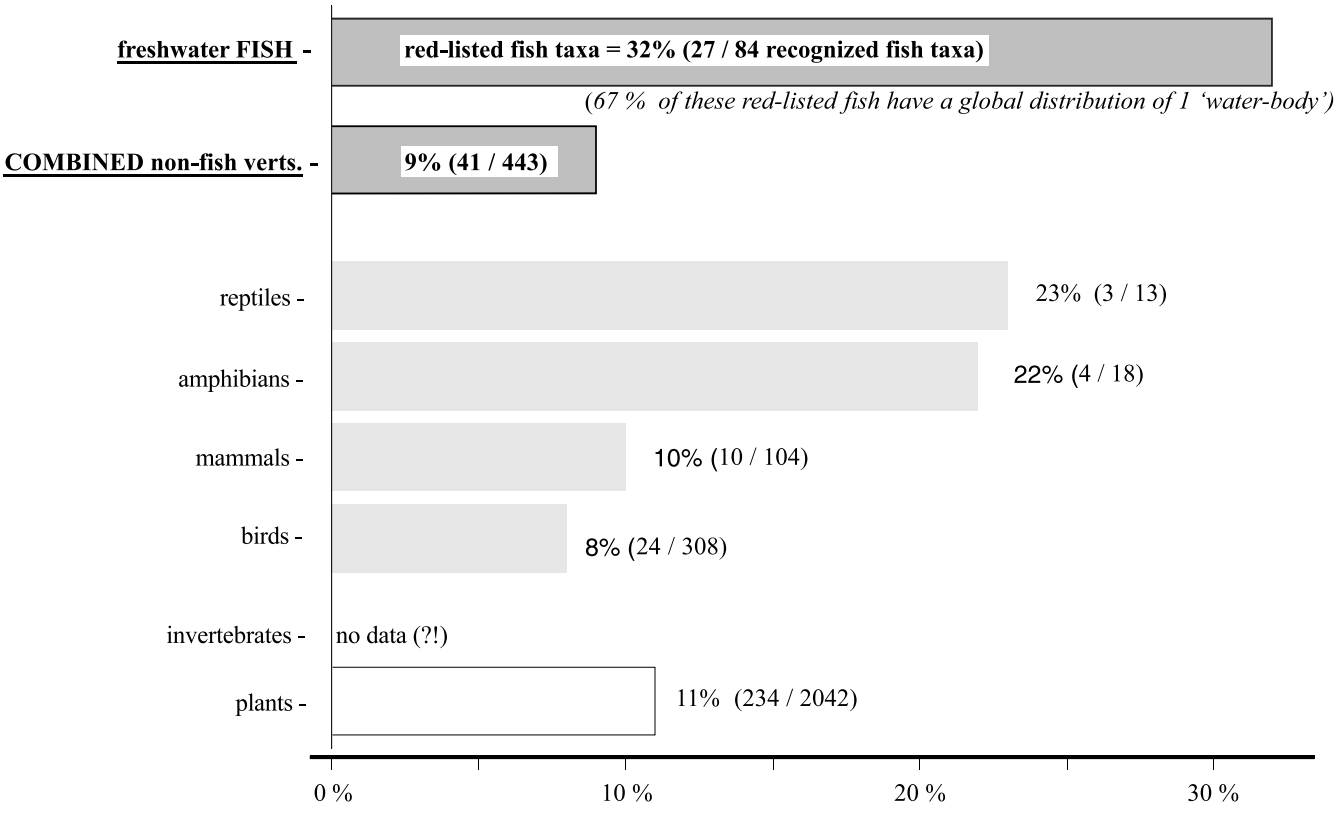

Figure 1. Percentages and numbers of Red-listed fish taxa compared to other non-fish vertebrate taxa and non-vertebrate taxa. Modified from Smith (1998). The term "taxa" is used as a surrogate for "species" due to incomplete taxonomies.

elevations (Fig. 7) than those at which many fish taxa occur. The relationship of the ecosections to the major overall drainage basins and their component watershed groups (B.C. MELP 1999*a*,*b*) is also not very strong (Fig. 5). This weak ecosection relationship is also the case with the post-glacial recolonizations and temporary drainage connections (Fig. 8) that structure most of the recent historical biodiversity and taxa in fish and in aquatic species and ecosystems.

DISCUSSION

Risks

The general public, and often even scientific, perception that fish and aquatic species and ecosystems are receiving enough, or even too much, of the overall conservation efforts and protection is not correct (McPhail 1993, Slaney et al. 1996, Haas 1998). Freshwater fish are at much more risk than any other taxonomic group designated and tracked by the CDC. These high risks are for Red-listed taxa (Fig. 1) and those designated as Forest Dependent (Figs. 1–2). The disproportionately higher risk for fish and for aquatic species and ecosystems is not matched by protection for them. Fish are inadequately represented under and within the Managed Identified Wildlife provision in the Forest Practices Code, which is skewed towards the other non-fish vertebrate taxonomic groups (Fig. 3). Fish and aquatic protection are also not well incorporated in the Protected Areas Strategy (Fig. 4), which has a similar terrestrial bias.

Protection

Forest Dependency and the Forest Practices Code

The FPC uses the Managed Identified Wildlife provision for "taxa that will not be adequately maintained through application of the Biodiversity and Riparian Management Area Guidebooks" (Forest Practices Code 1995, B.C. MELP 1999*b*). Forty-three vertebrate taxa presently have MIW status, while 282 vertebrate taxa are considered Forest Dependent (Smith 1998). This results in 15% of FD vertebrate taxa receiving MIW listing (Fig. 3). There would seem to be at least some shortfall in the MIW listings for vertebrates in general, even if some FD species are adequately protected by the FPC without MIW status. This situation is worst for fish, of which only 1 species, bull trout, is listed as MIW. Without accounting for commercial salmonids (e.g., Slaney et al. 1996), there are a minimum of 10 additional fish species that can be strongly argued as warranting special forestry consideration, and more fish taxa are likely candidates too (Haas 1998).

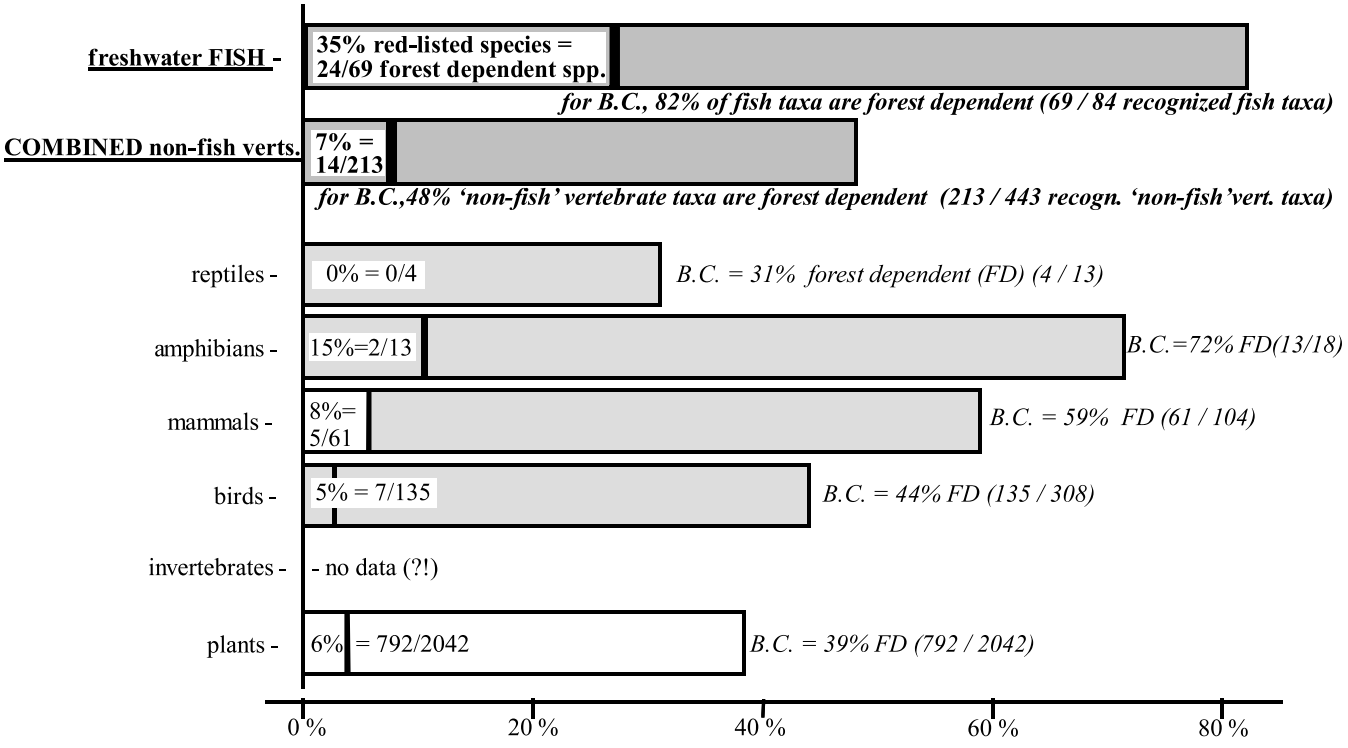

Figure 2. Percentages and numbers of Forest Dependent fish taxa compared to other non-fish vertebrate taxa and non-vertebrate taxa. Modified from, and using forest dependency data from, Smith (1998). The term "taxa" is used as a surrogate for "species" due to incomplete taxonomies.

A difficulty under the FPC is that the listing of more fish taxa as MIW is likely to result in unacceptable impacts (fixed as >1 %) on the Annual Allowable Cut (AAC) in forest harvesting in British Columbia (B.C. MELP 1999*b*). An example of attempting to deal with this is the situation where 3 additional fish species were submitted for consideration as MIW with provisions for limiting impacts on the AAC worked into their accounts (Haas 1997*a-c*). These limiting provisions may be legitimate in accommodating both biological and economic considerations, but, as a result, all populations will not necessarily receive the best protection under the FPC that is generally accorded other MIW vertebrates. These 3, and likely other, fish taxa submissions are presently being reconsidered under the FPC (S. Rautio, B.C. Ministry of Environment, Lands and Parks, Wildlife Section, pers. comm.).

A further limitation is that the present mainstay of MIW protection is the establishment of Wildlife Habitat Areas (WHAs; Forest Practices Code 1995, B.C. MELP 1999*b*). These WHAs involve setting aside critical and often smaller habitat areas for specific life-history stages or important events such as breeding locations. However, the WHAs may not work well for aquatic systems and taxa since they do not account for the interconnectivity of streams, which occurs at least at some scale (e.g., Hartman and Scrivener 1990, Stanford and Ward 1993, Reid 1998). Preserving small areas in watersheds may simply be insufficient, since anything happening upstream in a watershed is probably destined to affect it downstream, and downstream impacts can also prevent access, etc. to upstream sites.

To be fair, the FPC upon establishment was apparently designed to protect salmonid fishes (Dr. A. Tautz, B.C. Ministry of Fisheries, Research Section, pers. comm.) through its inherent riparian provisions (Forest Practices Code 1995). At present, and based on this and other analyses and expert opinions in British Columbia and elsewhere (e.g., Coats and Miller 1981, Stanford and Ward 1992, Frissell and Bayles

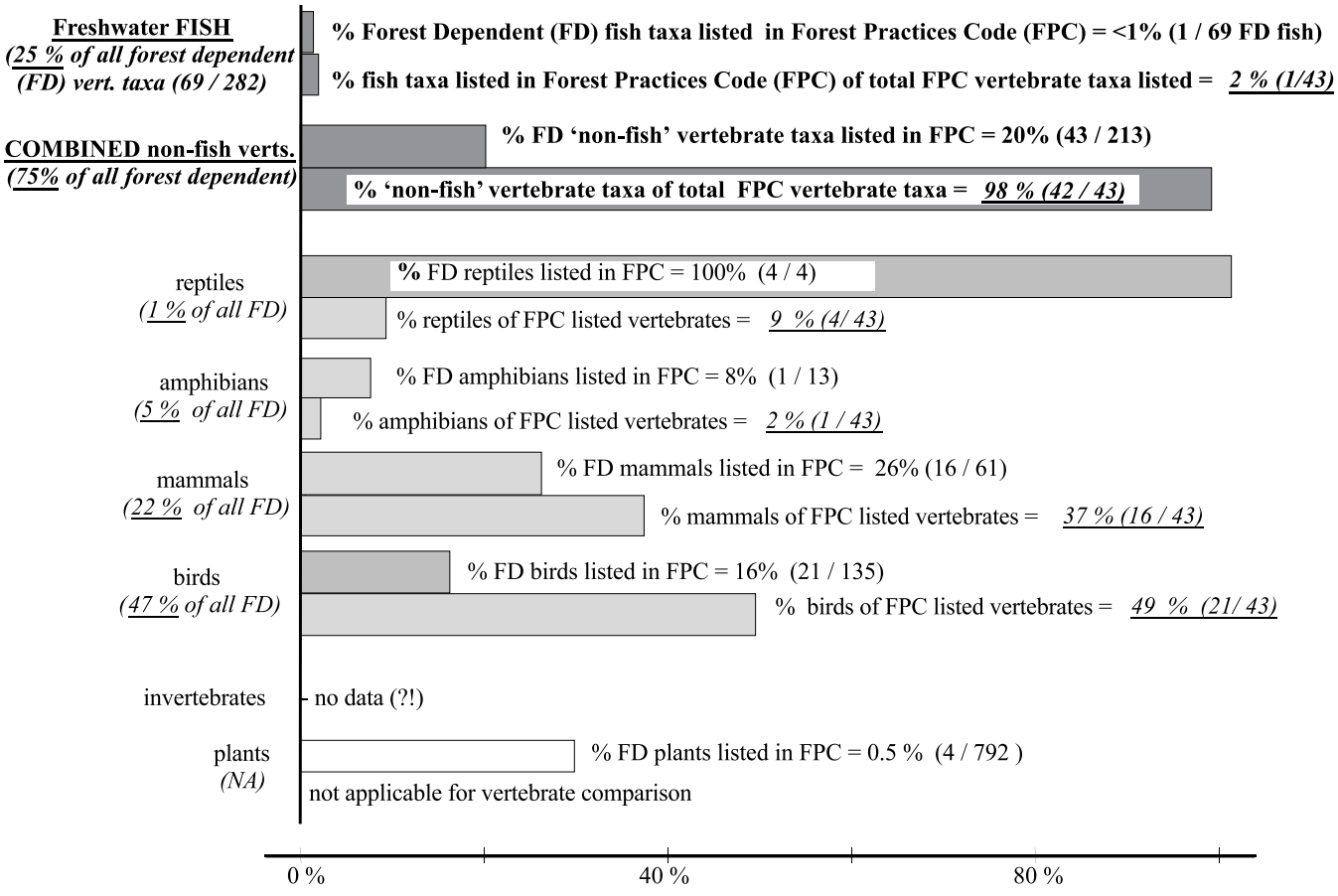

Figure 3. The first row in each histogram pair shows the percentage and number of Forest Dependent (FD) taxa that are listed in the British Columbia Forest Practices Code (FPC). The second row compares the number of taxa in that category to the combined total number of vertebrate taxa (43) listed in the FPC, with the percentage of each category compared to all FD vertebrate taxa (282) on the y-axis. Data from Smith (1998).

1996), riparian protection alone does not appear to be fully working. Fish and aquatic species and ecosystems need further, specific consideration. Outside of the often limited assistance of MIW provisions, the only present alternative options under the FPC are "general wildlife measures" (GWMs) outside of WHAs (B.C. MELP 1999*b*) and "higher level planning" within Land and Resource Management Plans (LRMPs; Land Use Coordination Office 1993, 1997, 1999; B.C. Ministry of Forests 1996).

GWMs have not yet been used for any MIW taxa. There again are concerns about their likely higher impact on the AAC. GWMs can partially or entirely limit any forest practice as defined under the FPC. This includes such things as road construction, road maintenance, grazing, haying, and timber harvesting, which are categorized under the following headings: access, range, recreation, restoration and enhancement, and silviculture. Once GWMs are approved, they, too, are legally binding.

LRMPs have been worked on in many regions of British Columbia, and provincial level strategies have even been enacted for such large-ranging, charismatic species as grizzly bears (*Ursus arctos horribilis*; B.C. MELP 1995). LRMPs attempt to consider all resource values and require public participation, interagency coordination, and consensus-based land and resource management decisions. LRMPs cover subregional areas of approximately 15,000–25,000 square kilometres. The plans try to establish direction for land use and specify resource management objectives and strategies. They work toward a comprehensive, accepted, and approved management framework to guide resource development and more detailed planning. In general, they have usually not yet fully addressed fish and aquatic species and systems. Future use of higher level planning within LRMPs to help protect these should be examined. Such procedures may be a key component for aquatic ecosystem protection given the limitations of, and the 1% impact cap on the AAC by MIW provisions.

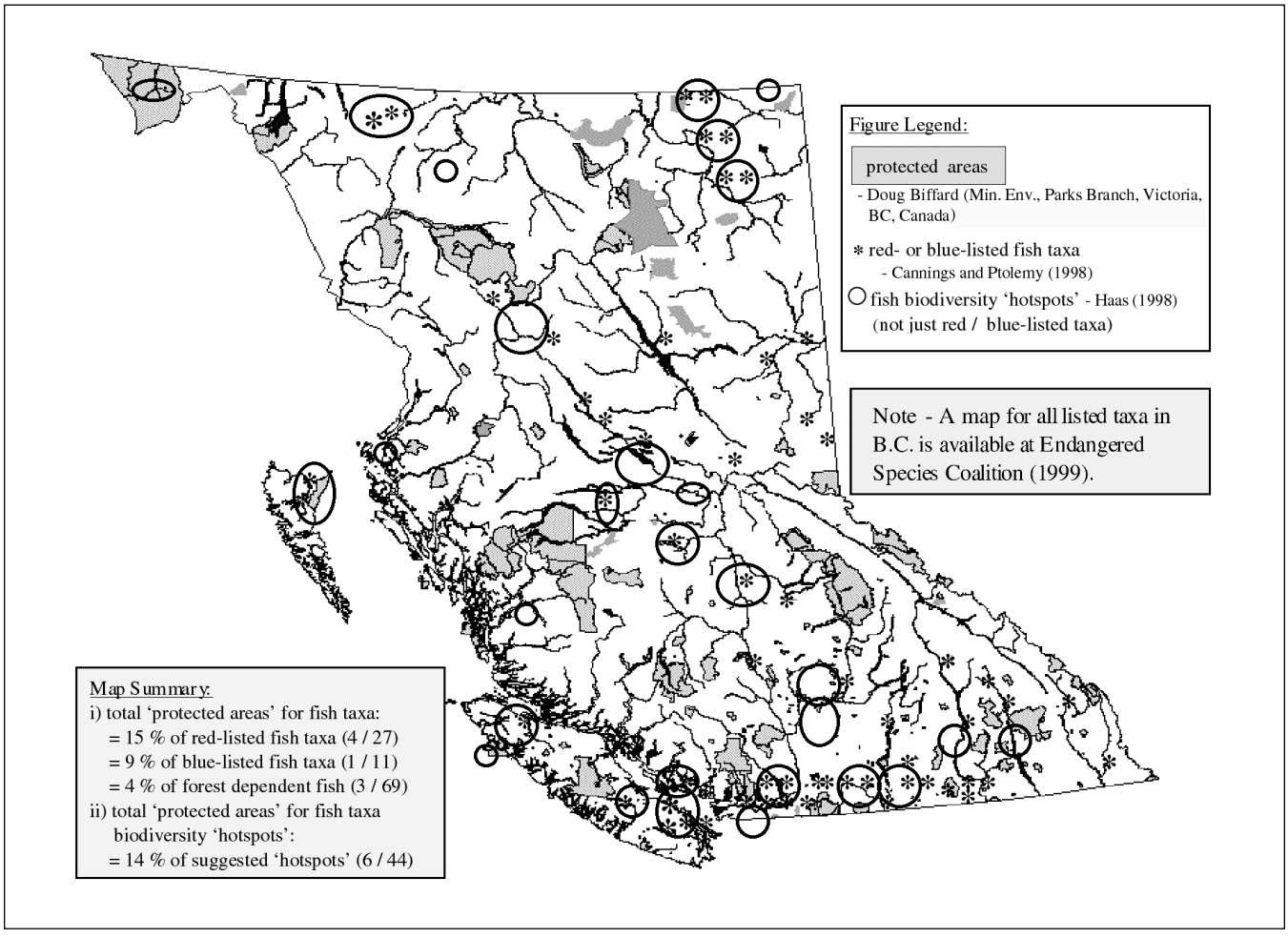

Figure 4. The British Columbia Protected Areas Strategy in relation to the distribution of Red- and Blue-listed fish taxa, and fish biodiversity hotspots.

Furthermore, such higher level planning might work beyond the 12% protected areas and encourage necessary conservation within the entire province, its working economy, and even non-endangered or non-listed taxa (in British Columbia, often termed "yellow-listed" taxa).

Protected Areas Strategy

The key objective of the Protected Areas Strategy in British Columbia is to increase representation and protection of ecosections (Land Use Coordination Office 1999). This means the preservation of enough of all ecosystem types of distinct biogeoclimatic zones that are composed of geological, climate, and vegetation features (Fig. 6). By doing this, it is anticipated that most species utilizing these distinct habitat regions will be coincidentally protected (e.g., Smith 1998). However, many ecoprovinces and ecosections can have little relation to important features of aquatic ecosystem and species (Fig. 5; Frissell 1993, Hitt and Frissell 1999, Newall and Magnuson 1999). What is important to fish and aquatic systems are overall drainage basins, distinct watershed groupings, isolated populations, aquatic habitat, and fish taxa distributions and composition, both at present and historically (e.g., McPhail and Carveth 1993*a*, Haas 1998). These important "aquatic ecosections" are not necessarily represented by the terrestrial-based biogeoclimatic ecosection or zone concept (Figs. 5–7).

Habitat protection for fish biodiversity might work in some cases within "complete" protected areas, given that 18 of the 27 Red-listed freshwater fish taxa (Cannings and Ptolemy 1998) have a global distribution of a single British Columbia site (Haas 1998). This means that 67% of British Columbia's Red-listed freshwater fish taxa are found globally in only 1 water body in British Columbia (Fig. 4; Endangered Species Coalition 1999), although several of these water bodies are quite large for complete protection (Cannings and Ptolemy 1998, Haas 1998). As well, 9 of the 38 Red- or Blue-listed taxa are peripheral isolates occurring in disjunct distributions or at the edge of the range for that taxon (Haas 1998). This means that 24% of these listed fish taxa are found in British Columbia in only 1 water body, but that these species have a larger distribution outside of the province. Peripheral isolates can nonetheless be interesting and important since they may be subject to distinct evolutionary or ecological forces, because they are somewhat or wholly separated from the rest of their taxon and are at the limits of their range (Scudder 1989, McPhail and Carveth 1993*a*, Haas 1998). Also, if the jurisdictional, and not just biological, range of a species is important, then these peripheral isolate fish taxa do occur in only 1 water body in British Columbia. As a combined total, 71% of the Red- and Blue-listed freshwater fish taxa in British Columbia are only found in 1 water body here.

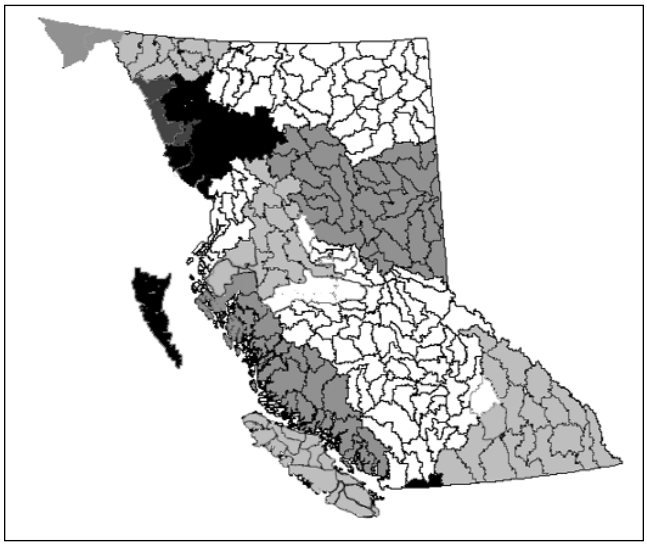

Figure 5. British Columbia's 246 distinct watershed groups (B.C. MELP 1999*a*,*b*), with their major overall drainage basins highlighted.

Such single-site patterns could also receive alternative protection under the Ecological Reserve System in British Columbia (B.C. MELP 1999*a*), but so far only 2 of all the ecological reserves (2 of approx 136, or 1.5%) were specifically set aside for fish. A difficulty with protecting fish and aquatic species and ecosystems in ecological reserves is that watersheds are interconnected. Preserving small areas in watersheds may be insufficient, and this must be anticipated in the planning of ecological reserves and protected areas, and assessment of resource utilization impacts (e.g., Haas 1998). The unique fish taxa found in some smaller isolated lakes in British Columbia may be the best candidates for preservation under such protection systems. The danger that remains in even these cases is the introduction of exotic fish species that can and have wiped out entire fish taxa (Cannings and Ptolemy 1998, Haas 1998). This threat of unauthorized exotic species introductions must be considered (McPhail and Carveth 1993*a*, Ricciardi and Rasmussen 1998), but admittedly is likely hard to address.

Another aspect of many protected areas is that they were previously set aside for scenic vistas and are often located at higher altitudes (Figs. 4, 6, and 7). These protected areas were created more for recreation than conservation. This lack of utility of protected areas for conservation is particularly true for biodiversity in fish and aquatic species and ecosystems, which are generally best represented at lower elevations in larger drainages (McPhail and Carveth 1993*a*,*b*; Sparks 1995; Haas 1998; Newall and Magnuson 1999). These lower elevation habitats have received little protection and the most human impact. Much of this land is in the valleys formed by water drainages, and is often already utilized, making it unsuitable or difficult for preservation.

In many instances, traditional parks also had increased access, use, and pressure on the ecosystems they were, in theory, protecting. Again, this is particularly true for fish and for aquatic species and ecosystems, since angling and water use are still permitted in most protected areas in British Columbia, in spite of this not being the case for other taxonomic groups of organisms (e.g., collection of plants and hunting are often prohibited). Furthermore, fish from outside the protected area's drainage were, and still are, stocked into their water bodies, in some cases even introducing exotic fish species not native to British Columbia. Fish stocking in watersheds, with portions fishless or not, also has had considerable impacts on aquatic taxa and their ecosystems (e.g., Dill and Cordone 1997). Many national parks in British Columbia (Parks Canada 1999) also had their own angling regulations under federal jurisdiction and these often were more lax. A final and key consideration is that the laudable goal of the PAS is to preserve 12% of British Columbia's land base. With 10–11% already set aside (Smith 1998), and with disproportionately very few fish protected, this strategy should consider immediate and strong aquatic representation.

Other Related Important Issues

Taxonomy and Identification

Another key unaddressed conservation issue is taxonomy. The term "taxa" is used instead of "species" by the CDC since the number of taxa it recognizes is its legitimate best estimate (but not necessarily universally accepted). For instance, Haas (1998) lists 6 other fish taxa/species not presently recognized and at least 10 more taxonomic problems within recognized taxa that may further increase the number of fish species in British Columbia. Emphasis of the scope and state of this taxonomic problem is that 25% of the fish taxa recognized by the CDC do not even have proper taxonomic nomenclature. All of these un-named fish are also either Red-listed, extinct (Cannings and Ptolemy 1998), or

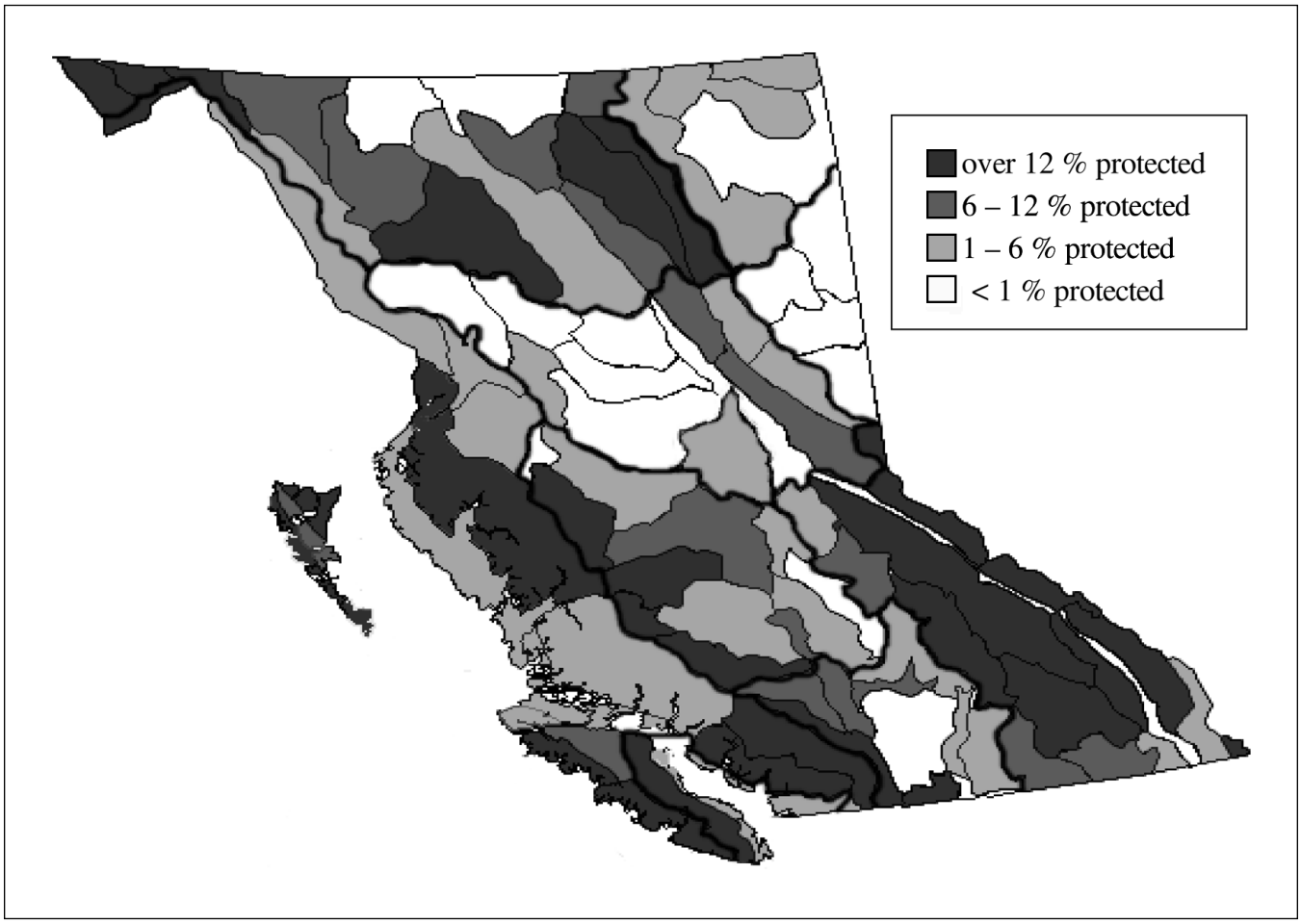

Figure 6. British Columbia's ecoprovinces (heavy black lines), ecosections (regular black lines), and percentage in protected areas (see legend) in each ecosection. Ecoprovince and ecosection data are from Demarchi (1995). Protected area percentage data are from Smith (1998).

prioritized as most at risk (Haas 1998). Conversely, several fish taxa with specific nomenclature recognized by the CDC are not necessarily accepted as distinct species by all fish biologists (e.g., McPhail and Carveth 1993*a*,*b*; Haas 1998) or the American Fisheries Society (Robins et al. 1991), which is the generally accepted governing body for fisheries in North America. A last testament to this issue is that the bull trout is the only fish species recognized under the FPC, and even it was not recognized as a distinct species in British Columbia until this decade (Haas and McPhail 1991), with its resurrection as a species occurring only slightly earlier (Cavender 1978).

These taxonomic problems are exacerbated by an average species misidentification rate of at least 24% (range 0–100% for different fish taxa) in fisheries inventory work (Resources Inventory Committee 1997*a*,*b*, 1998) for the FPC (Haas et al. submitted). This figure is also only for described, named, and generally accepted fish species. Knowledge of ecology and life-history for most fish and aquatic taxa is in even worse condition than knowledge of their taxonomy and species identification (Murphy 1990, McPhail and Carveth 1993*a*, Haas 1998). Correct species identification is the fundamental basis of biological work (e.g., Altaba 1997, Pimm and Lawton 1998, Haas et al. submitted), and proper species management and protection requires good working ecological knowledge based on good identification (e.g., Edwards and Morse 1995, Barbosa and Galdean 1997, Kareiva et al. 1999). A strongly related issue is that proper identification and work on biodiversity depends on natural history museums and their personnel, which presently do not receive this acknowledgement or adequate support in British Columbia and the rest of Canada (Haas et al. submitted).

Unique Within-species Variability and Patterns

As already discussed, aquatic species and ecosystems and taxa are best represented by drainage and watershed

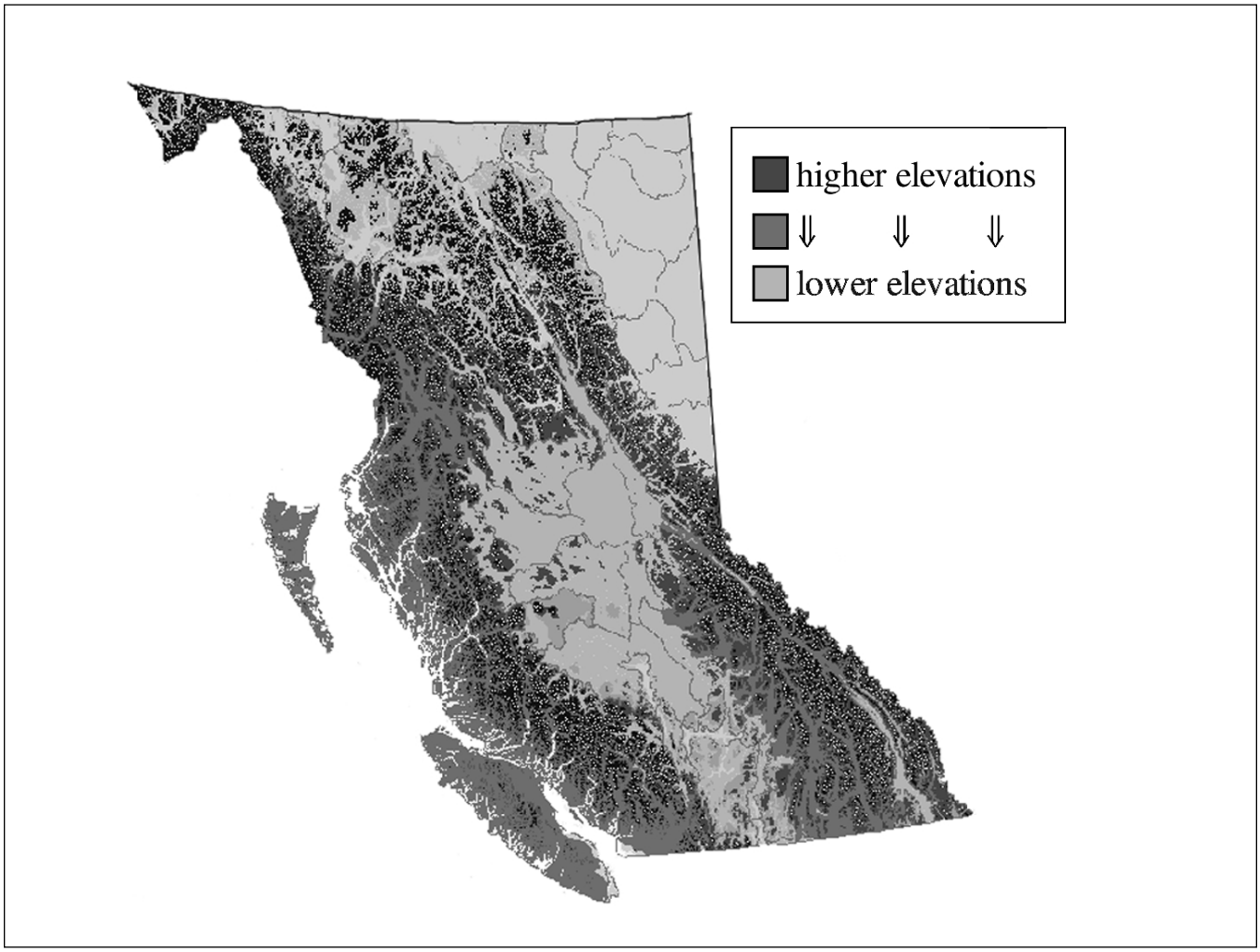

Figure 7. British Columbia topographical map showing elevation in relation to the ecosections in Figure 6.

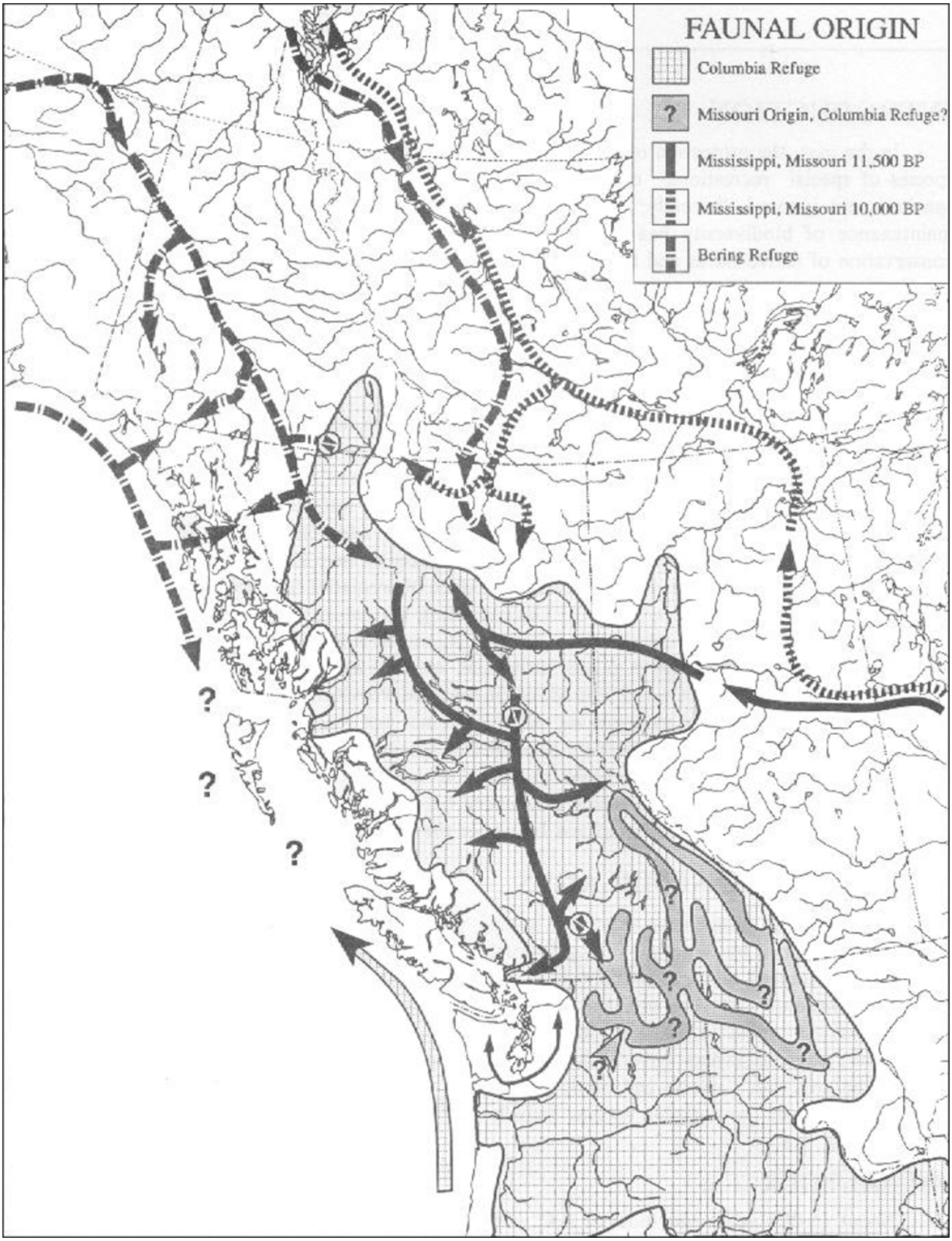

Figure 8. Fish glacial refugia, postglacial recolonization, and present fish distributions based on them. Map is from McPhail and Carveth (1993*b*).

patterns. These aquatic distribution patterns also produce related, and stronger, within-species variability (e.g., Taylor and Haas 1996) than for most other vertebrates, particularly than for those that are warm-blooded (e.g., Flather et al. 1998). Aquatic species and ecosystems are isolated from each other (Fig. 5) by being in separate overall drainages (e.g., Columbia vs. Fraser rivers) and, within those, by being in distinct watershed groups (e.g., Columbia → Kootenay → Elk River →). Even within the watershed groups, smaller aquatic ecosystems are still further isolated by being above barriers such as waterfalls. These populations may also have been strongly affected by other events such as founder effects. This all means that freshwater and anadromous fish have a tremendous level of within-species diversity even though the actual number of recognized fish taxa in British Columbia may not be as high as for other non-fish vertebrate taxonomic groups (e.g., Douglas et al. 1998*b*). The freshwater fish fauna of British Columbia is not rich in species, but does have a unique provincial make-up and tremendous within-species variability (McPhail 1993, McPhail and Carveth 1993*a*, Haas 1998). These fish species are also often not naturally found anywhere else in Canada or, in some cases, anywhere else in the world, whereas many fish in other parts of Canada are distributed in more than 1 province.

In conjunction with such unique aquatic distribution features, British Columbia's geologically recent glacial history has also had dramatic impacts on freshwater fish and other aquatic species biodiversity (McPhail and Lindsey 1970, 1986; Lindsey and McPhail 1986; McPhail and Carveth 1993*a*; Haas 1998). During the last Wisconsin glaciation, British Columbia was almost completely covered with ice for 40,000 years, up until approximately 10–15,000 years ago, when the glaciers began to recede (Fig. 8). During this glacial epoch, fish were wiped out in British Columbia or they survived glaciation in a limited number of distinct glacial refugia beyond the reach of the ice-sheets. The glacial refugia were well separated and had quite different environments, with the fish taxa surviving in them having had 40,000 years to evolve into somewhat or completely distinct forms. The vast majority of often already differentiated fish taxa then recolonized British Columbia from 1 or more of these distinct glacial refugia, often through temporary post-glacial drainage connections that no longer exist (Fig. 8).

After the fish recolonized the province, they had 10–15,000 years in which to further evolve in distinct drainage basins and watershed groups, again often with quite different environments, species compositions, etc. Fish taxa in British Columbia thus have within-species variability resulting from both historical glacial refugia and more recent ecological environments (Haas 1998, Haas and McPhail submitted). These types of within-species variability are much less prevalent in many terrestrial, and particularly warm-blooded, organism groups, and often need not be considered in these cases. Such terrestrial populations tend to be less isolated and more mobile, at least on a smaller scale. Those non-fish or terrestrial organisms that are highly isolated on a larger scale are also often given formal taxonomic status as subspecies or geographic isolates (e.g., O'Brien and Mayr 1991, Rojas 1992). This is again not the case for fish.

The recognition of within-species variability is well established and is explicitly considered in commercial anadromous salmonids as the stock concept. In this concept, populations of particular anadromous salmonid fish taxa are recognized as stocks somewhat or totally distinct from other populations of the same species, due to geographic, temporal, or ecological isolation. This concept even has legislative status under the United States Endangered Species Act, in which distinct salmonid stocks are recognized as "Evolutionary Significant Units" that can each be separately designated as threatened or endangered (Waples 1995). A problem in British Columbia is that only 57% of the estimated 10,000 salmonid stocks could be assessed due to a lack of information. It is further likely that the smaller stocks compose much of the overall salmonid biodiversity, and those are less well known (Slaney et al. 1996). Furthermore, even within the 5,700 stocks that could be assessed, there still were 142 extinct, 624 at high risk, 78 at moderate risk, and 230 of special concern (Slaney et al. 1996). None of these or other salmonid stocks are listed by the Conservation Data Centre and most do not receive other special protection or attention (Haas 1998).

Non-commercial or Non-sport Fish Taxa

Although such large problems exist for major commercial and sport fish, the situation is even worse for non-commercial or non-sport fish taxa (and for other non-fish aquatic taxa) in British Columbia (Haas 1998, unpubl. data) and elsewhere (e.g., Douglas et al. 1989, 1998*b*; Holden 1991). The stock concept and process is legitimate and useful, but it has not been extended to include most British Columbia freshwater fish taxa. This is in spite of these other, mostly non-salmonid fishes being largely less saltwater-tolerant and less migratory, and thus likely more structured and isolated as discrete populations (Haas 1998, Haas and McPhail submitted). To give an example for some perspective, coastrange sculpins (*Cottus aleuticus*) are often found in the same sites as coastal commercial and sport species of salmonids, for which some 2,000 stocks are estimated (Slaney et al. 1996). However, the coastrange sculpin, and other non-commercial or non-sport fish taxa, are treated at the species level, if they receive consideration at all. There is little, if any, recognition of their within-species differentiation (e.g., Douglas et al. 1989, 1998*b*), in spite of the aforementioned evidence suggesting it could be stronger than for anadromous migratory salmonids.

Much of the fish biodiversity in British Columbia is likely

represented in the taxa and their within-species variability that is presently unrecognized and unaccounted for in the province's predominantly non-salmonid fish (e.g., Haas and Ritchie in press). These non-salmonid fish taxa also compose most of the Red- and Blue-listed fish in British Columbia. Such conservation bias toward economically important species is largely unacceptable for other non-fish vertebrate taxonomic groups (Cannings et al. 1999, Douglas et al. 1998*a*, Harper et al. 1999). This situation is even worse for the other totally unrecognized taxonomic organisms and groups present in aquatic ecosystems such as invertebrates (Scudder 1996).

MANAGEMENT AND CONSERVATION IMPLICATIONS

Freshwater fish and aquatic species and ecosystems in British Columbia have the most Red-listed taxa, and many of these are found only in (or have disjunct distributions in) a single water body, often globally. They have the most taxa designated as Forest Dependent of any vertebrate taxonomic groups. Their disproportionately higher risk is not matched by protection or legislation. They also are inadequately represented under the Protected Areas Strategy. They should receive consideration now, given that the designated objective of 12% protected areas is soon to be reached (Smith 1998). Protected areas must consider conservation and not just recreation.

Fish and aquatic species and ecosystems are not equally represented in the Forest Practices Code or its riparian provisions. At least in specific instances of isolated single taxa occurrences in smaller water bodies, fish warrant more direct status and full protection as Managed Identified Wildlife. However, in many cases it is likely insufficient to only set aside particular smaller aquatic locations such as occurs under Wildlife Habitat Areas or Ecological Reserves. Protection under both the PAS and the FPC should recognize that watersheds are physically integrated ecosystems. This could be addressed with General Wildlife Measures under the FPC and through FPC higher level planning procedures such as Land Resource Management Plans. However, acceptable impacts (1%) on the Annual Allowable Cut could likely only be somewhat mitigated through LRMPs.

Fair and rigorous criteria that encompass all taxonomic groups in proper perspective should be implemented (Meffe et al. 1998, Colyvan et al. 1999, Kareiva et al. 1999). Terrestrial and aquatic biologists must work together as overall conservation advocates and not just on their own agendas. In some cases, the real economic values of biodiversity and conservation (e.g., Boyle and Bishop 1987, Stevens et al. 1991, Gavaris 1996, Loomis and White 1996, Baker and Pierce 1997, Bookbinder et al. 1998) could also be considered within this framework.

An aquatic ecosection system should be investigated and delineated (Moyle and Ellison 1991, Hitt and Frissell 1999, Newall and Magnuson 1999). The PAS in British Columbia is presently based on ecoprovinces and ecosections that utilize largely terrestrial criteria. The ideal would be integration of aquatic ecosections with terrestrial ones (e.g., Haas and McPhail submitted). At a minimum, distinct aquatic features and linkages must receive more consideration under habitat protection plans. Some effort towards an aquatic ecozone classification has been attempted in British Columbia (Perrin and Blythe 1998, also see Emmons et al. 1999), but it has not been validated for its correspondence to the actual biological distributions of aquatic taxa (e.g., see lack of correspondence in Wright et al. 1998).

There are particularly significant species-level problems or deficiencies for fish and aquatic species with regards to taxonomy, identification, life-history, and ecology (e.g., Collette and Vecchione 1995). There is still a strong need for fundamental research (e.g., Efford 1994, Mosquin et al. 1995, Auditor General 1998, Balmford and Gaston 1999), particularly where species nomenclature, identification, and knowledge are critical, such as under the FPC or within any upcoming federal endangered species legislation (Wildlife Habitat Canada 1995, Auditor General 1998, Spurgeon 1999).

Fish and aquatic biodiversity is more uniquely structured within species, and has both historical and ecological components. This is unrecognized for all but some commercial or sport salmonid fishes, and their conservation has not yet been addressed by the FPC or the CDC. Even for these salmonids, knowledge and management is biased towards larger populations, with many smaller stocks being poorly understood and unmanaged.

All aquatic taxa and stocks, ultimately including marine fish and ecosystems (Zacharias and Howes 1998), should be directly taken into account for protection (e.g., Franklin 1993, Orians 1993, Kendall 1999, Wardle 1999). This is already the case for non-commercial, not just commercial, taxa in other non-aquatic taxonomic groups such as birds and mammals (Haas and Ritchie in press). It should also be considered that effective conservation must work across British Columbia, its working economy, and even for non-endangered or non-listed taxa in all groups.

The poor fish and aquatic background information available warrants consideration of a risk avoidance and adaptive approach to conservation and management. Caution in favour of conservation is needed and it should be related to biological uncertainties and impact time frames (e.g., Kareiva et al. 1999). Conservation should, nonetheless, start now and work with "known data" in spite of quantitative information gaps. Stricter biological requirements could be implemented in the interim to help deal with this, and their effectiveness could be monitored and should be accommodated when potential impacts are unknown, large, or long-

term. Many fish taxa require immediate, and also fairly obvious (at least on a gross or fundamental [e.g. Naiman et al. 1992] level), conservation measures (e.g., Murphy 1990). There are recommendations and prioritizations for conservation, research, and data needs for British Columbia fish and for aquatic species and ecosystems in McPhail and Carveth (1993*a*) and Haas (1998).

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