4. Management and Conservation of Freshwater Ecosystems: Threats and Challenges

4.1 Introduction

The past 30 years have seen substantial improvements in the quality of Maine's lakes, rivers and streams. Nevertheless, many factors continue to threaten the integrity and continued improvement of the State's freshwater ecosystems. This chapter presents an overview of these threats and discusses what is known about the magnitude of their impacts in Maine.

Appendix 11.8 contains a variety of information about freshwater ecosystems recorded at meetings of experts from different parts of the state. Some of this information relates to threats and management issues.

One approach to visualize the range of threats that are affecting (or potentially affecting) freshwater systems in Maine is as a matrix of "stressors" and "stress pathways" (Table 4.1). Stressors are, for the most part, human-associated activities that influence freshwater resources. They include both contemporary resource exploitation and management practices (e.g. agriculture, forestry, aquaculture), as well as the results of past actions (e.g. forestry, dams). Species introductions have been included in this list of stressors since many expansions in species ranges are the direct or indirect result of human activities. "Stress pathways" refer to how the various stressors impact aquatic biota. Of course, in reality the threats to freshwater ecosystems are not as compartmentalized as suggested in Table 4.1. For example, a dam acts both as a barrier and as a modifier of river hydrology. However, the way in which a dam is managed influences downstream hydrology and lake level fluctuations within the reservoir.

4.2 Barriers

River and stream barriers range from large hydroelectric dams and low-head run-of-the-river dams, to small pond dams, beaver dams and improperly constructed or maintained culverts. Their impact on fish populations depends on size, fish passage facilities, fish species and operation practices. Adverse impacts can include blocked or reduced fish passage, reduced connectivity, fragmentation of riparian habitat areas, direct fish kill via turbines, changes in hydrologic and temperature regimes, changes in sediment downstream sediment loading and water quality, and physical alteration of downstream habitat. Positive impacts can include recreational opportunities, power generation, water supply and reductions in access by invading species.

Today there are fewer dams and weirs on Maine's streams and rivers than there were 50 years ago (for a review of obstructions on streams in northern Maine pre-1950, see Bond and DeRoche, 1950). This stems from the deterioration and removal of old logging dams and from the more recent initiation of active dam removals on environmental and economic grounds. The Edwards dam on the Kennebec River was the first FERC-licenced hydro dam in the country to be removed (in 1999) for environmental reasons (Courtemanch and Davies, ms). Other, smaller, dams have been removed in Maine over the past ten years. The proposed Penobscot River Restoration Project is a high-profile project that will involve main-stem dam removals and operational changes for some of the remaining dams.

Despite the large number of dams in Maine, there is no comprehensive, up-to-date, inventory of dams in the state. The GIS dams coverages for Maine (MDEP and National Inventory of Dams) include approximately 800 dams (Table 4.2). These records were last revised in 1981 and some do not reflect current conditions (C. Fay, Penobscot Indian Nation, pers. comm.). Many smaller dams and other barriers are not included in the GIS coverages. For lakes with fisheries surveys, MDIFW data include observations on the presence/absence of dams at each of the lakes. Approximately 25% of the ca. 2000 surveyed lakes are listed as having a dam at the outlet (Table 4.2). The most comprehensive list of dams was assembled by Betsy Elder at Maine State Planning Office (MSPO) in 1987 (Table 4.2) [8]. This database lists 1,369 dams that were functional at that time. Of these, approximately 50% were too small to be registered by MDEP (< 2 ft high and impounding < 15 acre-feet of water) (Elder 1987). The disparity between the GIS and Elder databases is particularly apparent in northern Maine where Elder records many more dams (Figure 4.1). According to the GIS dams database, the Downeast region contains the largest number of dams (Table 4.3), but most of these are very small. A recent position paper on river restoration policies in Maine has underscored the need to produce a comprehensive inventory of dams (LWRC 2004).

Many larger dams have fishways, although there is no comprehensive, up-to-date, inventory of fish passage facilities. There are significant variations in the efficiency of these fishways, both among dams and among species. Most existing passageways, for example, are designed to pass adult anadromous species (even though they do not always do so successfully) and are not appropriate for juvenile catadromous eels (Wippelhauser 1999). The FERC re-licensing process is being used to require improvements in fish passage at a number of dams. However, the majority of dams in Maine are not under FERC jurisdiction and are not affected by this process. Smaller dams can be significant barriers for species such as the alewife and smelt (e.g. Flagg 1972).

Bridges and poorly designed and/or maintained culverts also may represent barriers to fish passage. Some efforts have been made to inventory and evaluate these barriers. Project SHARE has surveyed barriers in some Downeast streams, and USFWS recently completed a survey of bridges and culverts in the Kennduskeag and Piscataquis drainages (Baker 2004, and C. Fay, Penobscot Indian Nation, pers. comm.). It is likely that better data and design improvements will gradually reduce the extent of fish passage problems at culverts and bridges. Biologists at the Atlantic Salmon Commission (ASC) and MDIFW are collaborating with MDOT to refine and implement fish passage policies (USASAC 2002; M. Gallagher, MDIFW, pers. comm.)

Beaver dams are today much more common than they were in the first half of the 20th century. Increases in the beaver population before the mid 1950s were probably related to reduced trapping (Rupp 1954). More recently, a shift in forest composition favoring hardwoods (birch, poplar and maple) following spruce budworm outbreaks of the 1980s, has also promoted higher populations (Arter 2003). Cunningham (2003) documented an 89% increase in the number of ponded wetlands on Mount Desert Island between 1944 and 1997. As barriers, beaver dams can represent significant obstacles to species such as brook trout. They also result in higher water temperatures and, at times, reduced oxygen concentrations. MDIFW has removed a number of beaver dams to enhance stream fish populations (R. Brokaw, MDIFW, pers. comm., Kircheis 2002). However, beaver dams are a natural part of the landscape and should be evaluated within this context. Additionally, they have a number of direct or indirect benefits, including restricting access by invading species. Beaver dams are ephemeral and their medium- to long-term impacts are likely variable.

Dams and weirs have resulted in substantial reductions in the amount of stream and lake habitat available to diadromous species. Busch et al. (1998, cited in ASMFC 2000) indicate that potential habitat loss for the American eel is greatest in the North Atlantic region (Maine to Connecticut), where accessible streams have been reduced by about 90% (from an estimated 111,482 miles to 10,349 miles). The extent to which dams impact diadromous species varies by river system (i.e. the number of dams and fishways) and by species. Dam removals will result in restored upstream fish passage. The experience in the lower Kennebec River after the removal of the Edwards dam suggests that this restoration can occur relatively rapidly (Davies et al., 1999).

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[8] This database is available only in hardcopy format.

Through their impact on fish populations, dams can also impact invertebrate species associated with fish. For example, dams are thought to be a major factor contributing to the decline of mussel populations in Maine and elsewhere (Nedeau et al. 2000, Williams et al. 1993).

By reducing the spread of non-native species or genetic stock, dams and natural falls can also have a positive impact, something that was acknowledged over 50 years ago by Bond and DeRoche (1950). The dam at the outlet of Lower Richardson Lake in western Maine, for example, is currently preventing the further upstream movement of smallmouth bass in the Rapid River / Richardson Lakes complex. This species was illegally introduced into Umbagog Lake in 1980 and from there moved into the Rapid River (F. Bonney, MDIFW, pers. comm.). In northern Maine, the Fish River Falls are potentially an effective barrier to the invasion of muskelluge and smallmouth bass – studies are currently underway to determine the effectiveness of this barrier and assess the need for structural modifications (D. Baseley, MDIFW, pers.comm.). On some Downeast rivers, weirs are being used to help protect the native Atlantic salmon gene pool by preventing upstream passage of aquaculture escapees – salmon collected at weirs are inspected by biologists and escapees are destroyed (NMFS and USFWS 2004).

4.3 Modifications to River and Lake Hydrology

Dams modify downstream hydrology and upstream hydrology in the area of the impoundment. The extent of these hydrologic modifications depends, in large part, on the management policies guiding water release. Relative to the undammed situation, variation in downstream flow and water levels may be either stablized or increased. Legislation adopted in 2002 by the State of Maine will further promote the development of in-stream flow and lake level standards to protect aquatic life. The FERC dam re-licencing process is also being used to improve flow regimes below dams (L. Miller, USFWS, pers. comm.), for example by using in-stream flow incremental methodology to evaluate hydrology needs to satisfy critical habitat requirements for fish and other ecosystem components. During re-licensing, MDIFW and MDEP biologists participate in evaluations of alternative flow regimes and minimum flow requirements, relying partially on both State and Federal policy guidelines addressing base flows, wetted area and the ratio of base to peak flows (Davies et al. 1999). The MSPO has recently released a compendium of hydropower and river restoration policies of Maine state agencies (LWRC 2004).

The 305(b) integrated water quality reporting by MDEP provides one measure of the contribution of hydrologic modifications (resulting from dam operation) to overall water quality impairment in Maine. Flow modification represents one of the source impairment categories listed in these assessments. The most recent data indicate that, for river and stream segments in impairment categories 4 (impaired or threatened but not requiring Total Maximum Daily Loads) and 5 (requiring TMDLs), flow modification as a result of hydro-generation was the cause of impairment for < 2% of impaired segment miles (MDEP 2004).

One of the first studies in Maine to address the impacts of flow manipulation on aquatic communities focused on changes in the operating regime of the Wyman Lake dam in western Maine (Trotzky 1971, Trotzky and Gregory 1974). Not unexpectedly, slow flows reduced the species richness of swift-water macroinvertebrate taxa. More recent studies by MDEP found low diversity and abundance of macro-invertebrates below Wyman dam. However, subsequent modifications to the flow regime have resulted in increases in both diversity and abundance. Similar findings were made in Squa Pan Stream (Davies et al. 1999).

A more recent study in the same general region of the Kennebec River (between Harris Dam and Wyman Lake) investigated the impacts on the fish community of intermittent watering and de-watering as a result of flow changes from Harris Dam (Eco-Analysts, Inc. 1999). Overall, there was no loss in the species richness of the Kennebec fringe community relative to communities of the unregulated Moose River. Since fish are more mobile than macro-invertebrates, variation in river discharge would be expected to be less stressful on the former group than the latter. In general, extreme variations in dam discharge (i.e. peaking power projects) are expected to negatively impact downstream invertebrates, via a combination of stranding and desiccation at low flows and displacement at high flows. Studies in Maine and elsewhere indicate that a high to low flow ratio greater than 10 is detrimental to aquatic communities (Davies et al., 1999). Invertebrates and fish are not the only faunal groups potentially affected by river flow modifications. Comption (1999) has documented the loss of about 25% of wood turtle nests in Maine as a result of water releases from an upstream dam.

Gibbs (1993) provides a classic illustration of how hydrologic modification can severely affect, to the point of presumed extirpation, a mayfly species (*Siphlonisca aerodromia*) that was highly dependent on seasonal flow and flooding events. Habitats in New York were flooded in the 1930s, destroying what at that time was the only known population of this mayfly. Fortunately, the species was re-discovered in Maine, at Tomah Stream (Washington County), in the 1970s. See further discussion about this species in Chapters 3 and 6.

Dam management also influences water levels in impounded lakes. Severe water level fluctuations can negatively impact both plant and animal communities. Cameron (2000) observed that species richness in macrophyte communities was much lower in Flagstaff and Graham Lakes than might otherwise have been expected, presumably as a result of substantial drawdowns in these systems. Similarly, MDEP (2004) reports significantly reduced macro-invertebrate diversity and abundance in Flagstaff Lake and other similarly managed impoundments. Jiffry (1984) documented mortality of mussels in Lake Sebasticook as a result of lake drawdowns that were part of a eutrophication control program. Lake level management (both timing and extent) is critically important for many fish species. MDIFW and tribal biologists provide input on lake level management during dam re-licensing projects (T. Obrey, MDIFW, C. Fay, Penobscot Indian Nation, pers. comm.). Among eleven water storage reservoirs, maximum permitted drawdowns range from 11 to 55 feet (latter is Aziscohos Lake). Average drawdowns are often half of these values. Twenty eight lakes with water control structures currently have “water level orders” imposed by MDEP, limiting the extent of drawdowns (data provided by D. Murch, MDEP, 1/2005).

Water extraction also impacts streams and ponds by reducing water levels and/or increasing water level fluctuations, and by reducing floodplain extent and functionality. It has been identified as a key threat to Atlantic salmon (NOAA and USFWS, 2004). Irrigation water for blueberry cultivation is withdrawn from the Pleasant, Narraguagus and Machias River watersheds, and water usage is projected to increase substantially over the next few years (NOAA and USFWS, 2004). In the Narraguagus watershed, water is withdrawn from six natural ponds and a series of man-made irrigation ponds, as well as three streams (Arter 2003). In 1999, LURC placed limits on the amount of water that could be withdrawn from several salmon rivers. Water use management plans (WUMPs) for several Downeast streams indicate that withdrawal of surface water during periods of low flow poses the greatest risk to salmon. Potential impacts of water withdrawals on salmon include reduced parr habitat, and impairments to redd development, adult immigration and smolt emigration. Blueberry growers appear to be in the process of moving toward a greater emphasis on groundwater sources for irrigation water. While the impacts of this are unknown at the present time, it is possible that both ponds and streams may be negatively influenced (NOAA and USFWS, 2004). Water extraction may also be causing adverse environmental impacts in other parts of the state, for example along the Saco River (B. Vickery, TNC, pers. comm..)

Although there are relatively few case history examples from anywhere in the country, it is clear that dam removal will have major impacts on the hydrologic regime of formerly impounded areas. The Edwards Dam provides the only data source from Maine. Here, a three-fold increase in macroinvertebrate species richness, and a thirty-fold increase in total abundance, occurred within two months of dam removal in 1999. Within six weeks, samples contained the full complement of expected riverine invertebrate taxa (Courtemanch and Davies, ms.). However, because fish populations also changed during the same period, changes in predation intensity may make it difficult to distinguish direct effects (from dam removal) from indirect effects (predation-mediated) on invertebrate communities (A. Casper, Université Laval, Quebec, pers. comm.).

4.4 Land Use Practices (& Point-Source Pollution)

Timber harvesting and agricultural practices: These may have multiple impacts on freshwater ecosystems and their biota, including:

- Habitat fragmentation.
- Reductions in riparian vegetation, leading to changes in thermal and light regimes, and destablization of stream banks.
- Changes in sediment quantity and quality.
- Changes in organic matter quantity and quality
- Reductions (or possibly short-term increases, depending on harvesting practices) in coarse woody debris, an important component in the structural habitat for invertebrate and, especially, fish populations.
- Elevated nutrient concentrations (nitrogen and phosphorus).
- Pollution from agrochemicals (pesticides).

Three reviews provide valuable syntheses of information relating to the impacts of forest and agricutural land management practices on aquatic systems. Loftin et al. (2000) present an in-depth review and bibliography of the influences of forest management activities on riparian and in-stream biota of New England. Arter (2003) provides an excellent summary of issues related to land management practices in the Narraguagus watershed. Many of these issues apply to broader areas of the state. Finally, Moring and Finlayson (1996) address land management in the context of Atlantic salmon conservation.

Impacts of land-use practices, such as forestry, agriculture and, especially, associated road construction activities, on stream habitat are of concern in many parts of the State. While many of these impacts have not been rigorously quantified or studied in Maine, it is important to underscore that professional biologists can readily point to examples of habitat degradation and their causes. Current efforts by MDIFW (and MDEP) are directed towards developing consistent databases of stream habitat information that should promote identification and prioritization of future habitat management and restoration efforts.

While there is a considerable body of information available from various parts of the world on the interactions between land-use practices and aquatic communities, Maine-based studies are relatively few. Adamus et al. (1986) noted that only two studies on the impacts of riparian logging in Maine had been published prior to that year. In a pioneering study of the effects of deforestation on aquatic communities of the East Branch of the Piscataquis River, Garman (1986) and Moring and Garman (1986) showed that there were rapid reductions in the density and diversity of macroinvertebrates. On the other hand, the functional group structure exhibited an unexpectedly high degree of stablity. Interestingly, annual production and feeding ecology of the stream fish fauna were relatively unaffected by deforestation, perhaps because the stream supported only a small brook trout population prior to cutting.

The effects of increased light penetration and higher water temperatures following clearcutting were demonstrated by Noel et al. (1986) in their study of ten watersheds across New England (four were in Maine). Macroinvertebrate and periphyton densities (numbers and biomass) were 2-4 times and 6 times greater, respectively, in clearcut sites relative to reference streams. Invertebrate diversity (numbers of species), however, was similar under both conditions. In this case, nutrient concentrations were largely unaffected by clearcutting. However, evidence from elsewhere in Maine has underscored the variability in temperature regimes that can occur between neighboring streams and the fact that this variation can complicate evaluations of forest cutting and buffer strips (Hagan 2000).

Recently, Manomet and University of Maine ecologists implemented a project designed to 'evaluate the effectiveness of different riparian management practices for maintaining ecological values' of streams in western Maine (Hagan 2000). Known as the Headwaters Streams Project, this research assigned four riparian treatments and a control, with data being collected before and after treatments. Data included water quality, aquatic habitat structure, aquatic biota (amphibians, fish, macroinvertebrates), and terrestrial biota.

Up until recently, Maine's riparian zone standards were 'complicated, inconsistent, and in need of consolidation' (Loftin et al., 2002). Furthermore, standards applicable to the unorganized territories regulated by LURC were significantly less strict for small streams than were standards set for organized townships regulated by MDEP. However, recent legislative developments have set the stage for a more unified approach to riparian zone management, including an explicit focus on 'maintaining or restoring the chemical, physical and biological integrity of aquatic ecosystems in forested areas' (MFS, 1999, cited by Loftin et al., 2002).

Beyond the riparian zone of streams, forest management practices can impact amphibian species via habitat fragmentation and reductions in connectivity between upland forest habitats and aquatic breeding sites (DeMaynadier and Hunter 1997, 1999; Guerry and Hunter 2002). It appears that, while clear-cutting has negative short-term impacts on amphibians, particularly salamanders, longer-term impacts are variable and can be mitigated if forest regeneration practices provide for adequate micro-habitat structure (DeMaynadier and Hunter 1996). Forest roads serve as partial filters (barriers) to the movements of some amphibian species (DeMaynadier and Hunter 2000). Direct road mortality is also significant for some amphibian and reptile populations (e.g. Compton 1999), especially where roads are close to wetland breeding grounds and where the species involved has low reproductive output (e.g. Blanding's turtle).

Agriculture can impact aquatic systems via multiple pathways, although quantitative data on specific impacts in Maine are sparse. A primary concern is non-point source sediment loading – see below. Agricultural non-point source pollution is responsible for non-attainment in 189 miles of Category 5 streams (streams requiring TMDLs; MDEP 2004).

Contamination by pesticides is a concern in the Downeast salmon rivers. Pesticides may enter streams through aerial drift, surface runoff and groundwater. MDEP and the ME Bureau of Pesticides Control (BPC) started a pesticides monitoring program on seven of these rivers in 1997 and has detected hexazinone in the Machias, Narraguagus and Pleasant Rivers, although at trace levels (Chizmas 1999, NOAA and USFWS 2004). Using new sampling methods, MDEP and the University of Maine have found persistent low levels of hexazinone and short-tem contamination of phosmet in waters near treated blueberry fields (D. Courtemanch, MDEP, pers. comm.).

Hexazinone is considered to be practically non-toxic to birds and invertebrates, and has very low toxicity to fish (Chizmas 1999). However, the effects of hexazinone as a phytotoxicant in freshwaters is unknown. Recent concerns have focused on pesticides (and other chemicals) from the perspective of endocrine disruptors. A large number of chemicals has been shown to disrupt endocrine systems, including various pesticides, dioxins, PCBs and heavy metals (Dill et al., 2003, NOAA and USFWS 2004). There is evidence from the Narraguagus River that endocrine disruptors affect smoltification in Atlantic salmon by causing osmoregulatory disruption via reductions in gill tissue Na/K-ATPase (Magee et al., 2001). Dill et al. (2003) noted that a number of research projects are focusing on the role of endocrine disruptors on salmon physiology. However, they concluded that, at that time, there was not "sufficient water quality data to ascertain the extent of exposure of Atlantic salmon to endocrine disrupting chemical in Maine rivers, nor are there sufficient research data to ascertain the potential effects of endocrine disruptors on salmon restoration, however the available weight of evidence indicates that this factor may be important in Atlantic salmon restoration" (Dill et al., 2003).

Earlier work on organochlorine pesticide residues in aquatic biota had documented low levels in the Narraguagus and other rivers (e.g. Mingo 1978). Furthermore, Haines (1983) has shown that brook trout in northern New England lakes had very low levels of organochlorines – comparable to those found in Antarctic fish, essentially global background levels. This earlier work, however, was done before the endocrine disruptor linkage became apparent.

Residential and industrial development: In southern Maine, "sprawl" is one of the major threats to biodiversity. The most direct way in which development can impact aquatic ecosystems is by direct destruction of habitat, particularly in the case of small, unregulated, wetlands and vernal pools. Urban areas contribute to non-point source pollution of streams, introducing sediments and toxicants, and raising water temperature. Such pollution is identified as the source of impairment for 85 miles of Category 5 impaired streams (MDEP 2004). Increased areas of impervious surface have been clearly shown to be inversely linked to stream habitat quality and stability, and water quality (Morse 2001, Morse et al. 2003). The amount of impervious surface in a watershed also impacts macroinvertebrate communities, with an apparent threshold of 6% areal coverage. Streams in catchments with impervious surface coverage below this threshold had almost twice the invertebrate species richness of those in catchments with over 6% impervious surface.

Roads: Road construction and use is clearly integral to all of the above forms of land-use. Roads are treated separately here only to underscore their role as contributors to non-point source pollution, in particular sediment loading. Sediments deposited in stream channels can reduce and degrade habitat, for example by increasing embeddedness and by reducing water depth in pools and thus the amount of cooler water habitat in summer months. In addition, sediments can produce direct mortality of fish eggs and invertebrates. Roads (especially roads under construction and road crossings), trails (especially ATV trails) and improperly constructed culverts are often major sources of sediment loading, in both agricultural and forest habitats. In the Narraguagus watershed, about 23% of all non-point source sites are associated with ATV use. Sedimentation was listed by NOAA and USFWS (2004) as a priority threat to Atlantic salmon rivers.

With current winter road maintenance tending toward increased use of salt, NaCl loading from roads is likely to rise in the future. Impacts of salt on aquatic ecosystems in Maine have been largely unstudied (Arter 2003), although a study investigating the influence of salting on stream water quality is currently underway at the University of Maine (K. Johnson, University of Maine, pers. comm.).

Point-source Pollution: Point-source pollution includes municipal wastewater discharges, individual overboard discharge (OBD) systems, and industrial discharges. Municipal and industrial point sources have been listed as the source of non-attainment for a total of 115 miles of Category 5 streams in Maine (MDEP 2004).

Dioxins, produced from pulp and paper mills, have been monitored in Maine waters since 1985 with the goal of determining the 'nature of dioxin contamination in the waters and fisheries of the State' (MDEP 2004). There is an extensive database on dioxin residues in fish tissue. However, these data are collected primarily from a human health perspective (consumption advisories). While there appear to be few data addressing the impacts of dioxins and other persistent bioaccumulating toxins on freshwater biodiversity, it would seem highly likely that impacts *are* occurring. This is urgent need for additional research in this arena.

Other point-source discharges have clearly impacted aquatic communities, particularly through increased BOD (biochemical oxygen demand) loading. Higher BOD levels reduce dissolved oxygen concentrations and stress invertebrates and, potentially, fish. Intolerant invertebrate taxa tend to be replaced by tolerant species. When these discharges have been reduced or eliminated, the communities often recover relatively rapidly. MDEP's biomonitoring program has documented many such biological recoveries as new treatment technologies are implemented (Davies et al., 1999).

Maine waters are comparatively low in ionic strength and support relatively low abundance and diversity. While toxic waters clearly exert a significant stress on biological systems, reducing the number and diversity of intolerant organisms, other pollutants (e.g. organic enrichment, nutrients) have a variable effect. If pollutant loads are light, they can cause an increase in the abundance and diversity of organisms. Under increasing loads of these pollutants,however, the aquatic system becomes stressed and diversity and abundance declines.

4.5 Biological Threats

Species Introductions: It is useful to think of introduced species in three categories.

(A) Not native to North America.
(B) Native to North America, but not to Maine.
(C) Native to Maine, but not to an individual waterbody or drainage.

In (B), relating nativity to political boundaries is useful from a policy and management perspective; from an ecological / watershed perspective it is approximate, since watersheds extend beyond state boundaries, particularly in southern and northern Maine.

Some non-native species in Maine, such as some of the minnows, may have little or moderate impact on the ecosystems in which they exist today (c.f. Vander Zanden et al., 2004). Other non-Maine natives, however, aggressively colonize habitats and pose a clear threat to the overall nature and integrity of ecosystems. These species are called “invasives” (“nuisance” species is another term that is sometimes used). The decision to label a species invasive is a somewhat subjective one; in reality, there is a gradient of impacts from moderate to major.

Invasive species can cause the following biological and socio-economic impacts (LWRC 2002):

- Displace native species, leading to a reduction in biodiversity value (species richness and/or ‘evenness’).
- Disrupt foodwebs.
- Degrade habitats.
- Suppress property values.
- Necessitate spending of public and private funds for control and compliance.
- Impair commercial fishing and aquaculture.
- Degrade recreational experiences.
- Impair public water supplies.
- Harm sport fisheries.
- Clog or foul pipes and drainage ditches.
- Threaten public health.

The economic implications of invasive species infestations can be substantial. On shoreline properties in Vermont, invasive plants have been estimated to reduce property values by $12,000 for the average property. New Hampshire spends almost $100,000 annually in state and local funds on just seven to nine control projects – however, 55 lakes are infested in the state (Bouchard, undated).

Invasive species threaten a significant number of Maine lakes and rivers and it is critical that adequate attention be paid to this issue. Two recent laws enacted by the Maine legislature in 2000 and 2002 focus on preventing the spread of invasive species and controlling existing infestations. The initial focus on invasive plant species has now evolved into a broader management and control program for both plant and animal species, under the auspices of both MDEP and MDIFW. For more information on management and control plans for invasive species, refer to the State of Maine's "Action Plan for Managing Invasive Aquatic Species" (LWRC 2002).

Aquatic Plants Introductions: The "advisory" list of freshwater invasive species contained in the action plan for invasive species (LWRC 2002) is shown in Table 4.4, with a number of revisions based on more current data in the MABP database. It contains 11 plant species, 17 fish (several of these are long-established in Maine and are important gamefish species in parts of the state), 7 crustaceans, 3 molluscs and 2 fish pathogens. The original list also includes 2 wetland animal species, 8 wetland plant species, 7 marine animal species, and 8 marine plant species.

Invasive aquatic plants have been confirmed from 18 sites (through June, 2004), all in southern Maine, with most records being variable milfoil (Figure 4.2). This species has been recorded from both lakes and slow-moving streams. Hybrid milfoil has been recorded from one waterbody, as have hydrilla (*Hydrilla verticillata*), curly-leaf pondweed (*Potamogeton crispus*) and Eurasian milfoil (*Myriophyllum spicatum)*. The biological and socio-economic impacts of most of these eleven species are predicted to be high.

Prevention is the strongest defense against further spread of invasive plants (Van der Zanden et al., 2004); however early detection of new occurrences is also critical. State biologists and volunteers are involved in surveying freshwater systems for new records of invasive plant species. MNAP biologists surveyed 68 lakes and ponds in 2002 and 2003, using a rapid bioassessment protocol (D. Cameron, MNAP, pers. comm.). They recorded variable milfoil from four of these sites. Coordinated by the Volunteer Lake Monitoring Program (VLMP) and the Maine Center for Invasive Aquatic Plants (MCIAP), volunteers also check waterbodies and report any 'suspicious' species for further investigation (R. Williams, MCIAP, pers. comm.).

Fish Introductions: While all plants on the LWRC advisory list are clearly considered invasive, the situation is less clear for the fish species on this list (Table 4.4). Some species are relatively recent arrivals and pose a threat to ecosystem integrity and functioning. Examples include green sunfish, northern pike and muskellunge. Green sunfish is the one of the most recent additions to Maine's fish list, recorded from the Sebasticook River drainage (Table 4.5). There is considerable concern that it will invade other waters and compete with native species. In other parts of the country, it is considered an indicator of highly disturbed systems (Halliwell et al., 1999). Northern pike has been recorded from a number of sites in southern and central Maine (Figure 4.3). It is likely that it will spread; however, it is less invasive than the muskellunge. The muskellunge was introduced to the St. John basin (Lac Frontier) by Canadian biologists between 1970 and 1979 – after this time the population was self-sustaining (D. Baseley, MDIFW, pers. comm.). MDIFW first confirmed this species from Maine waters in 1974. Since 1995, impacts on the brook trout fishery have been noted. In the mid-1980s, juvenile fish were collected from several sites in the Upper St. John, including Baker Lake and, more recently, Glazier Lake (source of the state record of 43 inches). The New Brunswick Department of Natural Resources first reported muskies further downstream on the St. John, in the Mactaquak fish trap at Fredericton, in 1998. Currently, expansion of the muskie's range in northern Maine is being limited by natural falls on the Allagash, Aroostook and Lower Fish Rivers. Fisheries managers are considering construction of a barrier on the Fish River to block muskie and smallmouth bass from entering the Fish River chain of lakes.

In contrast to these three species, other non-Maine native "invasive" species have been here for a long time and are significant components of many sports fisheries. However, their spread within Maine today is of considerable concern in view of their likely impacts on Maine-native fish species, including brook trout and Atlantic salmon. Spread occurs both via illegal introductions by humans and by the fishes' own dispersal into areas not previously inhabited. Smallmouth bass is perhaps the best example. It has been present in Maine for over 100 years and is a valuable gamefish species. However, it has been introduced illegally into many waters around the state and its presence and potential spread is of concern, particularly in parts of western Maine, such as the Rapid River / Richardson Lakes complex, and northern Maine.

Not all non-Maine native fish species on the LWRC advisory list are as invasive as the muskellunge and smallmouth bass. Brown trout is on this list and is not native to North America. It is actively being stocked by MDIFW. While there are some concerns that it might represent a significant threat to Atlantic salmon (NOAA and USFWS, 2004), this species does not generate the same level of concern as smallmouth bass and muskellunge since it is a less aggressive predator. The National Park Service would like to ensure that brown trout is not stocked in Acadia National Park, in view of its non-native status (D. Manski, Acadia National Park, pers. comm.).

In addition to the introduction and establishment of Maine non-natives, Maine-native fish species have been introduced into numerous waters in which they did not previously exist (Table 4.5). These translocations have been going on for over 100 years and continue today. Primary examples include some of the minnow species (e.g. golden shiner, fathead minnow), yellow perch, and land-locked salmon. Stocking by MDIFW has contributed to species translocations in the past. Today, illegal introductions are the primary threat (e.g. the so-called bait bucket introductions).

Four examples illustrate the extent of fish introductions in various parts of Maine (further discussion of these issues is deferred to Chapter 6.4.)

> Mount Desert Island: Stone et al. (2001) recorded a total of 28 freshwater fish species on Mount Desert Island out of a total of 31 species noted from historical records. About one half of this total (15 species) is considered likely native to the island; the others have been introduced from other parts of Maine or from outside of Maine.
>
> Rangeley Lake: From surveys conducted in the early years of the 20th century, Kendall listed ten species in this lake (Kendall 1918), with another six species being recorded from neighboring lakes. By the time of Kendall's surveys, landlocked salmon and smelt had already been introduced to the lake. Approximately 35 years later, Cooper (1940) listed 14 species from Rangeley Lake, including the recently and illegally stocked brown trout. By the mid-1970s, the list had grown to 21 species (DeSandre et al. 1977) and included the yellow perch (first reported in 1953), landlocked alewife (introduced in 1971-72), and the banded killifish (first reported in 1975). MDIFW's most recent (2002) update of its inventory database lists 22 species for Rangeley Lake; white perch is the one species on this list that did not appear on DeSandre's list.
>
> Moosehead Lake: Early introductions included landlocked salmon (1879) and smelt (introduced in 1892; Brown 1998). In the mid-1940s, Cooper and Fuller (1945) listed a total of 17 species from Moosehead Lake, with an additional four species being collected from tributary streams. MDIFW currently lists 25 species from this lake, including pumpkinseed and white perch, both of which are introduced and near the northern-western extent of their ranges in Maine.
>
> Fishless ponds: These are unique systems and are highly vulnerable to both legal and illegal stocking. Although the number of ponds in Maine that were historically fishless is unknown, it is certain many have lost that status over the past half century and more. Recent sampling has shown that a number of ponds that were considered fishless now contain fish (E. Schilling, University of Maine, pers. comm.). On-going studies will

provide a basis for predicting the location of fishless ponds in Maine and thus guide future survey efforts.

Whatever the origin of introduced fish, it is important to underscore the fact that Maine's freshwater fish fauna is today becoming increasingly homogenized. Presumably, this is often to the detriment of native assemblages – it always reduces the extent to which systems are pristine. Maine is not alone in suffering from the homogenization of fish assemblages – it is a trend that is occurring throughout the U.S. (Rahel 2000).

While there are many documented examples of fish introductions in Maine, we do not have a complete, quantitative, picture of the extent of this trend. There are several reasons for this: (1) adequate time-series data do not exist for many lakes -- at least in a readily available, computerized form; (2) older lake surveys tended to de-emphasize non-game species, so it is impossible to be sure of the early species composition even when historical data do exist; (3) there are too many lakes and streams to systematically survey.

Introduced fish species may impact native species directly via predation, as is the case for landlocked salmon and brook trout in the Rangeley Lakes (Kendall 1918, Bonney 2005) or indirectly via competition for food and/or habitat. The current public controversy over attempts to restore populations of anadromous alewives stems from the concern that alewives will compete for food and thus impact landlocked salmon and smallmouth bass populations. Evidence from a lengthy study of Lake George, however, suggests that alewife populations can be re-introduced without negatively impacting gamefish species (Kircheis et al. 2002). Furthermore, it is thought that alewives, migrating upstream at the same time that sea-run salmon are migrating downstream, would provide some cover from predation for the young Atlantic salmon. However, Gately (1978) has suggested that smelt growth rates decreased in Echo Lake (Mount Desert Island) following the intial introduction of alewives, probably as a result of similarity in diets. Although there are no equivalent data from Maine, evidence from Canada suggests that the impacts of an introduced fish species (smallmouth bass) on native species (lake trout) depends in part on the composition of the lake's fish community, specifically whether or not pelagic prey species are present (Van der Zanden et al. 2004).

There are few published case studies documenting the impacts of introduced fish species in Maine. However, there is a wealth of qualitative knowledge about these impacts within the community of biologists managing Maine's lakes and streams. In most cases, studies that have addressed the impacts from fish introductions have focused on individual species, often using growth rates of these species, rather than impacts on the full assemblage. Examples include Kircheis et al. (2002), Lackey (1968), Wohnsiedler (1965), Gately (1978); other sources of information include Warner and Havey (1985) and Bonney (2005). A number of reports published by MDIFW include references to impacts on fish growth, population structure, etc., associated with newly introduced or stocked species.

Introductions of Species Other Than Plants and Fish: The LWRC (2002) advisory list (Table 4.4.) includes ten invertebrate species, six of which are presently recorded from Maine. While not yet in Maine, the Asian clam (*Corbicula fluminea*) and the zebra mussel (*Dreissena polymorpha*) are both considered likely to reach Maine (LWRC 2002). It is likely that many Maine waters are too dilute (insufficient dissolved minerals, especially calcium) for the zebra mussel to become established or thrive. Based on alkalinity data from the probability-based survey of the Environmental Monitoring and Assessment Program (EMAP), Whittier et al. (1995) suggested that two regions of Maine in the central and northeastern areas of the state are at high risk for future zebra mussel colonization, i.e. lake water expected calcium concentration greater than 12 mg/l.

Predation by Birds & Mammals: This "threat" – a natural phenomenon, of course – applies principally to Atlantic salmon, where numbers are so low that any predation is potentially significant in terms of recruitment and population size. Although there has been some concern over predation by seals, there is apparently little hard data on the role of seals in the decline of salmon. Predation by cormorants is perhaps of greater significance for salmon stocks (NOAA and USFWS, 2004).

Aquaculture: Salmon culture is a threat to other aquatic species, particularly wild Atlantic salmon, for two main reasons. First, high fish densities in cages may be a source of pathogens that can infect wild salmon (e.g. infectious salmon anemia and salmon swimbladder sarcoma). Second, aquaculture escapees may potentially contaminate wild genetic stock, particularly since cultured salmon were (until recent legislation outlawed this practice) primarily derived from European stock (NOAA and USFWS 2004). Stocking of various fish species, in general, can influence the genetic composition of fish populations (e.g. Bonney 2005).

Human "Take": This is likely a significant threat for some species. Four examples of human "take" are:

> (i) the pet trade, primarily for amphibians and reptiles. Compton (1999) has estimated that the annual removal of a single adult from a population of 100 wood turtles would lead to a 60% decline in population size over 100 years; annual removal of two individuals would lead to extirpation of the population within 60 years.
>
> (ii) accidental road mortality (amphibians and reptiles);
>
> (iiii) over-harvest of sensitive fish species (e.g. formerly Atlantic salmon – angling for this species is now illegal in freshwaters; potentially for eels; lake whitefish); and
>
> (iv) harvest of Atlantic salmon in the marine habitat. Commercial harvest of wild salmon, particularly in the Greenland area, has long been considered a significant threat to the restoration of North American stocks. Recent international agreements will likely reduce the extent of commercial fishing of salmon stocks, although harvest for internal consumption within Greenland is still permitted (NOAA and USFWS, 2004).

4.6 "Global" Threats (i.e. arising from outside of the state)

Several factors that potentially threaten Maine's freshwater systems and biodiversity are externally sourced. Marine harvest of Atlantic salmon was mentioned above. Climate change could have major repercussions for lake and stream communities, but consideration of this topic is outside of this report's scope.

Atmospheric deposition is one of the most ubiquitous non-point sources of chemical pollution to ecosystems (Stoddard et al., 2002). Two groups of contaminants introduced to Maine via atmospheric transport have been the subject of considerable research in recent years: (i) sulfur and nitrogen, and resultant acid deposition; and (ii) mercury.

Acidity: Extensive research outside of Maine indicates that acidic lakes often have lower numbers of fish species and that acidification from atmospheric deposition adversely impacts fish populations (e.g. Haines and Baker 1986). pH may have direct or indirect consequences for other taxonomic groups.

Current concerns about acidic conditions in Maine focus primarily on the Downeast rivers and the recovery of Atlantic salmon. Ongoing research is focusing on the linkages between pH, aluminum and DOC in the salmon rivers, and influences on salmon physiology, particularly during the stressful period of smoltification. (Magee et al., 2001, NOAA and USFWS 2004). There is evidence that Maine Atlantic salmon have unusually low levels of sodium and potassium ATPase in gill tissue and that this may be impacting smolt survival. An upcoming project will experimentally lime sections of a salmon river to evaluate if this would ameliorate the effects of episodic acidification during critical periods of the salmon life cycle in streams. Available data suggest that brook trout are more tolerant of combined aluminum / acidity stress than Atlantic salmon (Smith 1991)

It is important to distinguish between naturally acidic systems and those that may have become acidified as a result of acid precipitation. Early studies concluded that, in Maine, there was no evidence that acidification had led to reductions in lake fish species richness (Haines and Baker, 1986). Haines (1987) found no evidence of streams in the Downeast region becoming more acidic. However, he did note episodic increases in both acidity and dissolved aluminum and suggested that these could be toxic to fish. Kahl et al. (1991) and Kahl and Johnson (2003, 2004) have also concluded that there is no evidence for major changes in pH or calcium from the 1970s to the current time. Regional increases in dissolved organic carbon (DOC) may be contributing organic acidity, which may be offsetting recovery from any improvement in acidification linked to decreases in pollutant loading as a result of the Clean Air Act amendments of 1990 (Stoddard et al., 2002).

As discussed in Chapter 3, some Maine lakes and streams, particularly in the Downeast region, are naturally acidic and a number of these ponds are fishless (Figure 3.11) Hunter et al. (1985) showed that two acidic and fishless lakes in eastern Maine had higher numbers and biomass of invertebrates – presumably as a result of there being no fish predation. In his study of 22 Maine lakes, Brett (1985) found that lake pH had a strong effect on rotifer densities (Brett notes, however, that studies elsewhere have shown the reverse effect), whereas crustacean density and diversity was uncorrelated with either pH or any other physical or chemical variable. Analogous to the findings of Hunter et al. (1985), densities of nekton (surface-swimming invertebrates) were considerably higher in acidic, fishless lakes.

Mercury: Mercury is one of the most significant contaminants in the Northeast. While there are natural sources of mercury for Maine's freshwaters (Peckenham et al., 2003), a very significant proportion of mercury loading is derived from atmospheric transport of pollutants produced by power plants, incinerators and other sources outside of the state (Evers 2005). Mercury deposition is routinely measured at four sites in Maine, part of the Mercury Deposition Network (network can be viewed at: nadp.sws.uicu.edu) .

Using a number of indicator species (common loon, bald eagle, yellow perch, brook trout, otter and mink), nine major hotspots of mercury contamination have been detected in the Northeast (New York through Nova Scotia). Four of these hotspots are in Maine: in the Rangeley Lakes region, Upper Penobscot Basin, midcoast Maine and the St. Croix basin (Evers 2005). Seven of the nine regioinal hotspots are not associated with known mercury point sources. Waters with high mercury levels are generally distant from point sources and urban centers. In some areas, however, point sources do have significant impacts on a local scale.

Regionally, nine fish species have shown average tissue mercury levels in excess of the U.S. EPA limit of 0.30 ppm in fillets. In order of increasing mercury levels, these are:

> Yellow perch, Landlocked salmon, Chain pickerel, Largemouth bass, Smallmouth bass, Northern pike, Lake trout, White perch and Walleye. (Evers 2005)

Most mercury monitoring in Maine's biota has focused on the common loon (*Gavia immer*) and fish. Recently, Bank et al. (2005) compared mercury levels in two-lined salamanders (*Eurycea bislineata*) from two regions in Maine (Acadia National Park and Bear Brook watershed) with those in Shenandoah National Park. MDEP's Surface Waters Ambient Toxics program has been monitoring residues in fish and other tissues since the mid 1980s. Fish consumption advisories have been in place since 1994. At a regioinal level, 98% of New England lakes contain fish with methyl mercury levels that exceed the critical level for birds (Yeardley et al, 1998, cited in Evers et al., 2002). Common loons breeding in Maine have the highest mean mercury blood levels in the U.S. At least 26% of the breeding loon population in Maine is at risk from in-body mercury levels, and 19% of eggs are impacted. Risk levels vary spatially in response to methylmercury availability, which is in turn affected by lake hydrology, biogeochemistry, habitat and topography.

Kramar et al. (2005) demonstrate that loon blood mercury levels are closely associated with land cover type in the buffer area around loon territories – higher wetland densities in the surrounding area were associated with higher blood mercury levels in the loons. In another study (Pennuto et al. 2005), the virile crayfish (Orconectes virilis) has been shown to be a good indicator of mercury levels in stream systems.

Other recent research on mercury in Maine's freshwater biota include the following studies:

- Mercury in two-lined salamanders: Tissue concentrations were higher at Acadia National Park than at Shenandoah National Park (Bank et al. 2005). Levels were higher in salamanders than in brook trout and most of the mercury was in the form of methylmercury. At Acadia, mercury levels were higher in unburned watersheds than in areas burned by a major fire in 1947.
- Predatory fish species in Acadia National Park: Mercury levels in smallmouth bass from one pond (Hodgdon Pond) were 2.5 times the statewide average for this species, perhaps because hypolimnetic deoxygenation in this pond enhanced bioavailability of mercury. Concentrations in smallmouth bass in other ponds on MDI were lower; overall levels in the island's predatory fish appear to be similar to statewide averages. Mercury levels in salmonids are lower than the statewide average. (Burgess 1997)
- 117 randomly selected lakes were sampled for fish tissue mercury levels in 1993. Concentrations in brook trout were positively associated with fish size, lake elevation and watershed:lake area ratio. Mercury in smallmouth bass was positively associated with fish size and water color. Overall, mercury concentrations in predatory fishes appeared to be controlled by life history patterns as well as water chemistry. (Stafford and Haines 1997)
- Smelt in three northern Maine lakes had unusually high levels of mercury, probably contributing to the elevated levels in predatory species. Mercury levels in lake trout in a lake that did not contain smelt were lower than the two lakes that did. (Akielaszek and Haines 1981)
- Mercury concentrations in fish from the paired watersheds at Bear Brook were compared. It appears that experimental watershed acidification may be decreasing the export of organic matter, reducing the amount of mercury available for methylation and uptake by brook trout. (Abbott 1994)
- At the same paired watersheds site, mercury concentrations in sediment and invertebrates were not significantly different between acidified and control watersheds. (Powell 1997)
- Mercury in American eels from the Pleasant River (Washington County) were significantly higher than from the East Machias and Medomak Rivers. (Leaman 1999)

While there are considerable data on mercury levels in the ecosystem, much less is known about the ramifications of this contamination on aquatic ecosystem processes and structure. In fish, mercury can adversely affect embryo maturation, growth and hormonal status. At higher contaminant levels (0.88 – 8.46 ppm in diet), spawning success is decreased by between 50% and 64% (Evers 2005). Webber (1998) has shown that elevated mercury concentrations in golden shiner impact fish behavior in such a way as to make them more susceptible to predation. Thus it could be that piscivorous birds are, in effect, biassing their feeding toward more highly contaminated prey. The area of ecosystem responses to mercury contamination is clearly one that needs considerably more research (D. Evers, pers. comm.).

Table 4.1: Overview of threats to Maine's freshwater species and communities.

STRESS PATHWAYS ►	PHYSICAL HABITAT DEGRADATION / LOSS								WATER CHEMISTRY								BIOLOGICAL PERTURBATIONS		
STRESSORS ▼	Habitat loss/degradation	Fragmentation	Channel morphology modification	Sediment quality / quantity	Coarse woody debris	Riparian vegetation: reduction	Thermal Regime	Impeded Passage	Nutrient enrichment	pH & Alkalinity	Aluminum	Mercury + trace metals	Salt	Pesticides	Endocrine disruptors	PBTs *	Pathogens	Predation / Competition	Removal / Direct Mortality
BARRIERS																			
Dams/Weirs	X	X	X	X			X	X										X	
Bridges / Culverts	X	X	X				X	X											
Beaver Dams	X	X	X	X			X	X										X	
HYDROLOGIC REGIME MANAGEMENT																			
Stream Flow Regime Modifications			X	X	X		X												
Lake Water Level Modifications							X											X	X
Water Extraction	X	X					X												
LAND / WATER USE																			
Mining				X						X	X	X							
Timber Harvest		X	X	X	X	X	X		X										
Agriculture	X	X		X	X	X	X		X	X				X	X				X
Residential/Commercial Development	X	X	X	X	X	X	X		X				X	X	X				
Roads		X		X									X						X
Peat Harvesting	X			X															
Point Source Pollution							X		X			X			X	X			
BIOLOGICAL																			
Invasive Species	X																	X	
Other Spp. Introductions																	X	X	
Predation by Mammals/Birds																		X	
Aquaculture									X								X	X	
Local Human "Take"																			X
GLOBAL																			
Harvest (=human take)																			X
Contaminants										X	X	X							
Climate Change	X						X											?	

* PBTs: persistent bioaccumulative toxins.

Table 4.2: Comparison of numbers of dams in four data sets.

GIS Coverages:	
National Inventory of Dams:	782
State of Maine Dams Database:	807
SPO / Elder Database:	
“Unregistered” dams:	860
“Registered” dams:	735
Total Unregistered & Registered:	1,595
Breached Dams:	226
Net Total Dams:	1,369
MDIFW Lakes Index Database:	
# surveyed lakes with no functional dam:	1,451
# surveyed lakes with minor dam:	435
# surveyed lakes with major dam:	79
MDEP Hydropower Projects Database:	
# FERC-approved projects:	102
# FERC non-jurisdictional projects:	12
# FERC-licenced projects:	74

Notes:

(1) Both GIS coverages appear to be based on the same original data set. Most records in these databases were last revised in 1981; some records are today inaccurate (C. Fay, Penobscot Indian Nation, pers comm.)., but no attempt has been made to revise any records.

(2) SPO / Elder database was produced in 1987 and provided by B. Elder. It consists of a printout of dam records (electronic file is not available) and a hardcopy map of dam locations.

(3) MDIFW lakes database contains information on dams only for those lakes that have been surveyed for fisheries by MDIFW. A minor dam is defined as increasing the surface area of the pre-dam lake by < 50%. A major dam is defined as increasing surface area by >50%. (Note that metadata for this database uses the term “flowage”, but this almost certainly refers to surface area.)

(4) MDEP hydropower projects data are from “Hydropower Projects in Maine” (July 1, 2002).

Table 4.3: Number and cumulative height of dams in Maine, by watershed, and number of mainstem dams.
Data are from State of Maine dams GIS database, obtained 12/2002, and National Inventory of Dams (for Salmon Falls River).

Watershed (HUC-8)	# Dams	# Mainstem Dams 1)	Cumulative Height (ft) 2)
Upper St. John	3	**0**	83
Allagash	1	**1 (at Churchill Lake)**	20
Fish	5	**0**	41
Aroostook	27	**1**	676
Meduxnekeag	13	**2**	199
West Branch Penobscot	22	**6 (up to Chesuncook L.)**	676
East Branch Penobscot	5	**1**	74
Mattawamkeag	8	**0**	66
Piscataquis	28	**5 (incl. East Branch)**	365
Lower Penobscot 3)	59	**7 (incl. Stillwater Branch)**	636
Dead	18	**5**	154
Upper Kennebec	14	**11 (Upper and Lower Kenn.)**	371
Lower Kennebec	117		1909
Upper Androscoggin	15	**15 (Upper & Lower And.)**	236
Lower Androscoggin	87		1217
St. Croix	25	**5**	218
Maine Coastal	124	**1 (Dennys); 1 (E. Machias @ Crawford Lk.); 1 (Narraguagus); 2 (Union)**	1305
St. George – Sheepscot	55	**4 (St. George); 2 (Sheepscot); 1 (Medomak)**	835
Presumpscot	66	**10**	728
Saco	47	**11**	835
Piscataqua-Salmon Falls	38	**24 (including NH)**	556
TOTAL	**783**		**11,200**

1) Mainstem dam totals include some on lakes at headwaters of river.
2) Cumulative dam height includes all dams within watershed, not just the mainstem dams.
3) Penobscot River Partners list a total of 113 dams on the Penboscot River, of which 20 are hydro generating (www.penobscotriver.org; accessed 10/2004).

Table 4.4: Invasive freshwater plant and animal species on LWRC's "advisory list" (LWRC 2002) *, modified to reflect updated occurrence data available to MABP.

Scientific Name	Common Name	Present in Maine?	Closest Occurrence	Management Status**
Freshwater Plants				
Myriophyllum spicatum	Eurasian milfoil	YES, one location	MA, VT	P
Myriophyllum heterophyllum	Variable milfoil	YES		P
Myriophyllum aquaticum	Parrot feather	No	MA	P
Egeria densa	Brazilian elodea	No	NH	P
Hydrilla verticillata	Hydrilla	YES		P
Cabomba caroliniana	Fanwort	No	NH, Qu	P
Trapa natans	Water chestnut	No	NH	P
Potamogeton crispus	Curly leaf pondweed	YES		P
Najas minor	European naiad	No	VT, NH?	P
Hydrocharis morus-ranae	European frog-bit	No	VT	P
Nyphoides peltata	Yellow floating-heart	No	MA	P
Freshwater Fish				
Cyprinus auratus	Goldfish	YES		P
Cyprinius carpio	Common carp	YES		P
Scardinius erythrophthalmus	Rudd	YES (?)		P
Pomoxis nigromaculatus	Black crappie	YES		P
Esox masquinongy	Muskellunge	YES		P
Lepomis macrochirus	Bluegill	YES		P
Lepomis cyanellus	Green sunfish	YES		P
Umbra limi	Central mudminnow	YES		
Sander vitreus	Walleye	YES		P
Ictalurus catus	White catfish	YES		P
Gymnocephalus cernuus	Eurasian ruffe	No	Great Lakes	P
Neogobius melanostomus	Round goby	No		P
Micropterus dolomieu	Smallmouth bass	YES		S
Micropterus salmoides	Largemouth bass	YES		S
Esox lucius	Northern pike	YES		S
Perca flavescens	Yellow perch	YES		S
Morone Americana	White perch	YES		S
Crustaceans				
Orconectes rusticus	Rusty crayfish	YES		P
Orconectes obscurus	Obscure crayfish	YES		P
Procambarus clarkia	Red swamp crayfish	YES		P
Procambarus acutus	White river crayfish	YES		P
Mysis relicta	Opossum shrimp	YES		P
Cercopagis pengoi	Fishhook waterflea	No	Great Lakes	P
Bythotrephes cederstoemi	Spiny waterflea	No	Great Lakes	P
Molluscs				
Cobicula fluminea	Asian clam	No	CT	
Dreissena polymorpha	Zebra mussel	No	CT, VT	
Cipangopaludina chivesis	Chinese mystery snail	YES		
Cipangopaludina japonica		No		
Fish Pathogens				
Proteocephalus ambioplitis	Bass tapeworm	YES		
Myxobolus cerebralis	Whirling disease	No	RI	

* Original list can be found at www.state.me.us/dep/blwq/topic/invasives/invadvisorylist.pdf
** P = prevention and eradication; S = Selective control/impact management

Table 4.5: Annotated list of introduced fish species in Maine (modified from Halliwell 2003). See Chapter 6.4 for additional information on these species, and Appendix 11.5.2 for species distribution maps.

European / Asian Species Introduced to Maine ("exotic" species)

Common carp (*Cyprinus carpio*) - Russian food-fish, first introduced in 1880 (Richmond). Restricted in Maine to Merrymeeting Bay and the Kennebec River downstream of Fort Halifax dam.
Goldfish (*Carassius auratus*) - historic ornamental, mid-1800's introduction
Brown trout (*Salmo trutta*) - historic sportfish, late 1800's introduction
Rudd (*Scardinius erythrophthalmus*) - illegal transplants, suspected baitfish trade (1973)

North American Species Introduced to Maine

Green sunfish (*Lepomis cyanellus*) - illegal introduction, Sebasticook River drainage (<2002)
Bluegill (*Lepomis macrochirus*) - interstate (NH - 2000), illegal introduction, Sebasticook River drainage (<2002)
Gizzard shad (*Dorosoma cepedianum*) - naturally occurring range extension? (2000)
Central mudminnow (*Umbra limi*) - accidental release from nearby baitfish dealer? (<1999)
White catfish/bullhead (*Ameiurus catus*) - accidental stock?, illegal transplants (1990's)
Eastern silvery minnow (*Hybognathus regius*) - baitfish origins (1982)? (uncommon)
Spottail shiner (*Notropis hudsonius*) - baitfish origins (1979)? Common in lower Kennebec R.
Emerald shiner (*Notropis atherninoides*) - illegally released baitfish species (1970's)
Muskellunge (*Esox masquinongy*) - accidental migrant from intentional release in Quebec (St. John River) early 1970's
Northern pike (*Esox lucius*) - illegally introduced <1970's, continuing spread to present day.
Black crappie (*Pomoxis nigromaculatus*) - accidental stock (1969), illegal transplants (1925)
Walleye (*Sander vitreus*) - historical (early 1900's, Great Pond), illegal transplant - Long Pond
Largemouth bass (*Micropterus salmoides*) - historic stock, legal/illegal transplants since 1900
Smallmouth bass (*Micropterus dolomieu*) - historic stock, legal/illegal transplants since 1869
Rainbow trout (*Oncorhynchus mykiss*) - recent stock, actively managed (TU), late 1990's

Maine-Native Species Translocations (species that have been widely moved within Maine to locations where they were not originally present)

White perch (*Morone americanus*) - widespread historical sportfish and illegal transplants
Golden shiner (*Notemigonus crysoleucas*) - widespread baitfish species illegal transplants
Fathead minnow (*Pimephales promelas*) - common baitfish species illegal transplants
Alewife (*Alosa pseudoharengus* - landlocked) - historic forage stock and illegal transplants
Rainbow smelt (*Osmerus mordax* - landlocked) - historic forage stock and illegal transplants
Yellow perch (*Perca flavescens*)
Chain pickerel (*Esox niger*) - native to southern Maine
Managed salmonids: Brook trout (*Salvelinus fontinalis*) Lake trout (*Salvelinus namaycush*), Splake (Lake and Brook trout hybrid) & Atlantic salmon (*Salmo salar* - landlocked).

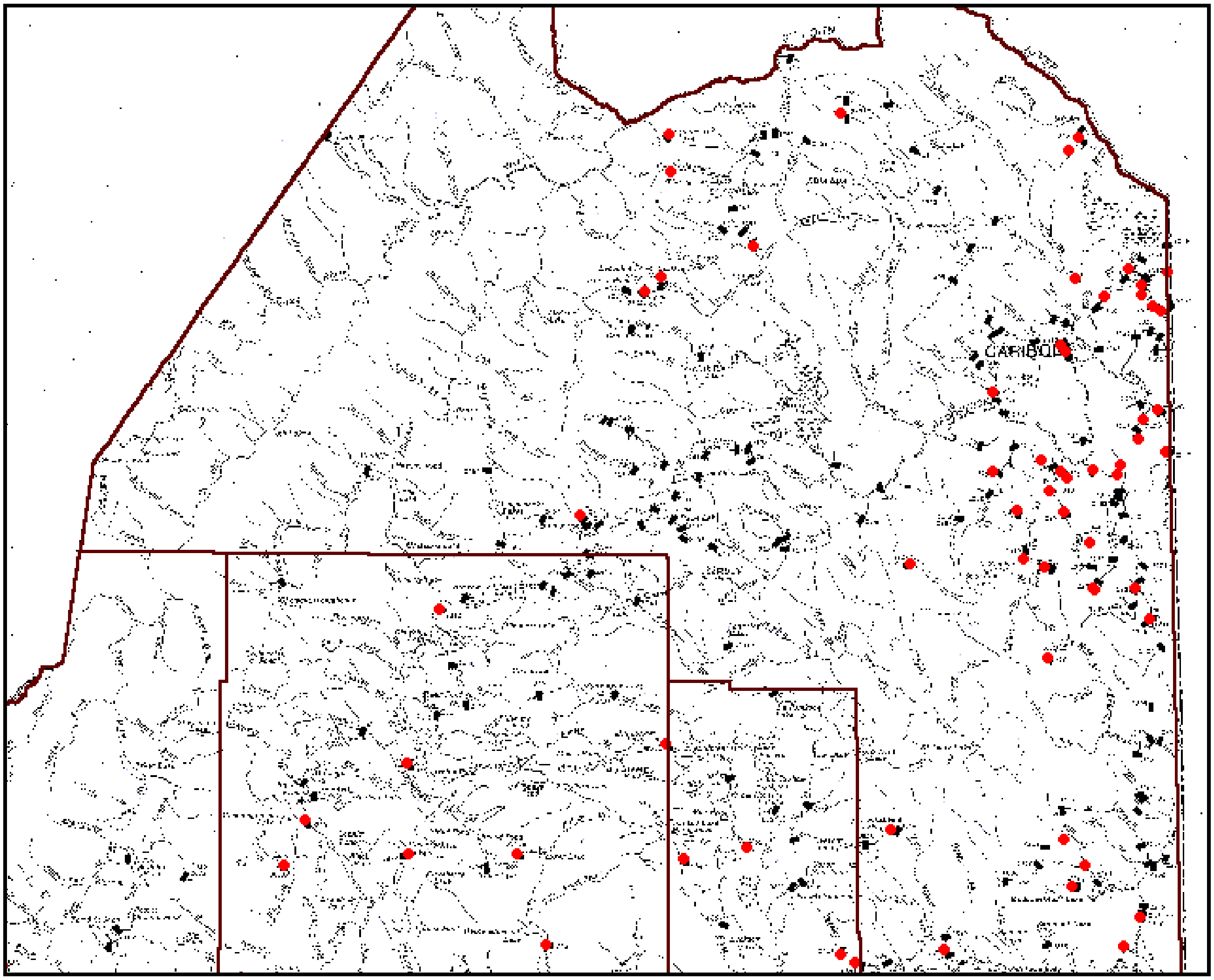

Figure 4.1: Dams in Northern Maine – a comparison of two databases.
Red dots are from MDEP GIS coverage. Black squares are from map produced by B. Elder (SPO, 1987). The difference in the spatial density of dams is particularly obvious in the northern part of the state. Note that the Elder map is not available as a GIS coverage but only as a hardcopy document. An image was created to overlay on the GIS dams coverage. The dotted lines are rivers and labels from the Elder map, which do not show clearly at this resolution.

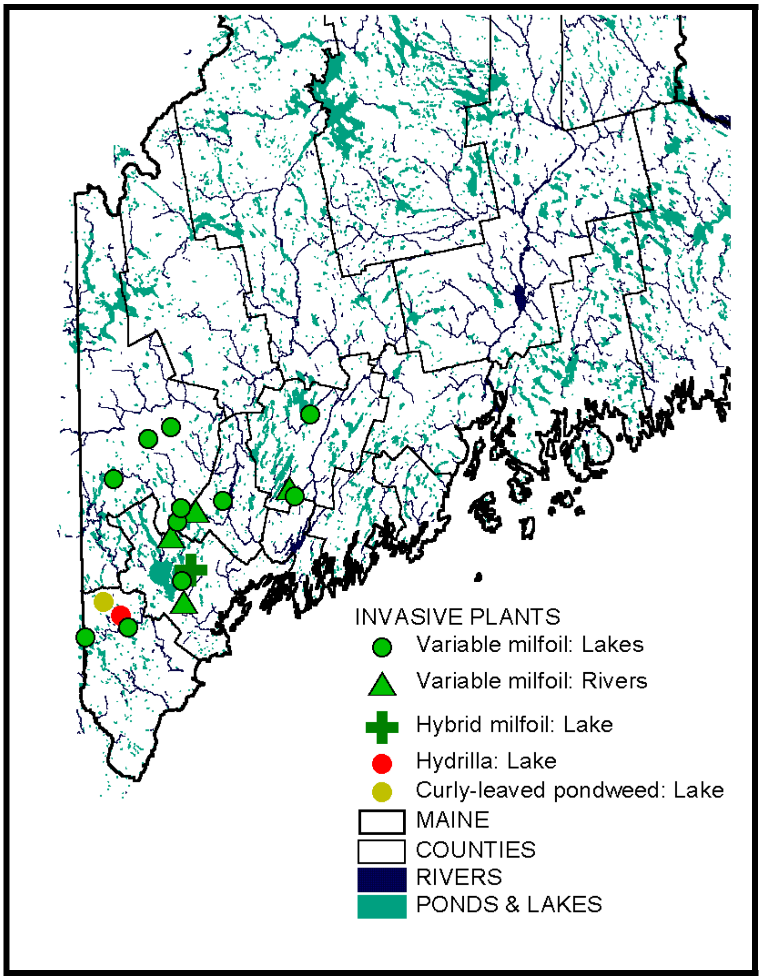

Figure 4.2: Documented sites of invasive aquatic plant species, as of June, 2004. Data source: MDEP.

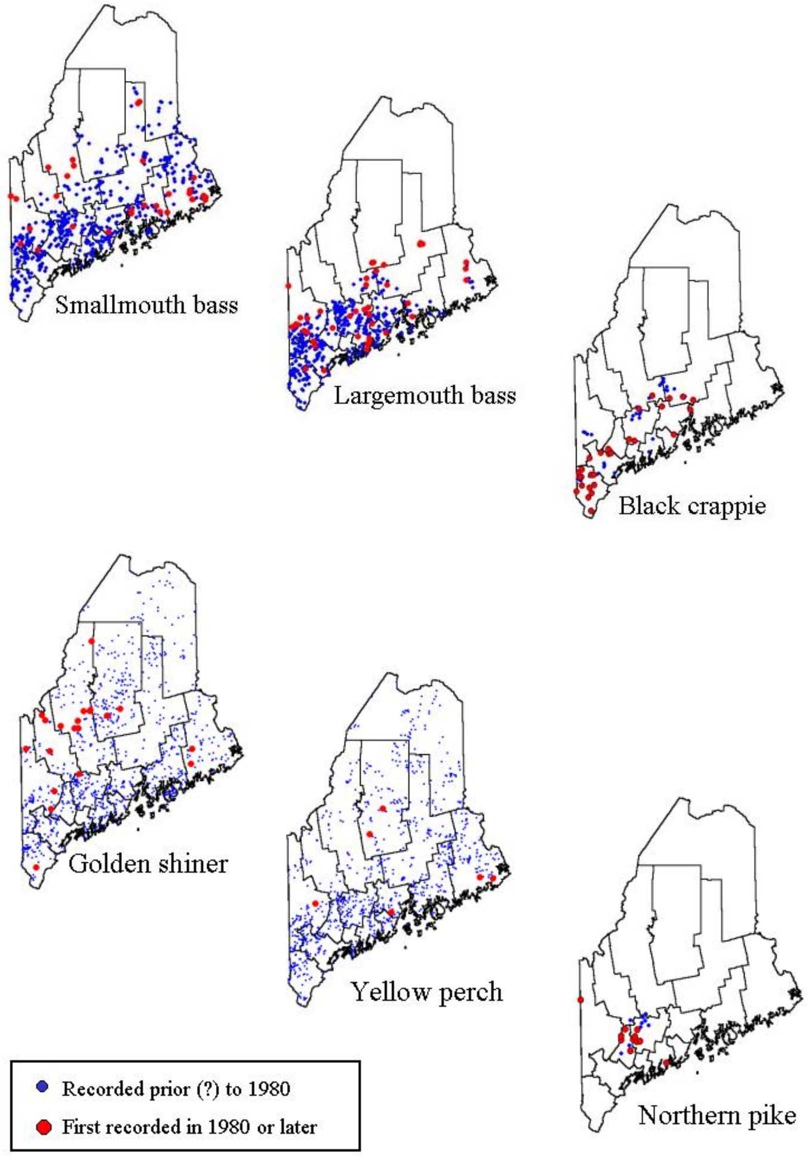

Figure 4.3: Examples of recent introductions / translocations of selected species in Maine (as of 2003).

Note that it is not known whether many of the locations with pre-1980 records of golden shiner and yellow perch (both Maine-native species) represent native or introduced populations. Data source: MDIFW fisheries biologists.