A Review of Academic Literature Related to Climate Change Impacts and Adaptation in Newfoundland and Labrador

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Contents

A Review of Academic Literature Related to

Climate Change Impacts and Adaptation in Newfoundland & Labrador

Executive Summary

Climate change and variation impacts every sector, environment, and resident of Newfoundland and Labrador. This review is an attempt to list and summarize the available literature considering impacts and potential adaptations within and relevant to Newfoundland and Labrador as of March, 2010.

The literature review is divided sectorally. References of general applicability are listed in the *Introduction*. Successive sections discuss the *Terrestrial Ecosystems, Marine and Fisheries, Coastal Zone, Water, Agriculture, Forestry, Transportation, Energy,* and *Tourism* sectors. The following two sections include references relevant to human *Health* and *Communities*. In addition, the references are listed *Regionally* within Newfoundland and Labrador in the following section. The *Conclusion* summarizes the research which is available on a regional basis throughout Newfoundland and Labrador, and indicates suggestions concerning future research needs.

Terrestrial ecosystems in both parts of the province are less exposed, sensitive, and vulnerable than those elsewhere in Maritime Canada. Species which could colonize the island under present climate conditions cannot reach Newfoundland without human assistance or in the absence of human monitoring. A moderate to substantial amount of research has focused on the boreal forests, barrens, wetlands, and lakes of Newfoundland, particularly concerning protected areas. Research on particular species is relatively limited.

Changes are ongoing in terrestrial ecosystems in Labrador, as indicated by treeline migration in the Mealy Mountains and the arrival of new species in westernmost Labrador. Substantial research has been conducted on boreal forests, treelines, and tundra areas in northern and central Labrador. Lesser research has been conducted on the boreal forest environment of western Labrador, and on the environments of southeastern Labrador. Caribou have been the subject of research, but other species have not been extensively investigated.

Marine waters require longer times to respond to climate changes, but also require longer times to revert to previous conditions. Marine ecosystems in the northwest Atlantic Ocean and

Gulf of St. Lawrence have been subjected to greater pressure from human activities than have many terrestrial environments in Newfoundland and Labrador, which has substantially reduced their ability to adapt to changes in the short term. Marine fisheries have been extensively investigated, with the impacts on cod and capelin being particular foci. Research has also concentrated on oceanography, storm activity, and the North Atlantic Oscillation. Gaps in Newfoundland-oriented marine research include impacts on shellfish, warm-water (Gulf Stream) species, and invasive species.

Numerous facets in coastal zones are impacted by climate change and variation, both directly by waves, tides, and storms, and indirectly by winds and weather systems generated over marine waters. Coastal zones are highly exposed, sensitive, and vulnerable to climate change and variation. The east, southeast, and west coasts of Newfoundland have been investigated in detail, including studies of individual sites. The northeast coast has not been as extensively studied. The coastal zone of Labrador has received relatively little attention, although generalized studies have been conducted in communities.

Changes in precipitation, particularly seasonal variations, can have limiting effects on water availability, especially where compounded by water quality issues. Sensitivity and vulnerability range from moderate to high, depending upon community size, options for water supply from new surface sources or groundwater sources, and treatment facilities. The use of water in agricultural and urban settings has recently come under review, but continuing research efforts are required. Study of freshwater fish has concentrated on Arctic char (Labrador) and Atlantic salmon (Newfoundland).

Flood susceptibility, another facet of water management, has been investigated in numerous communities in Newfoundland, but has received relatively little attention in Labrador. Adaptations include floodplain mapping and assessment of flood probabilities and magnitudes (future exposure), but also involve comprehensive land-use planning, restrictions on construction in floodplains, engineering measures, and preparation for future events.

For agriculture, variation is more critical than long-term change: a single frost, drought, or rainstorm can eliminate all the theoretical advantages resulting from an overall long-term change. The necessity for suitable growing conditions for crops and forage, and the requirement for seasonal availability of water, increases the sensitivity of this sector. Human factors act to increase vulnerability and reduce adaptive capacity. Additional research is required on impacts and adaptations for agriculture in Newfoundland and Labrador.

Forestry operations are less vulnerable than agriculture, due to the life-span and nature of the forest assemblages, although pathogens and pests represent a somewhat uncertain threat. Uncertainties exist with respect to fire, accentuated by the difference in fire regime between Newfoundland and Labrador. The time lag between the introduction of a new species and its growth to marketability, and that between development of a successful pathogen-control strategy and the recovery of the affected forest, limit adaptive capacity in forestry. Little work has been conducted on forestry in Labrador, but studies throughout boreal Canada are relevant to Newfoundland forestry. Additional research is needed concerning regeneration, fire, and management strategies.

The transportation sector is moderately vulnerable to climate change and variation, with concerns focusing around ferry services and road maintenance (including susceptibility to slope failures and coastal erosion). Research has concentrated on the Gulf Ferry-TCH system in western Newfoundland on the impacts of frost wedging on slope failures in western Newfoundland and the Burin Peninsula, and on the influence of coastal ice conditions in Labrador.

Unlike the challenges facing other sectors, those facing transportation and energy can be localized, and adaptations are already underway. Adaptive capacity is limited primarily by technical and financial considerations. In addition to impacts on offshore petroleum extraction, research could focus on ice storm impacts on power lines.

Tourism in Newfoundland and Labrador has come under increasing study, particularly in western Newfoundland, but much additional work needs to be done (particularly in central Newfoundland). Potential exists for significant tourism-related research in Newfoundland, particularly in central and Avalon. Research elsewhere in Canada is of relevance to tourism-related impacts in Newfoundland. No tourism-related research specific to Labrador was noted, in common with the general shortage of research on tourism-related impacts in northern and Arctic regions in Canada.

Health-related issues are frequently combined with water quality concerns, and with assessments of rural (particularly First-Nations) and urban communities. Substantial variation exists among communities, and also is associated with individual events (such as contamination resulting from floods or hot, dry weather). The bank of available research outside Newfoundland and Labrador is valuable for adaptation within the province. In Labrador, health-related research has focused on northern and First-Nations communities. In Newfoundland, it has focused on rural, primarily fishery-related communities.

Communities differ widely demographically and socio-economically, with substantial differences existing between rural and urban communities and within each of these categories. Adjacent communities may be exposed to a particular climate-related hazard to the same degree, but differences in their available human and economic resources may result in great differences in sensitivity, and hence in vulnerability and adaptive capacity. Change should not be seen as an independent, solely-dominant actor, but as one of several stressors acting on communities. In Labrador, research has focused on northern, coastal, and First-Nations communities, comparable to communities elsewhere in the north. In contrast, although some Newfoundland rural communities have been studied in detail, it is more difficult to transfer experience and 'lessons' to other communities with different physical settings, resource bases, and demographic compositions. Research has focused on rural, primarily fishery-related communities.

Urban centres have the same degree of exposure to climate, but theoretically less sensitivity than adjacent rural communities, due to their larger availability of human and institutional resources and larger, more diversified economies. Some adaptation research has been undertaken in urban communities in Newfoundland, but no comprehensive study of an urban area has been undertaken. Very limited research has been conducted on any aspect focused on Happy Valley-Goose Bay or Labrador West.

Review of Academic Literature Related to

Climate Change Impacts and Adaptation in Newfoundland & Labrador

1. *Introduction*

Climate change and variation impacts every sector, environment, and resident of Newfoundland and Labrador. The volume of literature, both that directly considering impacts and potential adaptations in Newfoundland and Labrador, and works conducted in other places but which are relevant to provincial issues, continues to grow yearly. This review is an attempt to list and summarize the available literature as of March, 2010.

The review includes the literature relevant to the impacts of climate change and variation, and suggested adaptations. It only includes climate changes and variations which have occurred relatively recently (within ca. the past 100 years): details of the glacial history of Newfoundland and Labrador, or the history of natural climate changes over the past 10,000 years, for example, are not included here.

The literature review is divided sectorally. References of general applicability are listed in the *Introduction*. Successive sections discuss the *Terrestrial Ecosystems, Marine and Fisheries*, *Coastal Zone*, *Water*, *Agriculture*, *Forestry, Transportation, Energy,* and *Tourism* sectors. The following two sections include references relevant to human *Health* and *Communities*. In addition, the references are listed *Regionally* within Newfoundland and Labrador in the following section. The *Conclusion* summarizes the research which is available on a regional basis throughout Newfoundland and Labrador. Discussion concludes with consideration of the Exposure, Sensitivity, Vulnerability, and Adaptive Capacity with respect to climate change for the sectors within Newfoundland and Labrador, and lists suggestions for future investigations.

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1. Introduction – Page 1

2. *Terrestrial Ecosystems*

Although terrestrial ecosystems are frequently difficult to 'value' quantitatively (see Costanza *et al*., 1997; Gunderson *et al*, 2000), they are among the first sectors where climate change impacts can be recognized. Terrestrial ecosystems are dependent upon climate, as well as exhibiting seasonally-dependent biological rhythms and cycles. Climate-induced changes interact with several anthropogenic factors, principally those related to land management and resource use. Although northward migration under warmer conditions would be expected, and has been observed in many locations (see Deutsch *et al*, 2008; Price *et al*., 2001; Wang *et al*., 2006), the response will be complicated by the existing species assemblages, the interactions between new species and biological pests and predators, soil types (which limit colonization by vegetation), and slow response times of long-lived species (e.g. Holtmeier and Brolle, 2005; Masek, 2001; Sonesson, 2000). Different tree species also respond differently to increases in ambient CO_2 levels (Huang *et al*, 2007). Newfoundland's isolation as an island is an additional complicating factor: many animal and plant species which could survive under present climates have been unable to reach the island (see Lewis, 2005). Differences in responses of species to past climate changes, both within terrestrial ecosystems and between terrestrial and marine areas, have long been recognized by palaeoclimatological researchers (e.g. Kaplan and Wolfe, 2006; Sawada *et al*, 1999). Coastal regimes are particularly sensitive (e.g. Hughes *et al*., 2006a, 2006b; Levac, 2003).

Theoretically, forests would expand both to the north and to higher altitudes in Labrador. A combination of techniques, including direct observation, GIS, and dendrochronological analysis, has established ongoing changes in treelines throughout Labrador and adjacent Québec (Gamache and Payette, 2004; Gingras *et al*, in preparation; Jacobs *et al*. 2006; Loader, 2007; Munier, 2006; Munier *et al*., 2010; Payette, 1993, 2007; Trindade, 2008). The longer-term response to climate changes can also be identified through both dendrochronological (Bégin *et al*., 2007; Briffa *et al*, 1994; D'Arrigo *et al*., 2003, 2008, 2009) and pollen and microfloral studies (Elliot-Fisk *et al*., 1982; Kaplan and Wolfe, 2006; Lamb, 1985; Short, 1978; Short and Nichols, 1977). Although most research in Labrador has focused on black spruce, the most common species throughout the forest and at the treelines, other work has investigated white birch (Foster and King, 1986). Jack pine is currently expanding in southwestern Labrador (see Catto, 2006 and references therein; Rudolph and Laidly, 1990). In Newfoundland, most research has concentrated on forestry-related issues (discussed in the *Forestry* section).

Phenological spring, marked by budding-out, flower blooms, and bird migrations, has generally advanced by ca. 1 week in eastern North America since 1959 (see Bonsal and Prowse, 2003; Schwartz and Reiter, 2000; White *et al*. 2009), although significant regional and local variation exists. For many species, the occurrence of cold nights after the onset of the phonological spring is of greater significance, particularly in the mid-boreal forest environment of central and eastern Newfoundland. Frequent episodes of winter thaw and late spring frost have lead to widespread tree crown dieback in yellow birch throughout eastern Canada (Bourque *et al.,* 2005; Campbell *et al.*, 2005). Winter climate is also a significant driver of black spruce growth (Berninger, in preparation). Biogeochemical processes, including CO_2 production, operate as feedback in boreal forests under changing climate (Campbell *et al*., 2009; Deutsch *et al*, 2008), and can complicate palaeoclimate interpretation (see D'Arrigo *et al*., 2008; Foster and King, 1986; Munier *et al*, 2010).

In general, ecotonal boundary areas (such as treelines) and landscapes with unique vegetation assemblages are considered to be most susceptible to change (Hermanutz *et al*, 2004; Rose and Hermanutz, 2004; Slater, 2005). Small populations of isolated plants are the species at potential risk of extinction (e.g. Hermanutz *et al*., 2002), unless overriding geological conditions prevent new species from becoming established (e.g. Ryan, 2006).

In addition to the possibility of encroachment along treelines, tundra and barrens areas are also susceptible to change (Bean and Henry, 2001; Jacobs *et al*, 2006; Parks Canada, 2007; Prowse, 2009; C. Yurich, 2006; N. Yurich, 2005). Areas currently underlain by permafrost currently are widespread in northern and central Labrador (e.g. Brown, 1975; Heginbottom, 1995). Discontinuous patches are present in southern Labrador, and at altitude in the Mealy Mountains and the interior of the Northern Peninsula (Berger *et al*., 1992; Clark and Schmidlin, 1992). Climate warming is expected to cause degradation of permafrost in areas near its southern or lower altitudinal limit (Lawrence and Slater, 2006; Schuur *et al*, 2008; Smith, 2009; Smith and Riseborough, 1996, 2002; Wang and Allard, 1995; Zhang *et al*., 2008a, 2008b). In addition to the temperature effects on ground stability, permafrost ablation has negative impacts on plant species that utilize the micro-terrain features created by seasonal freeze-thaw (Sutton, 2002; Sutton *et al*., 2006).

Barrens environments are influenced by seasonal frost activity, which can be altered through combinations of climate, removal of vegetation, reduced snow cover, and human activity (e.g. Catto, 2006; Henderson, 1968; Speller, 2001; Taylor, 1994; Zhang *et al*., 2008c). A combination of slow rates of organic accumulation, and vulnerability to fluctuations in temperature and water supply, makes peat areas particularly susceptible to changing climate (Davis, 1993; Tarnocai, 2006, 2009; Tarnocai and Kienast, 2003).

Lakes and wetlands are subject to changes in chemistry and organic content under the influences of changes in temperature and hydrologic regime (Bello and Smith, 1990; Blenckner *et al*., 2006; Clair *et al*, 1996; Petzold, 1980; Prowse *et al*, 2009; Schindler *et al*., 1990; Walker *et al*, 1991). This is particularly true in lakes that have been disturbed by the introduction of contaminants (e.g. Cameron *et al*., 1998; Christopher, 1999; Paterson *et al*., 2003). All wetland plants, including blueberries (Vander Kloet and Hill, 1994), and pitcher plants (Trzcinski *et al*., 2005a, 2005b) will be influenced by changing climate.

The seasonal migration of white-tailed deer in New Brunswick is restricted by deep snow cover (Sabine and Morrison, 2002). Milder winters in southwestern Labrador may allow this species to expand its range northeastward. Caribou populations in both northern Quebec and Greenland decline during periods of warmer winters (Post and Stenseth, 1999), a pattern noted in the George River herd by Boudreau *et al* (2003), Jacobs *et al* (1994), and Laing *et al* (2002). The available data suggest that woodland caribou populations of Newfoundland and Labrador will be negatively affected under climate warming. Muskoxen in Labrador (Chubbs and Brazil, 2007) and pine marten (Wilbert *et al*, 2000) also respond to changes.

Birds are subject to problems associated with climate variability, particularly changes in the phenological spring. The timing of bird migration is also affected by increases in spring temperature, although long-distance migratory birds appear to alter the timing of migration in response to changes in weather and phenology (Marra *et al.*, 2006). The spectrum of bird life in a region represents many different habits and habitats. As they are widely observed and studied by both birders and researchers, they have the potential to be useful indicators of environmental change (Boucher and Diamond, 2001; Diamond, 2009; Francis, 2007). Recent research on songbird migration has been conducted by Calvert *et al* (2009a, 2009b), Dalley *et al*. (2008, 2009), and Taylor (2006). Settington *et al*. (2000) investigated woodpecker abundance in Newfoundland. Boyd and Madsen (1997) considered the impacts on arctic-breeding populations. In addition, substantial research has been conducted analyzing the impacts on marine birds (discussed in the *Marine* section of this review).

Substantial research has been conducted on boreal forests, treelines, and tundra areas in northern and central Labrador. Lesser research has been conducted on the boreal forest environment of western Labrador, and on the environments of southeastern Labrador. Caribou have been the subject of research, but other species have not been extensively investigated.

In Newfoundland, a moderate to substantial amount of research has focused on the boreal forests, barrens, wetlands, and lakes, particularly concerning protected areas. Research on particular species is relatively limited.

Study Needs and Adaptations

The approaches to minimize climate impacts on terrestrial ecosystems are similar to those required to minimize other human impacts:

- development of integrated land use management strategies and policies;
- inventory of species numbers and health;
- protection of key habitats and species;
- baseline studies in protected areas;
- analysis of invasive species;
- development of adaptive measures to protect biodiversity;
- assessment of the sustainable level of human use of species;
- promotion of effective public involvement; and
- incorporation of climate change and variability analysis into species recovery and management plans.

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2. Terrestrial Ecosystems

Forests – Page 4

Tundra and Barrens – Page 8

Lakes and Wetlands – Page 12

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3. Marine and Fisheries

The potential for impacts due to climate change extends beyond fish species, to include numerous aspects of fishery operations, transportation, marketing, occupational health-and-safety, and community health (Catto *et al.*, 2006; Seguin, 2006; Sjare *et al.*, 2006). The role of climate change has varied throughout the Atlantic, both in place and over time, from that of "supporting player" to mere "background noise" (Catto and Catto, 2004; also see Hamilton, 2007; Rennie, 1990; Stokoe, 1988). Only in cases of collapse of stocks due to purely ecological causes could climate change be considered as the "driving force".

Most recent studies of marine species have indicated that climate change and/or variations and oscillations (particularly the North Atlantic Oscillation, NAO) influences the health of the populations. Substantial variations exist in local conditions and marine communities (e.g. Catto *et al*., 1999; Templeman, 1997).

For cod, studies are numerous (e.g. Chabot and Dutil, 1999; Chmura *et al,* 2008; Clark and Green, 1991; Drinkwater, 1996, 2005; Jakobsson and Astthorsson, 1994; Kukla *et al*, 1995; Levesque *et al*, 2005; Petersen and Steffensen, 2003; Pörtner *et al.*, 2008; Rose, 2004, 2005a; Ruppert *et al*, 2009; Sheppard, 2005).

Changes in cod stocks are also related to the capelin population, a preferred prey species. Capelin stocks are concentrated in the region extending from the 2°C isotherm southwards to the northern fringes of the Gulf Stream (Narayanan *et al.*, 1995). Spawning both offshore (Anderson *et al*., 2002) and in nearshore (Rose-Taylor, 2007) and beach zones (Andrews, 2005), around Newfoundland, capelin spawning time is inversely correlated to the temperature of the uppermost 20 m of the marine water column (Carscadden and Frank, 2002; Carscadden *et al.*, 2000; Carscadden and Nakashima, 1997; Narayanan *et al.,* 1995). Colder water conditions induce spawning later in the season. The health of capelin stocks is thus a critical indicator of impacts of changes in water temperature (Rose, 2005b).

Beach-spawning capelin are affected by changes in beach substrate and wave conditions (Andrews, 2005; Catto *et al*., 2003; Nakashima and Taggart, 2002; Taggart and Nakashima, 1987). Narrower and coarser beaches are less productive spawning areas, and eggs and hatchlings can be killed by storm activity. If spawning is delayed until the start of hurricane activity, the net result could be a loss of productivity.

Capelin is also a major food source for seabirds (Davoren and Montevecchi, 2003;

Davoren *et al.,* 2003; Regular *et al*., 2009). The impacts on ongoing changes in food sources, water temperature, and ice conditions have been documented for several species, including eider (Chaulk *et al*., 2007), puffin (Durant *et al*., 2003), razorbills (Gaston, 2008; Gaston *et al*., 2002, 2005; Lavers *et al*, 2008), and Northern gannet (Montevecchi, 2007; Montevecchi and Myers, 1997). A general overview for marine birds in Labrador is provided by Russell and Fifield (2001).

Changes in water temperatures, food availability, and the extent and timing of sea ice formation could impact seals and other marine mammals (Doniol-Valcroze *et al*., 2007; Friedlaender *et al*, 2010; Sjare, 2007; Sjare and Stenson, 2010; Sjare *et al.,* 2006). In several NL river and estuarine systems, seals have increased residence times by up to 3 months since the 1990s (Lenky *et al.,* 2006; Sjare, 2007). The increased time spent in estuaries by seals could lead to increased predation on both capelin and salmon. Changes in the distribution of walrus have been studied by Dyke *et al*. (1999).

Warmer water conditions in the Gulf Stream would result in lengthening of the 'soft-shell' phase of crab moulting. During this time, harvested crab cannot be effectively processed or marketed, leading to wasted effort and a loss of income for harvesters. Dionne *et al.* (2006) and Gravel (2002) studied the thermal sensitivity of snow crab. Other invertebrate species studied include squids (Dawe *et al*., 2007) and shrimp (Koller *et al*., 2007; Ouellet *et al*, 2007).

Potential impacts on aquaculture operations in NL have not been studied extensively, although research on the relevant species exists elsewhere in Atlantic Canada (e.g. Drinkwater, 1996). Khan *et al* (2006) looked at environmental influences on blue mussel quality, and Simms (2002) used GIS analysis to assess the effects of rainfall events on the suitability of aquaculture sites near Burgeo.

Plankton, the smallest but most numerous organisms in marine waters, have been investigated recently by DeSeve (1999), DeVernal; and Hillaire-Marcel (1996), Head and Sameoto (2007), Leterme and Pingree (2006), Rochon and DeVernal (1994), and Short (2007). The ongoing effects of changing climate are apparent with changes in plankton species distribution (e.g. Gewin, 2007; Reid *et al*., 2007).

Ongoing acidification of the ocean (Colley and Doney, 2009; Zeebe *et al*, 2008; also see Hughes, 2005) will also impact marine life. Circulation patterns in the North Atlantic Ocean have undergone both long-term change and significant variability (Battisti *et al*, 1995; Belkin, 1998; Bower *et al*, 2009; Colbourne, 1995, 2004; Danabasoglu, 2008; Dickson, 2003; Dickson *et al*., 2003; Emery *et al*., 2006; Kase *et al*, 2001; Maillet *et al*., 2005; Weaver *et al*., 2007; Wood *et al*., 1999; Yang, 2005). Studies concentrating on the Labrador Sea include Azetsu-Scott (2005), Dickson (1997), Felzer and Stanley (2001), and Yashayaev *et al*. (2008). The challenges facing communities dependent on marine capture fisheries are numerous, and require broadly-based adaptation efforts (Baethgen *et al*., 2005; Chuenpagdee and Bundy, 2005; Grafton, 2010; Templeman, 2007).

Increased irregularity and variability in storm frequency requires corresponding improvements in weather forecasting, with more locally-based facilities. Differences in recent trends in wind velocity and direction observed in sites around Cabot Strait (Catto *et al.*, 2006) indicate that meteorological conditions in individual areas represent different responses to overall regional climate conditions.

The North Atlantic Oscillation (NAO) is a cyclic variation in pressure regimes which influences northern North Atlantic environments and communities, including Newfoundland and Labrador (Czaja and Frankignoul, 2002; Delworth, 1996; Drinkwater *et al*., 2003; Hurrell, 1995; Hurrell *et al*., 2003; Mariotti and Arkin, 2007; Petrie, 2007; Reyers *et al*, 2010; Rivière and Orlanski, 2007; Song *et al*, 2009; Strong and Magnusdottir, 2008, 2010; Thompson *et al*, 1986; Topliss, 1997; Wohlleben, 1994). The NAO is based on the difference in winter atmospheric pressure regime between the low pressure system, usually located southwest of Iceland (Icelandic Low), and the high pressure system located near the Azores Islands (Azores High). A 'positive' NAO phase is defined as one where the pressure differential between the Icelandic Low and the Azores High is at maximum. A 'negative' NAO phase is defined as one where the pressure differential or gradient between the Icelandic Low and the Azores High is minimized.

A strongly positive NAO phase results in colder temperatures in Labrador, particularly along the coastline. Positive NAO conditions also result in temperatures at or slightly below average along the eastern coastline of Newfoundland (Topliss, 1997; Catto *et al.*, 2003). A positive NAO phase also produces strong northwesterly to northeasterly winds, varying with latitude from northern Labrador south to the Avalon Peninsula, large wind stresses on the ocean surface, low sea surface temperatures (especially in winter), and extended areas and durations of pack ice and brash ice. The effects of a positive NAO phase are most pronounced in the winter months, when the majority of the temperature change has been recorded (Hurrell *et al.*, 2003).

Strongly positive NAO phase years (e.g. winter 2000-2001) or periods within winters (e.g. mid-February to late March 2006) result in large snowfall totals along the east and northeast coasts of Newfoundland, particularly over the Avalon Peninsula (Catto *et al.,* 2003). Ice foot development can occur as far south as Placentia Bay during positive NAO winters. NAO effects are greater in eastern Newfoundland than along the west coast of the island or in the interior. In the interior of Labrador, NAO effects are muted by the prevailing westerly winds, bringing air from the continental interior.

The negative NAO phase produces the opposite effects, resulting in warmer, drier winters, particularly with reduced snow cover, to coastal Newfoundland. Southwesterly winds are dominant, sea ice is reduced or restricted, and ice foot development does not occur on southern Newfoundland beaches.

In addition to the NAO, and the somewhat linked Arctic Oscillation (Ambaum *et al*., 2001; Nie *et al*, 2008), other oscillations and cyclic variations occur on a variety of time scales (e.g. Bond *et al*., 1999; Deser and Blackmon, 1993; Kulan and Myers, 2009; Laîné *et al*., 2009; Marshall *et al*., 2003; Rennert and Wallace, 2009; Resio *et al*., 1995; Turney *et al*, 2005; Venegas and Mysak, 2000). Feedback relationships exist between ocean circulation and atmospheric circulation patterns, resulting in mutually reinforcing relationships (e.g. Cayan, 1992; Deser and Timlin, 1997; Drijfhout *et al*., 2008; Gerdes *et al*, 2003; Jongma *et al*, 2007; Levac and Mudie, 2003; Lorenzo *et al*, 2009; Lozano and Swail, 2002; Myers, 2003; Myers and Donnelly, 2008; Pickart *et al*., 2003; Robertson *et al*., 1998; Seidenkrantz *et al*., 2007; Shulz *et al*., 2007; Solignac *et al*., 2004; Wang *et al*., 2007).

The relationship between changes in frequency and magnitude of hurricanes and increases in air temperature or sea surface temperature is not clear at present, and consensus does not exist among hurricane specialists (for differing recent opinions, see Elsner *et al*., 2008; Emanuel at al, 2008; Kossin *et al*, 2007; Landsea *et al*, 2006; Saunders and Lea, 2008; Trenberth, 2005; Webster *et al*, 2005). Difficulties have centred around the linkage between general changes in climate and specific weather events, and the lack of detailed historical records (e.g. Chang and Guo, 2007). The number of hurricanes arriving in Newfoundland waters is not linked to the total number of hurricanes occurring over the Caribbean Sea in any particular year (Catto, 2006a, 2006b, 2010). Consequently, a cautionary policy would assume no significant changes in hurricane frequency for Newfoundland, but would also assume that significant events remain likely. Further discussion is presented in the *Coastal Zone* section of this review.

The duration and extent of sea ice activity will vary under climate change, but the anticipated effects differ throughout the coastal regions of Newfoundland and Labrador. The relationship between sea surface temperatures and atmospheric circulation patterns (including the NAO) and ice conditions in the Labrador Sea and adjacent Davis and Hudson Straits has been investigated by several researchers (e.g. Deser *et al*, 2000, 2002; Drinkwater *et al*, 1999, 2004; Kvamsto *et al*., 2004; Marko *et al*, 1991; Moros *et al*, 2006; Mysak *et al*, 1996; Newell, 1990; Strong and Magnusdottir, 2009; Vinje, 2001; Yao *et al*., 2000; Zhang *et al*, 2004). Changes in the distribution and thickness of both pack ice and landfast ice in the eastern Arctic (Baffin Bay) have also been investigated extensively (e.g. Dumas *et al*., 2006; Hilmer and Lemke, 2000; Parkinson, 2000; Piwowar, 1996).

Southwesterly winds can drive ice northeastward in the Gulf of St. Lawrence, resulting in thicker and more persistent ice along the Northern Peninsula north of St. Paul's. For species dependent upon ice-marginal conditions for breeding, the result is a displacement of the breeding areas (Johnston *et al*, 2005). Positive NAO conditions, dominated by northeasterly winds, would allow the ice front to move southwestward if the temperature of the Gulf of St. Lawrence waters remained unchanged.

Along the northeast coast of Newfoundland and Labrador, the strength of the Labrador Current carries ice southwards. During negative NAO years (e.g. 1996-1997; 2009-2010), maximum ice extent is restricted to the coastline north of Cape Bonavista, whereas during positive NAO years (1990-1992, 2004), coastal ice may extend south of Cape St. Francis, and ice foot development occurs on beaches in Placentia Bay. Positive NAO years are marked by increased northeasterly wind activity, which drives ice onshore in Labrador and northeast Newfoundland, obstructing harbours, blocking drainage at estuary and cove heads (causing local flooding), and resulting in ice shove, potentially damaging infrastructure (e.g. Catto *et al.*, 2003; Catto, 2006).

In areas where sea ice is used for winter travel, the relationship between ice extent and quality and human communities has been studied (e.g. Laidler, 2006). The development and establishment of open leads (polynya) is important for marine mammals, but poses a potential problem for human transportation. Polynya formation and persistence has been investigated by

Marsden *et al*. (2004) and Yao and Tang (2003).

Iceberg numbers are of significance for both shipping and offshore operations (negative) and for tourism (positive). Early speculation that iceberg numbers were directly linked to climate change (e.g. Wuethrich, 1999) has been replaced by more detailed research. The numbers of icebergs seen off the Newfoundland coast vary substantially from year-to-year (e.g. Petersen, 2003, 2005), but the variations are not primarily due to changing water temperatures. The largest single factor appears to be the initial supply of icebergs from glacial calving in Greenland (among many, recent studies include Amundson *et al*., 2008; Howat *et al*, 2007; Rial *et al*, 2009). The icebergs observed by tourists off eastern Newfoundland are small fragments of the original calved masses (Marko, 1996), and a single calving event in Greenland can eventually result in the arrival of numerous small icebergs in southern latitudes.

From a regional perspective, gaps in Newfoundland-oriented marine research include study of impacts on shellfish, warm-water (Gulf Stream) species, and invasive species. Throughout the province, marine fisheries have been extensively investigated, with the impacts on cod and capelin being particular foci. Research has also concentrated on oceanography, storm activity, and the North Atlantic Oscillation.

Study and Adaptation Needs

Research will continue into fish species (especially those of commercial interest) and changes in the marine environment, driven primarily by federal programs and academic researchers. Adaptation remains an issue for fishery-dependent communities, with ramifications extending beyond individual species. Impacts on fishery-dependent communities include operational and occupational health and safety concerns. Operational changes may result in more demands being placed on search-and-rescue personnel. This problem is compounded by currently existing regulations specifying vessel length without corresponding restrictions on beam and height.

Participants in capture fisheries are constrained in their potential responses to climate change and variation by the existing regulatory regimes. The ‘soft-shell crab’ problem represents one such example where the constraints of an established season may conflict with ideal harvesting time under the influence of warming Gulf Stream temperature. Maintenance of species licences, quota systems, and harvesting seasons is required for effective fisheries management. However, adjustments to seasons on regional bases may be required to effectively manage harvesting under changing water temperature and sea ice regimes.

Aquaculture operations are theoretically able to respond to climate shifts with more flexibility than harvesters of wild marine resources. This adaptation strategy would be most effective if aquaculture operations were sufficiently flexible to allow shifts in the species cultivated and the periods of cultivation. Impacts on aquaculture operations have not been extensively studied in Newfoundland and Labrador, and opportunities exist here for more research.

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3. Marine and Fisheries

Marine Species and Fisheries – Page 14

Marine Waters – Page 21

Climate Oscillations and Storms – Page 22

Sea Ice and Icebergs – Page 27

4. *Coastal Zone*

Several issues in the coastal zone are influenced by climate change and variation, including sea level rise, storm surge activity, and coastal erosion. These factors are discussed individually in this section of the review. The potential for economic loss in the coastal zone of NL is high, both as a result of coastal storm and wave dynamics (e.g. Bouws *et al*., 1996; Bruce, 2005; Catto, 2004, 2007; Danard *et al*, 2003; Debernard *et al*, 2002; Forbes *et al*., 2000, 2002; Knutsen and Tuyela, 2004; Mercer *et al*, 2002; Murty and Greenberg, 2002; Parkes and Ketch, 2002) and due to the increasing value of coastal infrastructure (see e.g. Batterson *et al*., 2006; Brun *et al*., 1997; Catto, 2008a, 2008b; Catto and Tomblin, 2009a; Paone, 2003; Plante, 2009).

All of these factors potentially influence transportation, and to lesser extents agriculture and forestry, in coastal areas. NL's coastal communities are also impacted by sea level rise, storm surge activity, and coastal erosion. Tourism in coastal zones is also significant in NL, and erosion impacts coastal infrastructure and results in changes in beach conditions. The references discussed here are thus also relevant to understanding the impacts of climate change in these sectors. Marine and freshwater aquatic species are discussed in the *Marine and Fisheries* and the *Water* sections of this review, respectively.

Sea Level Change

Changes in sea level are driven by a combination of local, regional, hemispheric, and global factors. Each coastal area responds differently to a different combination of factors, and the change in sea level is not identical either throughout the world or along Canada's Atlantic marine coastlines. From a coastal hazards perspective, the relative sea level with respect to the terrain is important, rather than the absolute volume of marine water in the ocean.

The observed sea level change in NL, and the projected changes in the future, depends upon the interaction between the changing volume of the oceans and glacioisostatic activity. The weight of glacial ice which covered the province during the most recent glaciation (beginning ca. 120,000 years ago) resulted in depression of the Earth's crust beneath the glacial load. Although the volume of sea water globally was lower during glaciation, due to the incorporation of large volumes of water in the terrestrial glacial ice, the recession of the ice during deglaciation exposed the glacio-isostatically depressed terrain to marine flooding along the coastline. Subsequently, the land began to recover from the glacio-isostatic depression. The rise caused the relative sea level to regress. In the Lake Melville area, glacio-isostatic regression is still occurring, resulting in progressively declining relative sea level. Northern Labrador may also be undergoing a very slow decline in relative sea level, although the available information is limited.

The decline in relative sea level in the remainder of the province continued until the coastal areas had rebounded in excess of their original pre-glacial elevation, resulting in glacio-isostatic overcompensation. The land then began to subside from the over-compensated positions, resulting in renewed sea-level rise. The rise in relative sea level throughout all the coastal areas of Newfoundland and southern Labrador resulted from a combination of subsidence from glacio-isostatic deformation, and the continuing increase in volume of the world's oceans due to ongoing melting of glacial ice. Evidence of transgression due to relative sea level rise is reflected by enhanced erosion along many NL beaches, and inundation of terrestrial peat deposits and trees.

Relative sea level change across NL as a whole over the past 2,000 years has been discussed recently by Carrera and Vanicek (1988), Forbes and Liverman (1996), Forbes *et al*. (1998), Liverman (1998), Shaw *et al*. (1998, 2001), Hilmi *et al* (2002), and Vasseur and Catto (2008). Shaw *et al*. (2002), Liverman *et al*. (2004) and Daly *et al*. (2007) discussed sea level changes across several regions of Newfoundland. Older analyses of sea level changes are cited in these works, but have not been included in this list of references[1].

In Labrador, glaciomarine features and relative sea level decline have been measured and discussed in the Lake Melville basin recently by Catto and Jacques Whitford (1998), Clark and Fitzhugh (1991), Kirby (1989), Klassen *et al*. (1992), Liverman (1997), Vilks *et al*. (1987), and Vincent (1989), building upon earlier work cited in these reports. Research in northern Labrador has been limited, including the work of Bell (1987) and Clark (1984, 1988) in addition to the Labrador-wide studies of Vincent (1989) and Klassen *et al*. (1992). The Porcupine Strand area was investigated in conjunction with mineral exploration (Meyer, 1990; Emory-Moore and Meyer, 1991; Williams, 1993). A later investigation on Porcupine Strand by Smith *et al*. (2003) found no conclusive evidence indicating the rate of relative sea level change, although dead trees in coastal situations may indicate rising sea level, resulting in killing of roots by salt water contamination.

In northern Newfoundland, relative rising sea level is evident on the Great Northern Peninsula at L'Anse-Aux-Meadows (Catto, 2006b; Catto and Vasseur, 2008; and unpublished research by Noordhof and Catto); Port-aux-Choix (Bell *et al*., 2005; Smith *et al*., 2005); and along the Gulf of St. Lawrence coastline (Proudfoot *et al*, 1988; Grant, 1989; Liverman *et al*, 2004; Catto, 2006b; Daly *et al*, 2007). Additional recent research on sea level changes in southwestern Newfoundland has been conducted by Batterson (1998, 2001), Bell *et al*. (2001, 2003), Catto (2006b, 2006d), Catto *et al*., (2006), Ingram (2004, 2005), and Rast (1999). In eastern and northeastern Newfoundland, regional and local studies include the work of Catto (1999, 2006a 2008b), Catto *et al*. (2000, 2002a, 2002b, 2003, 2006b), Jones (1995), Paone (2003), Paone *et al*. (2003), Shaw *et al*. (1998, 2001), and Smith *et al*. (2004a).

[1] References discussing sea level changes during and following deglaciation in Newfoundland and Labrador, but which do not discuss recent changes in sea level, have also been excluded.

Storm Surge Activity

Ongoing relative sea level rise accentuates the risks from storm surge activity, as successive storms impact progressively higher areas on shorelines. Sand-dominated beaches, coastal dune complexes, tidal flats and estuaries, and salt marshes are at greatest risk of inundation due to storm surges.

A storm surge is defined as the elevation of the water resulting from meteorological effects on sea-level. The storm surge elevation is the difference between the observed water level during the storm and the level that the tide would normally rise to in the absence of storm activity (Forbes *et al.*, 2004). Recent temporary variations in sea level associated with storm activity have been analyzed by Greatbatch *et al* (1990) and Thompson *et al* (2009).

Since 1990, several storm surges have resulted in property destruction in Newfoundland and Labrador (e.g. Brake, 2008; Cameron Consulting *et al*., 2009; Catto, 1999; Catto and Hickman, 2004; Catto *et al.*, 2003; Catto and Tomblin, 2009a, 2009b; Forbes *et al.*, 1998, 2000; Hickman, 2006; Smith *et al.*, 2004a, 2004b; Wright, 2004). Historical storm surge disasters in Newfoundland include the 'Great Independence Hurricane' of September 1775, which killed a large but undetermined number of fish harvesters and people in Avalon and Burin coastal communities and St-Pierre-et-Miquelon (possibly as many as 4,000; *see* Ruffman 1995, 1996; Stevens, 1995; Stevens and Staveley, 1991), and the destruction of La Manche and damage to other Southern Shore communities in 1966 (Catto, 2006a, 2008b; Catto *et al*, 2003). Emergency management and preparation in communities subject to storm surges, such as Channel-Port-aux-Basques (Catto and Tomblin, 2009a, 2009b, in press; McMillan, 2006; Seguin, 2006) is essential.

Coastal Erosion

Coastal erosion is generally concentrated in the most sensitive coastlines, including coastlines backed by aeolian dune complexes, along sand or pebble gravel beaches, or where unconsolidated sediments or weakly consolidated bedrock forms coastal bluffs. The dune-backed coasts of Newfoundland indicate the combined impacts of climate change and variability over terrestrial areas, differential amounts of sea ice cover, and human pressure. Ingram (2004) noted erosion at the rate of 0.7 m per month between December 2003 and April 2004 at Sandbanks Provincial Park. Limited offshore winter ice conditions in the Gulf of St. Lawrence (Forbes *et al*, 2002; Hill *et al*., 2002; Prinsenberg *et al*., 1997) allow wave attack throughout the year, accelerating erosion of both coastlines and dune complexes in western and southwestern Newfoundland (Catto, 1994, 2002, 2004, 2007; Catto *et al*., 2006; Ingram, 2004; Pittman and Catto, 2001). Limited amounts of sea ice in Conception Bay (see Hill and Clarke, 1999) also have facilitated winter erosion along that shoreline (Catto, 1994, 1999; Catto *et al*., 2003; Liverman *et al*, 1994a, 1994b; Pittman, 2004), and similar enhanced erosion is evident at other sites during winters where ice and/or snow cover is limited (Nichols, 1995; Catto, 2004, 2006a, 2006b, 2007; Catto *et al*, 2003). In contrast, years with anomalously extensive landfast ice or persistent snow cover are marked by reduced erosion (e.g. Boger, 1994; Liverman *et al*., 1994a, 1994b).

In eastern Newfoundland, there is a general correlation between a positive NAO state (marked by enhanced northeasterly winds) and winter storm erosion, resulting in coarser beaches with steeper profiles (Catto, 2004, 2006a, 2006b; Catto *et al*., 2003). Local factors, however, play a dominant role in the results observed at any particular beach. Erosion of coastal cliffs by frost action can also be correlated with aspect, wind direction, and temperature regime (e.g. Brake, 2008; Catto, 2003; Catto *et al*., 2003; Speller, 2001; White, 2002). In contrasts, beaches in western and southwestern Newfoundland display no correlation between the NAO state and erosion (Catto, 2006b, 2007; Catto *et al*., 2006; Ingram, 2004, 2005), reflecting the limited role of northeasterly winds in generating significant waves impacting beaches facing west and southwest.

Analysis of coastal areas allows assessment of processes and rates of erosion. Coastal erosion accentuated by wave action and sea level rise has resulted in the modification of beaches and erosion of coastal bluffs in several areas of Newfoundland, including Mobile (Catto and Etheridge, 2006; Etheridge, 2005; Etheridge and Catto, 2005; Jones, 1995; Catto, 2006a); Ferryland (Catto *et al*., 2003; Catto and Etheridge, 2006; Etheridge, 2005; Etheridge and Catto, 2005; Pink, 2004; Wright, 2004); Bear Cove (Catto and Etheridge, 2006; Etheridge, 2005; Etheridge and Catto, 2005; Strickland, 2002; Chance Cove (Weiland and Catto, 2000; Strickland, 2002); Biscay Bay (White, 2000); Peter’s River beach (Nichols, 1995); St. Stephen’s (Hamlyn, 1995); Golden Bay (Catto, 2003); St. Brides (Pink, 2004); Gooseberry Cove (Whelan, 2000); Big Barachoix and Ship Cove, Placentia Bay (Boger, 1994; Liverman *et al*., 1994a, 1994b); Placentia (Cameron Consulting *et al*., 2009; Shawmont Martec, 1985); Whiffen Head and Ship

Harbour, Placentia Bay (Griffiths, 1999); northern Placentia Bay (Pink, 2004; McNeil, 2009; McNeil and Catto, 2009; Rao, 2007); the Marystown-Burin area (Brake, 2008; Catto and Hickman, 2004); McIver's Cove (Nichols, 1994); Flower's Cove (Hicks, 1995); Holyrood (Blundon, 2006); and Conception Bay South (Batterson *et al*, 2006; Paone, 2003; Paone *et al*, 2003; Pittman, 2004; Prentice, 1993; Smith *et al*., 2004a, 2004b; Taylor, 1994). Catto *et al*. (2003a) analyzed the susceptibility of each 50-m segment of coastline to sea level rise, coastal erosion, and petroleum contamination for the shoreline from MacCallum east and north to Cape Bonavista. Coastal erosion issues for each provincial park, provincial scenic attraction, and ecological and wilderness area were summarized by Catto (2006b). Coastal erosion at Mistaken Point Ecological Reserve is currently under study by Thompson-Graham (in preparation).

The dynamics of oil spill and litter transport in coastal environments provides indications of current and wave activity related to coastal erosion, in addition to their value for pollution mitigation. Studies in eastern Newfoundland include Alam (2009), Catto (1999), Catto and Etheridge (2006), Catto *et al*. (2003), Etheridge (2005), Etheridge and Catto (2005), Griffiths (1999), McNeil (2009), McNeil and Catto (2009), and Pink (2004), building on the assessment of Owens (1994).

Regionally, the east, southeast, and west coasts of Newfoundland have been investigated in detail, including several studies of individual sites. The northeast coast (Cape Bonavista to Cape Onion) has not been as extensively studied. The coastal zone of Labrador has received relatively little attention, although generalized studies have been conducted in communities, particularly in northern Labrador.

Study and Adaptation Needs

There are three generic categories of adaptation options that can be used in areas affected by sea level rise, storm surge activity, and/or coastal erosion: planned retreat, accommodation, and protection. Planned retreat involves recognition of the inevitability of coastal erosion, and responds by abandoning the areas closest to the shoreline, or locating only temporary or expendable structures in these areas. Accommodation involves constructing structures in ways to minimize damage (e.g. by placing buildings on elevated pylons), or developing land-use and zoning plans that allow only structures which must be built on the shoreline (e.g. port facilities or fish-processing plants) to be located there, while prohibiting others (such as private residences).

Protection involves physical reinforcement of the shoreline, either by ‘hard’ measures (seawalls, rip-rap, groynes) or by ‘soft’ measures (e.g., planting vegetation).

The simplest way to accommodate a major hazard is planned retreat. This involves designating a building set-back limit, and establishing a zone along the coastline where no permanent construction is permitted. A long-term erosion rate is a useful guide to the establishment of set-back limits (e.g. Taylor, 1994; Young *et al*., 1996), and indicates where specific structures are in danger. As the majority of the erosion is accomplished by individual storms, hazard assessment requires consideration of the probability of the maximum impact of a particular storm, rather than solely involving monitoring and dealing with incremental, infinitesimal removal of sediment on a daily basis. The absence of long-term monitoring of coastal erosion means that present erosional rates may not serve to indicate the magnitude of previous (or future) events. Investigation of individual beaches and coasts using a variety of techniques, including LiDAR surveying (Webster *et al*., 2004, 2006) is a necessary prerequisite, but the determination of long-term erosional rates requires repetitive monitoring (e.g. Liverman *et al*., 1994a, 1994b; Young *et al*., 1996; Paone, 2003; Vasseur and Catto, 2008). Relatively few locations in NL have been investigated on a repetitive basis.

Accommodation can allow impacts on natural systems to occur, and adverse impacts on people are minimized by adjusting the human use of the coastal zone. This involves constructing structures in ways to minimize damage, or developing land-use and zoning plans that allow only structures that must be built on the shoreline, such as port facilities, to be located there, while prohibiting others, such as private residences. At present, accommodation is not commonly employed as an adaptive strategy in NL.

Protection is frequently used as an adaptive strategy, in which the effects of extreme events, ongoing erosion, and climate related changes to natural systems are controlled by soft or hard engineering. Soft engineering options include grading coastal bluffs to reduce erosion, and planting or maintaining existing vegetation. Seawalls, breakwaters, groynes, and emplacement of rip-rap and gabions, represent the most common adaptive measures (e.g. Cameron Consulting *et al*., 2009), and the measures most favoured by a majority of coastal residents and property owners. These hard engineering structures are expensive, require constant maintenance and observation, and can fail (e.g. Brake, 2008; Catto and Hickman, 2004; Catto *et al*., 2003; Wright, 2004) if not adequately designed, constructed, and maintained. Repetitive storm activity and rising sea level both pose problems to designers of hard coastal protection. In some areas, aesthetic concerns influence the design of shoreline protection. A protective structure may be simultaneously designed to provide a recreational walking trail, as in Placentia and Trout River.

Although most provincial legislation and municipal development plans (e.g. Paone *et al*., 2003) have provisions to protect coastal zones, very few integrate climate change in their long term planning and protection of these habitats, leading to incapacity to adapt to changes in sea level and coastal erosion. Under those conditions, most coastal infrastructure will either have to be moved or will experience damage over time. In most cases, lack of long-term planning, funding and land to move the infrastructure are the limiting factors for adaptation.

An important aspect of any adaptation strategy is development of an understanding amongst the residents in the community of the issues facing them. Without community support, neither planned retreat nor accommodation through zoning can be effectively implemented as adaptation strategies.

There has been substantial research on climate and weather impacts on the coastal zones of Newfoundland and Labrador. Further research could focus on:

- Ongoing monitoring of sensitive coastal areas
- Establishment of base-line data for coastal erosion, using LiDAR surveys and other techniques
- Investigation of the effects of storm surge activity
- Continuing analysis of storm-surge dynamics and synoptic climatology
- Assessment of the current rates of sea level change in coastal Labrador
- Consideration of the effectiveness of adaptation strategies
- Analysis of the rates and processes of marine coastal bluff erosion

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4. Coastal Zone – Page 29

5. Water

Changes in temperature and precipitation influence the hydrological cycle and will affect evaporation and runoff, and the amount of water stored in lakes, wetlands and groundwater (Bruce *et al*., 2000; Charman, 2002; Clair, 1998; Clair *et al*, 2003; Rivard *et al.*, 2003; Schindler, 2001). These impacts in turn result in changes in the quantity and quality of water; the magnitude and timing of river flows, and the time required for water resource renewal. These changes will both influence the availability of water for human use and impact upon freshwater habitats and ecosystems.

Present trends indicate that overall precipitation throughout most of Atlantic Canada, with the possible exception of western and central Labrador, will continue to increase (Cayan *et al*, 2002; Jacobs and Banfield, 2000; Vasseur and Catto, 2008). An overall increase in precipitation, however, can obscure significant differences in both year-to-year variations and seasonal water supplies. The effects of the North Atlantic Oscillation and other cyclic variations are significant influences on precipitation and other hydrologic variables (e.g. Coulibaly *et al*, 2000; Enfield *et al*, 2001; Mignot and Frankignoul, 2005; also see references in *Marine and Fisheries* section).

Increased precipitation does not necessarily lead to more water in rivers, lakes, and wetlands due to evapotranspiration and the seasonal timing of the rainfall. Under the influence of increased summer temperatures, the increased rate of evaporation from ponds may exceed the influx of precipitation, causing declines in water levels. Wetland areas and lakes throughout the province are sensitive to variations in hydrology (Bobba *et al*., 1999; Charman, 2002; Clair *et al*., 1997, 1998; Hecky *et al*, 1997; Lomond, 1997; Price *et al*., 2005; Rahman, 2009; Rollings, 1997). Declines in summer precipitation noted in several Newfoundland sites (Catto and Hickman, 2004; Slaney, 2006) have contributed to seasonal desiccation of streams and wetlands.

In boreal regions, a shift from snow to rain also has hydrological implications (Barnett *et al*., 2005; Boyer *et al*, 2010; El-Jabi *et al*., 2004; Lemay and Bégin, 2008)). Uncertainities in measurement of snow cover (Crevier *et al*, 1991; Salmonson and Appel, 2004) hence translate into uncertainities in predicting water availability. Changes in the timing of spring freshet (Cayan *et al*., 2002; Déry *et al*., 2005; Hodgkins and Dudley, 2006; Schindler, 2001; Sveinsson *et al*., 2008) and in the intensity of precipitation events (Stone *et al*., 2000; Trenberth *et al*., 2003; Vincent and Mekis, 2006; Zhang *et al*., 2001) also affect streamflow, which can impact water supplies, freshwater fish, and flooding. Extreme flooding events can pose difficulties for natural ecosystems as well as human communities (Hersh and Wernstedt, 2002). Ultimately, the flow of freshwater into the oceans also affects marine environments (e.g. Holland *et al*., 2006).

Global stream flow trends analyzed by Milly *et al.* (2005) suggest that flows will increase in Labrador (also see Déry *et al*, 2005), but will decrease throughout the remainder of Atlantic Canada. Declining flows have been noted in the Saint John and St. Croix Rivers of New Brunswick (Bruce *et al.,* 2003). Although further study is needed elsewhere in Atlantic Canada, and in Newfoundland and Labrador specifically, the predicted response in streamflow from the Milly *et al.* (2005) model agrees with results from western Canada and changes observed in Québec (e.g. Déry *et al*., 2005; Boyer *et al*., 2010). In some instances, the existing variability in annual and seasonal precipitation is greater than the anticipated impact of climate change (e.g. Richter and Barnard, 2004). The complexity of potential hydrological responses and the general lack of specific data (e.g. Bobba *et al*., 1999; Rahman, 2009; Slaney, 2006) is a severe limitation on prediction of hydrological consequences (see Minville *et al*., 2008).

Groundwater reserves in Newfoundland and Labrador contain water resulting from both recent precipitation, and that which fell years to decades ago. Water residence times are generally short, and wells are relatively shallow, so that summer drought has a rapid impact on groundwater availability (Rivard *et al.,* 2003). Water tables in deeper wells drilled into bedrock generally respond to yearly to decadal variations in precipitation and withdrawal.

In coastal communities, drawdown of the water table adjacent to the ocean in conjunction with sea level rise can allow seawater intrusion inland, eventually contaminating wells and rendering the water undrinkable. The most susceptible areas are coastal plains, such as along the Gulf of St. Lawrence. Rapid withdrawal of groundwater in coastal areas can result in saltwater intrusion within a relatively short period, as at L'Anse-aux-Meadows between mid-July and mid-August 2000 (Gina Noordhof, personal communication).

Where water resources are shared across sectors, municipalities, or provincial boundaries, climate changes can impact transboundary management (Bruce *et al*., 2003). Questions of governance arise when formerly abundant resources become limited, even on temporary bases (see Cervoni *et al*., 2008; Conference Board of Canada, 2007; de Loë, 2008; de Loë and Kreutzwiser, 2007; Mallik and Teichert, 2009). Renewed investment in water-related infrastructure may be desirable (Bouchart, 2007).

Lowered water levels in ponds or decreased river flows in some areas could lead to poor drinking water quality. Most municipalities throughout Newfoundland and Labrador depend upon surface water supplies, leaving them exposed to declines in water level in ponds and rivers, and contamination. A decrease in the supply of water to treatment plants, due to lower water levels, could increase turbidity, resulting in the need for a greater level of water treatment (Coote and Gregorich, 2000). Increases in temperatures, prolonged summer dry seasons, and flooding resulting from intense storm events could also increase the risk of contamination of drinking water by waterborne parasites, such as *Giardia*, *Cryptosporidium*, and *E. coli* (Charron *et al.*, 2004; Coote and Gregorich, 2000; Dales *et al*., 1991; Prüss-Üstün *et al*., 2008; Thomas *et al*, 2006). Health-related water supply issues have been considered for several Labrador communities (Harper, 2009; INAC, 2009; Martin *et al*, 2007b; Moquin, 2005) as well as in Nunavik (Martin, 2007; Martin *et al*., 2007a.).

Changes in streamflow volume, velocity, and water temperature have impacts on fish populations, particularly salmonids (e.g. Beamish *et al*., 1995; Bielak, 1996; Casselman, 2002; Crick and Sparks, 1999; Marcogliese, 2001; Schindler, 2001). Most freshwater species are adapted to a relatively narrow range of temperature conditions (Chu *et al*, 2005; Minns and Moore, 1992). With warmer water temperatures, salmonid species will most likely suffer range contraction as a result of changing habitat, introduced competitors and predators, and increased parasitism (El-Jabi, 2002).

Studies on impacts on Atlantic salmon include Bielak (1996), Chaput (1997), Condron *et al* (2005), El-Jabi *et al*. (2004), El-Jabi and Swansburg (2004), Friedland (1998), Friedland *et al*. (2005, 2009); Jonsson and Jonsson (2004a, 2004b, 2009), L'Abée-Lund and Aspås (1999), Mather *et al* (2008), McCormick *et al* (1999), Power (1990), Swansburg *et al* (2002), Todd *et al* (2008), and Walsh and Kilsby (2007). Impacts on hatchery salmon have been considered by Pankhurst and King (2010) and Peyronnet *et al* (2008). The impact of local conditions, including both geromorphology (e.g. Pennell, 1993) and water chemistry (e.g. Gibson and Haedrich, 1988), have also been considered. The availability of salmon as a food resource in Labrador (Felt, 2008), and for recreational angling in Newfoundland (Dempson *et al*, 2001) may both be impacted by changing climate.

Arctic char are also sensitive to changing climate (Baker, 1983; Beamish *et al*, 1995; Reist *et al*, 2006a, 2006b, 2006c; Wrona *et al*, 2005). Labrador studies include Dempson (1999, 2002, 2008), Dempson and Green (1985), Duston *et al* (2007), Parks Canada (2007), and Power *et al* (2000).

Trout species investigated include brook trout (Clark and Scruton, 1999) and lake trout (Mackenzie-Grieve and Post, 2006; McDonald *et al*., 1996). Warmer water conditions are more suitable for pike (Byström *et al*., 2007) and less suitable for northern whitefish (rennie *et al*., 2009). Changing conditions have also impacted eels (Bouillon and Haedrich, 1985; Castonguay *et al*., 1994; Dutil *et al*, 2009; Jessop, 2010), including the arrival of parasites (Rockwell *et al*, 2009). Driftwood transported by ice and spring freshet provides habitats for invertebrates, which are vital as food sources for fish as well as pollinating blueberries and other plants (Lomond, 1997; Colbo *et al.*, 1999).

Flooding is among the most common of natural hazards in Newfoundland and Labrador (Batterson *et al*, 1999; Catto, 2005a, 2005b, 2008a, 2008b, 2010; Hickman, 2006; Kindervater, 1980; Liverman *et al*., 2001, 2006). The frequency of flooding, both within Canada (Etkin *et al*., 2004; Watt, 1989) and elsewhere (Füssel, 2009), has led to detailed consideration of emergency management techniques, impacts, and preventative measures (e.g. Birkmann, 2006; Canadian Council of Professional Engineers, 2008; Catto and Tomblin, 2009a, 2009b, in press; Etkin and McColloch, 1994; Gulik *et al*, 2000; Handmer, 2003; Haque, 2005; Riley, 2007; Scmidt-Thomé *et al*, 2006a, 2006b; Searle, 2007; Shrubsole, 2007; Shrubsole *et al*, 2003; Wallace, 2006).

Changes in the amount, timing, and nature of precipitation can result in increased flooding frequency (Alcorn and Blanchard, 2004; Ashmore and Church, 2001; Brooks *et al*., 2001; Clair *et al.*, 1998; Watt, 1989). Winter thaw and rain events could lead to increases in rain-on-snow flooding (Catto and Hickman, 2004). A rain-on-snow flooding event carved a 10-m deep channel through Bishops Falls, destroying the Abitibi-Price powerhouse and dam, all major roadways, and numerous structures, and required evacuation of the community (Ambler, 1985). Within the past 10 years, rain-on-snow events have impacted Humber Arm and the Burin, Baie Verte (Middle Arm, Fleur-de-Lys, Baie Verte), and northeast Avalon peninsulas (Brake, 2008; Catto, 2005a, 2005b; Catto and Hickman, 2004; Catto and St. Croix, 1998; Hickman, 2006). Flooding during spring freshet has occurred in numerous areas in the province (e.g. Brake, 2008; Catto, 2010; Hickman, 2006; Kindervater, 1980; Liverman, 1997; Sheppard Green, 1996). Flooding is also associated with hurricanes, extratropical transitions, and other summer and autumn storms (e.g. Catto, 2010; Liverman *et al.*, 2006).

Newfoundland experiences alternating cold and mild spells throughout the winter and early spring, resulting in several freeze-up and break-up events in rivers annually (Shabbar and Bonsal, 2003). Dynamic ice jams result from the deposition of floating ice against obstructions or obstacles in the river channel (Beltros, 1983, 1997, 2002; Beltros and Burrell, 2002). The formation of a dynamic ice jam results when a solid ice cover, formed during a cold period, resists break-up when impacted by a high velocity flow event. Significant ice jam floods have occurred at Badger (Fenco, 1985; Picco *et al.*, 2003) and elsewhere (Hickman, 2006; Kindervater, 1980; ShawMont, 1986; Vasseur and Catto, 2008). Ice-jam flooding and ice-push features are recorded in trees and sediments adjacent to rivers and lakes (e.g. Bégin, 2000, 2001; Boucher *et al*, 2009; Catto and Hickman, 2004; Pennell, 1993; Winter, 1996) Winter ice cover combined with irregular warm periods increases the potential for dynamic ice jams and consequent flooding.

Avalanche activity is also related to climate (Stetham *et al*., 2003). Newfoundland and Labrador has a long history of avalanches and consequent destruction (Liverman, 2008; Liverman *et al*, 2001, 2003, 2006).

In Labrador, study of water quality and availability has concentrated on northern and coastal communities. Flooding and avalanching have not been studied in detail in any areas, although some work has been done in Happy Valley-Goose Bay (flooding) and Nain (avalanching).

In Newfoundland, flooding and avalanching have been studied in several communities, particularly on the Avalon and Burin Peninsulas, in central Newfoundland, and on the southwestern coast (Gros Morne south to Port-aux-Basques). Little work has been done on the Northern Peninsula, South Coast (Connaigre), or the Bonavista Peninsula. Studies of water quality and availability are relatively limited across the island.

Study and Adaptation Needs

Suggested future actions include:

- Investigation of the impacts of weather and climate events on water quality and quantity in communities, particularly in Newfoundland
- Study of water usage by sector
- Continuation of flood mapping and infrastructure assessment
- Assessment of potential geological contaminants in water supply
- Investigation of impacts on aquatic species (in addition to salmonids)
- systematic assessment of avalanche exposure, sensitivity, and vulnerability
- linkage between water quality and quantity and impacts to other sectors

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5. Water

Water Quality and Quantity – Page 41

Anadromous, Catadromous, and Freshwater Fish – Page 45

Flooding and Avalanches - Page 50

6. Agriculture

Agriculture is highly dependent on climate. In Newfoundland and Labrador, the projected changes in climate present both opportunity and risk (Wall *et al.*, 2004; Weber and Hauer, 2003). The opportunity to extend the growing season and grow higher value crops is balanced against the risk of increased frequency of extreme events which may damage crops and or infrastructure, impacts on the environment, uncertainty in global markets, and potential changes in pest spectrum and incidence of disease.

Study of adaptation in the agricultural sector in Canada began before most other sectors were analyzed. Much of the theoretical understanding of the principles for investigating adaptation from a socio-economic perspective resulted from the work of Barry Smit and his colleagues at the University of Guelph (e.g. Belliveau *et al*, 2006; Bryant, 2008; Bryant *et al*, 2000; Dolan *et al*, 2001; Smit *et al*, 1996, 2000; Smit and Wandel, 2006; Wall and Marzall, 2006; Wall and Smit, 2005; Wall *et al*., 2004, among other works). Simultaneously, agricultural communities were the initial focus for much of the community-based work on impacts and adaptations in Canada, especially under the direction of Michael Brklacich at Carleton University (e.g. Brklacich, 2006; Brklacich and Curran, 2002; Brklacich *et al*, 2007; Brklacich and Smit, 1992; Brklacich and Stewart, 1995). The pattern of research has continued with subsequent studies by others (e.g. Rousseau *et al*, 2007).

A primary point raised in these research efforts is the multiplicity of challenges facing Canadian agriculture in general and in Atlantic Canada in particular (Agriculture and Agri-Food Canada, 2005; Aubin *et al*., 2003; Power and Burton, 2007), including economic conditions, demography of producers, sustainability of rural communities, ability to utilize new technologies, and competition, in addition to the purely physical factors. The abilities of the agricultural sector to respond to either climate or non-climate factors are linked to socio-economic and political conditions. Recognition that agricultural adaptation involves more than coping with climate thus came relatively early (Kandlikar and Risbey, 2000). Subsequent efforts in Newfoundland and Labrador have stressed both the value of this approach to other sectors (e.g. Catto, 2007; Vasseur and Catto, 2008), and the linkage of challenges raised by previous studies (Ramsey, 1993) to issues resulting from climate change and variability.

Change, involving annual average conditions (de Jong *et al.*, 2001; Gameda *et al*, 2007), is of concern in agriculture. However, the problems posed by increased year-to-year variation and greater incidences of extreme events (Coote and Gregorich, 2000; DeKimpe, 2002) are equally if not more serious. A single extreme event (later frost, extended drought, excess rainfall during harvest period) can eliminate any benefits from improved "average" conditions. Current scenarios predict an increased frequency of the number of hot days during the growing season, potential for late spring and early fall frosts, an increased number of consecutive dry days, and more intense precipitation events. A warmer growing season may increase the potential for forage production (e.g. Bootsma *et al*., 2005a, 2005b; see Gameda *et al*, 2007; Smith *et al*, 2009c), but warmer winter conditions may result in overwintering stresses and greater winter kill, offsetting any gains in production during the growing period (Bélanger *et al.*, 2001; Bertrand and Castonguay, 2003). Similarly the warmer summer conditions may allow for a greater range of crops, but more extreme weather during the spring and fall may adversely affect the productivity of these species. An increased frequency of climate related impacts could result in a greater dependence on risk management programs.

Another, sometimes overlooked, effect is the impact of chane on pollinating species (Richards and Kevin, 2002). Bees as pollinators have high economic value as pollinators in agriculture in Atlantic Canada. Already under pressure from invasive species as well as parasitism and disease, bees will likely suffer greater negative consequences from climate change.

Agriculture in many climatically-suitable regions of Newfoundland is limited by soil conditions and competing demands for suitable land (e.g. Ramsey, 1993; Sigursveinsson, 1985). Assessment of the potential competing uses for land conducted using economy-ecosystem response models (Hauer *et al*, 2002), has not been conducted in Newfoundland and Labrador. Potential for development of new crops, or expansion of present efforts (e.g. Debnath, 2009), may exist. Expansion of agriculture in suitable areas of Labrador (c.f. Government of

Newfoundland and Labrador, 2004; Tarnoci, 2003), could also be considered.

Pathogens such as the Golden Potato Nematode (*Globodera rostochiensis*) also restrict the amount of potentially available land for large-scale agriculture, even under changing climate. Changes could impact pest populations and associated predators (Bourgeois *et al*, 2004; Boxall *et al*, 2009; Coakley *et al.*, 1999). The time required to develop and adopt new pest control approaches is significant, particularly if the new approach requires the registration of new chemical control agents, where health aspects must be considered (Boxall *et al*, 2009; Milburn *et al*., 1995).

The potential impacts of climate change on animal production are multifaceted, but largely unstudied (especially in Atlantic Canada). One potential impact is the need to introduce artificial cooling of livestock buildings. The variability of climatic conditions during the reproductive period for fur-farmed species has a significant impact on reproductive success. Animal diseases and their spread can be influenced by climate. Water usage in agricultural operations (Dryden-Cripton *et al*., 2007) is a potential issue under changing climate.

The desire or requirement to reduce GHG emissions represents another potential adaptation impact (Burton and Sauvé, 2006; Desjardins *et al*, 2007a, 2007b; Janzen *et al*, 2006, 2008; Smith *et al*., 2009a, 2009b). In Canada, recent studies have highlighted the issues for the livestock industries (Kebreab *et al*, 2006; Stewart *et al*., 2009; Vergé *et al*, 2008, 2009; also see O`Mara *et al*, 2008). Nitrogen management has been investigated under both different scenarios of climate change (DeJong *et al*, 2008), and under different cultivation and operational techniques (Christopher and Lal, 2007; Rochette, 2008; Rochette *et al*, 2004, 2008; Rochette and Bertrand, 2008; Rochette and McGinn, 2008; Yang *et al*., 2007).

Within the province, impacts and adaptations concerning agriculture have not been studied extensively. Research elsewhere in Maritime Canada is of relevance to Newfoundland agriculture. The only work accomplished in Labrador deals with the Happy Valley-Goose Bay area.

Study and Adaptation Needs

In addition to the research outlined above, substantial efforts are underway at Newfoundland & Labrador Natural Resources (Agrifoods), Agriculture and Agri-Foods Canada, the NL Federation of Agriculture, and Memorial University to investigate climate-related impacts on agriculture. The academic literature thus does not provide a full picture of the amount of information available.

One difficulty facing agricultural adaptation in NL is the limted and outdated information available concerning soil types, distribution, and capabilities, with most soil mapping in the province dating from more than 20 years ago. Another difficulty, currently being addressed, is quantifying the amount of water use in agricultural operations in the province. Research needs include:

- Soil mapping and assessment
- Assessment of impacts on forage production and/or outside supply
- Consideration of climate-related impacts (not limited to crop production) in analysis of agricultural issues
- Issues impacting livestock production
- Issues impacting berry production

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7. *Forestry*

This section focuses on issues connected to forestry management, succession of commercial species, and forest fires. Other aspects of *Terrestrial Ecosystems* are discussed in that section of the review. The focus in this section is primarily on the potential changes in commercially-exploited forests, mainly on the island of Newfoundland.

Species faced with climate change can adapt, migrate, or be extirpated (Aitken *et al*, 2008; Beaulieu and Ranville, 2005; Gray, 2005). As long-lived, immobile species, the distributions of trees are slower to respond to changes in climate under natural conditions (Nielson *et al*., 2005). Once established, mature trees can persist in climates that are unsuitable for the establishment of new seedlings, creating the potential for a deceptive perception of the impact of change on forests in the short term.

Forest assemblages throughout much of Newfoundland reflect the combined influences of climate, topographic isolation, human modification, pest species, and fire. The potential impact of changes in climate must be considered in the context of previous and ongoing modification from these factors. Adaptation strategies in forestry management (Evans and Pershel, 2009; Lemprière *et al*., 2008; MacIver and Wheaton, 2005; McCurdy and Stewart, 2003; Pham, 2005; Stennes *et al*., 1998; Williamson *et al*., 2009) must also consider the existing suite of influences beyond climate change and variation.

A national study of measured and anticipated impacts and suggested adaptation measures has recently been conducted by Williamson *et al*. (2009), including some attention to the boreal forests of the Maritimes and Newfoundland. Another recent review by Lemprière *et al*. (2008) focused on the boreal forests of Canada. Both reviews update current adaptation strategies for forestry management. Although each part of the Canadian boreal forest is different in both species composition and climate (e.g., the boreal forests of western Canada are considerably drier than those of Newfoundland), there are sufficient similarities in forest assemblages to make these studies useful in a Newfoundland context. The literature review of Forget *et al*. (2003) for impacts in Québec was comprehensive, but is now dated.

Direct impacts from changes in temperature and precipitation have been investigated by several authors. With decreased summer precipitation, the possibility of disturbance due to seasonal water shortages is increased (c.f. McCurdy and Stewart, 2003). Trees with deep root systems are resistant to drought (Dale *et al.*, 2001), but shallow-rooting trees such as spruce can experience negative impacts. Most studies have concentrated on the forest assemblage or community as a whole (e.g. Davidson *et al*., 2003; McCurdy and Stewart, 2003; Soja *et al*., 2007; Williamson *et al*., 2007, 2009).

Impacts on the growth of white spruce (Forget *et al*., 2003; Andalo *et al*., 2005) and black spruce (Gamache and Payette, 2004) have been investigated in Québec, with higher summer temperatures promoting growth and lower moisture availability retarding it. Changes in treeline species (including those in Labrador) were considered by Gamache and Payette (2004) and Holtmeier and Brolle (2005), in addition to the studies discussed in the *Terrestrial Ecosystems* section of this review.

Seasonal variations in moisture supply are significant, especially anomalous cold or dry periods during the spring growing season (Arian *et al*., 2002). Yellow birch (*Betula alleghenansis*), a species present in sheltered areas in central Newfoundland and the interior of the Avalon Peninsula, is subject to crown dieback if exposed to frequent episodes of winter thaw and late spring frost (Bourque *et al.*, 2005; Campbell *et al.*, 2005; Cox and Arp, 2001).

Climate change will impact both the biodiversity and the genetic variation of forests. Genetic variation is the basis for forest health, and it will become increasingly important as climate shifts (Mosseler *et al.*, 2003; Beaulieu and Rainville, 2005). Assessment of the existing forest assemblages and associated biodiversity, both for the boreal forest as a whole and for Canada, has been accomplished to some extent (Karsh *et al*, 2006; Pavlic *et al*., 2007; Price and Apps, 1995; Price and Scott, 2006; Wang *et al*., 2006), although specific Newfoundland-based studies appear to be lacking. Biodiversity considerations are increasingly considered in forest management efforts (Beazley *et al*., 2005; Hauer *et al*, 2002; McCurdy and Stewart, 2003; Moola and Vasseur, 2004; Williamson *et al*, 2009).

Forest response to climate change involves substantial feedback, because forests represent both sinks and sources of CO_2, CH_4, and N_2O (e.g. Hättenschwiller *et al*., 1997; Kurz and Apps, 1999). Adjacent species respond differently to elevated CO_2 levels (Bazzaz *et al*., 1990; Wullschleger *et al*., 1997), and the responses are not independent of temperature (Lindroth *et al*., 1998). As a whole, the boreal forest is evolving in response to changed CO_2 levels, not merely growing faster (Price and Apps, 1995; Price and Scott, 2006; Woodwell and Mackenzie, 2005; Woodwell *et al*., 1998).

Most disturbances in oceanic influenced forest ecosystems originate from wind, ice storms, and flooding (Foster *et al*., 1998; Seymour, 1992). Increases in the strength and frequency of wind events and thunderstorms could be of significance, particularly in western Newfoundland. Wind speed is the determining factor in the extent of damage to trees, with larger trees and those which have undergone recent disturbance from fire or pathogens being more susceptible to windthrow (Flannigan *et al.*, 2000; Gray, 2005; McCurdy and Stewart, 2003; Peterson, 2000; Williamson *et al*, 2009). Ice storm damage can range from breaking of individual branches to annihilation of entire stands (Dale *et al*., 2001; Irland, 2000). However, the potential for damage from ice storms is highly species-dependent, and is least for those species accustomed to heavy snow and ice loads, such as spruce and balsam fir. Flooding also has a greater effect on those species which are not genetically adapted to sporadic inundation (Anella and Whitlow, 1999).

Shifts in the abundance of insects, pathogens, and herbivores have substantial potential to adversely affect Newfoundland forests. Under a warmer climate, insects and pathogen ranges are expected to shift north (Fleming, 2000; Fleming and Volney, 1995; Gray, 2005; Logan *et al*, 2003). Warmer winter temperatures will decrease mortality. The relatively short lifespan of these species will result in an increased number of generations per season and rapid adaptation to evolving climate conditions. Greater numbers of insects and pathogens may disturb forest ecosystems, which can result in shifts in nutrient cycles and forest species composition, which in turn can significantly alter soil associations for stands. Invasive species can affect forests by shifting nutrient cycles, forest succession, fire regime, shifts in herbivores and predation, can cause regional extinctions through hybridization with native species, and cause increased mortality from the transportation of exotic diseases (Dale *et al.*, 2001). Reduced fragmentation, in response to the influx of invasive species, may facilitate the spread of pathogens by allowing unrestricted migration through previously restricted forest stands (Holdenrieder *et al.*, 2004), although the arrival of predators of invasive species may counterbalance this effect.

The impacts of changing climate on the spruce budworm have been the subject of several recent studies (Bergeron and Leduc, 1998; Candau and Fleming, 2005; Candau *et al*, 1998; Gray, 2008; Volney and Felming, 2007). Changes in climate projected for Atlantic Canada appear to be favourable for the spread of the spruce budworm. Other pest species, such as hemlock looper, balsam fir sawfly, and balsam wooly adelgid, have been studied, but in lesser detail. In central Newfoundland, red pine has recently been attacked by the European pine sawfly (Rose *et al*, 1999) and the fungus scleroderris canker (Hudak and Singh, 1984; Skilling *et al*, 1986). Both these pests arrived in Newfoundland on imported specimens of Austrian pine (*Pinus nigra*), a common ornamental tree.

Fires can generally be expected to be more frequent under hotter, drier summer conditions with increased lightning strike activity (Amiro *et al*., 2001; Flannigan, 2002; Flannigan *et al*., 2000, 2001, 2008, 2009a, 2009b; Gillett *et al*, 2004). However, because the ratio between human-caused and lightning fires varies significantly across Newfoundland and Labrador, the impacts of changing climate will also vary. Lightning strikes are responsible for relatively few forest fires in eastern and central Newfoundland, with most caused by human activity. The interaction between increased human use of forests during dry summers also should be considered (e.g. Hyndman *et al*., 2008; Wotton *et al*., 2003). Forest fires can also have implications for the health of nearby residents, with smoke and particulates aggravating respiratory illnesses (Cofer *et al*, 1996; McMichael *et al.*, 2003; Moore *et al.*, 2006; University of British Columbia Okanagan, 2005; University of Washington, 2001).

Impacts of climate change on fire frequency have been investigated in the boreal forests of eastern Canada (Bergeron *et al*., 2002, 2004, 2006; Bergeron and Flannigan, 1995; Carcaillet and Richard, 2000; Jiang *et al*., 2009; LeGoff *et al*, 2007, 2009; Stocks, 2007; Stocks *et al*., 1998; Weber and Flannigan, 1997). As with tree growth, feedback relationships between increased fire, carbon, and climate change may occur (Wein, 1990).

An increase in forest fire activity would favour pine over spruce (Clark, 1990; Hosie, 1990; Farrar, 1995; Lynham and Stocks, 1991; Rowe, 1983). Particularly in western Labrador, an increase in fire frequency would favour jack pine, balsam fir, and larch. Increases in summer temperature trigger increased lightning strikes and hence the potential for natural fires. However, a simultaneous increase in summer precipitation would result in damper soil and a decrease in forest fire frequency, as has been recorded in central Québec (Flannigan *et al*., 2001). At present, the balance of opinion suggests that drier conditions will accompany warming summers in westernmost Labrador, favouring the expansion of jack pine under increased fire frequency.

A contributory factor could be changes in the moose population, as moose preferentially browse balsam fir over jack pine (Peek, 1974). Forest fires generally are considered beneficial to moose, by creating open areas colonized by alders, willows, and aspens. The beneficial effects of fire on habitat are estimated to last less than 50 years, as the moose population peaks 20 to 25 years following a fire (LeResche *et al.*, 1974). Fires at 2- to 3-year intervals may entirely destroy the aspen population, making the area unsuitable for moose. Increased fire frequency coupled with summer warming thus may increase moose browse pressure on balsam fir, further favouring jack pine.

Trees damaged by insect infestation are more susceptible to forest fires, The relationship between spruce budworm outbreaks and forest fire damage has been investigated by Bergeron and Leduc (1998) and Fleming *et al*. (2002a, 2002b, 2006).

Regionlly, little work has been conducted on forestry in Labrador, particularly compared to the extensive work on terrestrial ecosystems. In Newfoundland, although work has also not been focused on climate-related impacts and adaptations, the greater volume of forestry-related research provides baseline data. Research elsewhere in boreal Canada is of relevance to Newfoundland forestry. Additional research is needed concerning regeneration, fire, and management strategies throughout the province.

Study and Adaptation Needs

Adaptation options are more limited within the forestry industry over the short term. Suggested adaptation involves management strategies that include enhancement of the capacity of the forests to cope with shifting climate conditions and affected site conditions. Enhancement and preservation of genetic variability is critical, as it is linked to the ability of a forest stand to offset the outbreak of pathogens or insects. Harvesting and reforestation should be conducted with a view towards maintaining the maximum possible degree of genetic variability.

Substantial research exists for the boreal forests of Canada as a whole, and for terrestrial ecosystems in Newfoundland and Labrador. Both can be applied to forestry adaptations in Newfoundland, updating the NL Sustainable Forest Management Strategy (2003). However, very little research has been conducted which has focused directly on Newfoundland in the climate change context, and even less on Labrador. The Newfoundland Forest Sector Strategy Final Report (Halifax Global Consultants, 2008) does not consider climate impacts.

Future lines of research could include:

- Focus on specific pathogens, such as hemlock looper, wooly adelgid, balsam fir sawfly, and pine sawfly;
- Detailed analysis of fire frequency and contributing factors in various regions;
- Analysis of the potential for adaptation strategies in NL forests, cf. Lemprière *et al*. (2008) and Williamson *et al*. (2009);
- Study of the regional frequency and severity of wind damage, in conjunction with fire and insect disturbance;
- Analysis of the impact of changing climate on regeneration rates;
- study of implications for forest resources in Labrador.

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7. Forestry

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8. Transportation

Climate influences on transportation will directly impact most other sectors, such as resource extraction and distribution, tourism, communities, and agriculture (e.g. Koetse and Rietveld, 2009; Maoh *et al*, 2008). As well, changes in other sectors will influence demand for transportation (Apparicio *et al*., 2007; Yevdokimov, 2003). National and regional assessments have concentrated on ground and air transport (e.g. Transport Canada, 2003), with lesser attention to marine transportation. Discussion of the most desirable mix of transportation alternatives in the face of climate change (e.g. Berritella *et al*, 2008) has been considered only to a very limited extent in the Canadian context. No study of general transportation issues explicitly focused on Newfoundland and Labrador has been undertaken.

Air

Concerns with air transport elsewhere in Canada have focused on flooding and storm surge damage (e.g. Transport Canada, 2003). With the possible exception of Stephenville Airport, facilities in NL are not located in low-lying coastal areas. Aircraft icing remains a concern, but the available data suggests decreases in freezing rain and fog frequency (Wang, 2006). Enhanced frost activity could shorten the lifespan of paved runways at airports, as for roads.

Allard *et al* (2007) conducted an assessment of the potential for permafrost ablation and climate change on the degradation of airport runways in Nunavik (northern Québec). This study has potential applicability to airport maintenance and design in Nunatsiavut, although local terrain conditions (particularly permafrost regimes) vary substantially between sites.

Marine

In Newfoundland and Labrador, marine transportation is primarily short-sea shipping, over short distances without crossing open oceans or within coastal waters (see Langevin, 2003). Impacts of climate change on marine activities discussed elsewhere in this review include storm surges and coastal erosion (*Coastal Zone* section), and Icebergs and Sea Ice (*Marine Regions and Fisheries* section). Impacts on fishery-based communities are considered in the *Marine Regions and Fisheries* and *Communities* sections.

Research on marine transportation systems outside the facets listed above is limited.

Catto *et al.* (2006), McMillan (2006), and Seguin (2006) investigated the effects of storm winds and surge activity on marine and road transportation through Port-aux-Basques, concluding that increasing easterly winds strengths posed a potential hazard. Weather-related delays to the Marine Atlantic ferry service resulted in substantial economic cost (Catto *et al.,* 2006). Retrofitting of older marine vessels may be required to cope with changes in weather conditions. The level of emergency preparedness provided by the Canadian Coast Guard will need to be able to cope with greater demands resulting from more frequent storms and extreme events. Reduction in fog frequency and intensity (Wang, 2006) can be anticipated in coastal NL, following trends ongoing since 1950. Although fog will remain a hazard for marine transport, its significance in accidents and incidents for fishing vessels is less than that of wave conditions and ice (see Wu *et al*., 2009, for an assessment for Atlantic Canada).

Rail

No research has been conducted on the direct impacts of climate change on the railways of western Labrador. In other regions of North America, including Maritime Canada, the focus has been on warping of rails due to excessive summer heating (e.g. Coles Associates Ltd, 2000; Mills and Andrey, 2003; Transport Canada, 2003). Difficulties with terrain during the initial construction of the Québec North Shore & Labrador Railway suggest that changes in freeze-thaw regimes could result in maintenance issues where the railway passes over silt- and clay-dominated terrain, although these areas are primarily located in the vicinity of Sept-Iles. Construction over permafrost terrain is not an issue in western Labrador due to the limited distribution of permafrost and the thin sediment cover over bedrock.

Road

Road transportation is the largest component of the NL transportation sector. Climate factors impacting permanent road systems in the province include the potential for summer heating, resulting in pavement softening (e.g. Mills and Andrey, 2003; Mills, 2005; Mills *et al*, 2007, 2009; Woudsma, 2006), extreme cold on exposed pavement (Trans-Labrador Highway), freeze-thaw cycles (creating potholes, weathering concrete (e.g. Almulsallam, 2001), and initiating failures of road cuts in unconsolidated sediment and fractured bedrock; e.g. Brake, 2008), icing (“black ice” development and freezing rain), and damage to roads and bridges resulting from flooding and river ice jams. Disruption of road traffic due to extreme weather events is also an issue (Catto *et al*., 2006).

Tighe *et al* (2008) noted increases in rutting and longitudinal cracking, and corresponding decreases in transverse cracking, associated with fluctuations in temperature and frost conditions on “low-volume” roads (this criterion would apply to most, if not all, roads in the province). However, the dominant influences were the ambient climate and traffic volumes. Tighe *et al*. (2008) recommended using 30-year averages of climate variables in assessment of construction materials and techniques and maintenance regimes. Similar conclusions were noted by the same research team in other studies (Mills *et al*., 2007, 2009).

Andrey *et al* (2003), Brijs *et al*. (2008), and Andrey (2010) have recently analyzed impacts of weather conditions on accident rates. Based on data from 10 Canadian cities, including Moncton and Halifax, Andrey (2010) noted a downward trend in the relative risk of automobile accidents during rainfall events over the period 1984-2002. Over the same period, the risk of significant injury during snowfall events remained unchanged. The research has implications in estimating ongoing rates of accident occurrence and severity under changing climate conditions.

Sea level rise, storm surges, and erosion pose difficulties for roads located in coastal areas. The impacts are discussed in the *Coastal Zone* section of this review. Terrestrial flooding, a factor in bridge and road design, is discussed in the *Water* section of this review.

In Newfoundland, transportation-related research has concentrated on the Gulf Ferry-TCH system in western Newfoundland, and on the impacts of frost wedging on slope failures in western Newfoundland and the Burin Peninsula. Research elsewhere in Canada is of relevance to impacts on roads in Newfoundland. The only transportation-related research in Labrador has concentrated on the influence of coastal ice conditions.

Study and Adaptation Needs

The relative scarcity of research on issues directly impacting transportation in NL is evident from the review of the literature. Issues of importance elsewhere in Canada (heat impacts on rails, snow/ice road maintenance, airport susceptibility to flooding) are not significant in NL. In conjunction with research in the Coastal Zones, assessment of the vulnerability of infrastructure to storms and extreme events, and identification of the measures needed for effective response, would be useful. Further research could focus on:

- Impacts on road and bridge design;
- Economic impacts of interruptions to ferry and road transportation;
- Dependency on transportation for food supply;
- Impacts of slope failures and coastal erosion.

A greater frequency of freeze-thaw events in winter months is predicted for all of NL. Adaptive changes to road maintenance and salt usage will have to be examined in order to avoid pavement damage and improve safety (c.f. Mills *et al*., 2007, 2009; Tighe *et al*., 2008). As road-based infrastructure is generally short-lived compared to marine and air facilities, adaptation strategies can be implemented in a relatively effective manner to facilitate cost-effective replacement using improved designs (Andrey and Mills, 2003).

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9. Energy

Issues associated with energy production and distribution in NL include potential low-water levels in hydroelectric reservoirs during peak summer demand season, damage to dams and turbines resulting from flooding and ice jams (discussed in *Water* section), offshore ice and storm activity (*General* and *Marine Regions and Fisheries* sections), damage to coastal installations due to storm surge (*Coastal Zone* section), hydrocarbon spills associated with adverse weather conditions (*Coastal Zone* section), damage to transmission lines associated with freezing rain and wind, and the development of new sources of energy. Changing weather conditions, especially increases in temperature (decreased winter heating demands, increased summer air conditioning and refrigeration) may also influence the energy sector (e.g. Vasseur and Catto, 2008). Successive studies of the energy sector in Canada have tended to focus on an overall national picture (e.g. Mercier, 1998; Street *et al*, 2002).

Hydroelectricity is the primary source of power in Newfoundland and Labrador, and long-term changes in annual precipitation would affect overall generation capability by reducing streamflow (Milly *et al*., 2005) and increasing evapotranspiration. The timing and nature of precipitation will affect hydroelectric generation, as water produced during extreme snowmelt and freshet events may be discharged through overflow channels to avoid damage to turbines.

Richter and Barnard (2004) conducted a study of the anticipated impacts on four small hydro-electric systems in Newfoundland, at Rose Blanche, Lookout Brook, Pierres Brook, and Petty Harbour, considering five scenarios of changed temperature and precipitation. The effects vary substantially across the four systems studied, with all scenarios resulting in more electricity generation at Lookout Brook, and all but the coldest (also dry) resulting in increased generation at Rose Blanche. At Petty Harbour and Pierres Brook, generation increased only under the warmest and wettest scenarios. Changes in both magnitude and seasonal timing of water inflow were the primary factors in changing generation. All of the systems studied were relatively small, with limited storage capacity, and all were located in either southwestern Newfoundland or on the Avalon Peninsula. Study of NL's larger hydroelectric facilities, such as the Bay d'Espoir, Cat Arm, and Churchill Falls installations, has not been undertaken.

Bruce *et al*. (2003) considered the impact of reduced stream flow during dry summers, focusing particularly on trans-boundary cases (both international and interprovincial boundaries). This study noted that seasonal precipitation variations could become issues in cases where water sources straddle boundaries.

Hydroelectric systems without reservoirs would be more exposed to changes in precipitation patterns. The operational and proposed small-scale hydroelectric developments, particularly 'run-of-river' systems, would be subject to variations in water level, particularly during dry summers. Low stream levels could add to ongoing concerns respecting the impacts of these systems on migratory fish (e.g. Bonnell, 1998; Scruton *et al*., 2005). Coping with both anomalous peak and low flows in river systems can also impact fish habitat (Scruton *et al*, 2008).

Offshore hydrocarbon exploration and production is sensitive to storms, sea-ice and icebergs (e.g. Bell and McKenzie, 2004; Catto, 2008b). Most studies have not focused on the needs of the hydrocarbon industry specifically (see discussion in *General* and *Marine Regions and Fisheries* sections). C-CORE (2005a, 2005b) conducted research assessing the state of offshore ice activity and the risk of iceberg collision off the eastern coast of NL, primarily to assess the potential risks to resource development. These studies are relevant both with respect to the current hydrocarbon industry and the potential for the development of either natural gas or methane gas hydrates (e.g. Majorowicz and Osadetz, 2001) in offshore environments. Impacts on pipeline construction and maintenance under changing climate conditions considered in non-permafrost areas northwestern Canada (e.g. Brennan *et al*., 2001) could be of potential relevance if onshore on near-offshore oil and/or natural gas deposits are exploited in western Newfoundland.

Wind generation represents the fastest growing renewable energy supply in Atlantic Canada (Canadian Wind Energy Association, 2010), and is currently the only form of non-renewable energy exploited commercially in NL. Wind and hybrid energy projects have been developed or proposed for several regions (e.g. Arifujjaman *et al*., 2008; Blackler and Iqbal, 2005; Iqbal and Bose, 2007; Oprisian, 2007; also see Colby *et al*., 2009). The developments are based primarily on the strength and character of existing wind regimes (Khan and Iqbal, 2004; Canadian Wind Energy Association, 2010). Future wind regimes in NL have not been effectively modeled at present, although research is ongoing. The broader regional study of Price *et al*. (2001) suggested that as much as a 10% reduction in summer winds in the Atlantic Provinces could occur by ca. 2050, although winter winds strengths were anticipated to either remain unchanged or increase slightly. The impact of ice buildup on turbine blades appears limited (Canadian Wind Energy Association, 2010).

Distribution of power requires transmission lines, which are vulnerable to damage during ice storms accompanied by strong winds (Catto *et al*., 2006; Catto, 2008b, 2010; Hyndman *et al*, 2008). Studies commissioned by NL Hydro and NL Power have examined the impact of present wind conditions in several areas, notably Wreckhouse. Weather Engineering Corporation of Canada (1982) using the data obtained from the St. Andrew's weather station for the period 1953-1966 determined the frequency distribution and extreme values of wind speed, return periods of extreme wind events, and the probability of occurrence of any wind speed. The primary objective of this study was to assess the design of Transmission Line 214. Consideration of the data indicated that TL 214 should be designed to withstand an extreme sustained wind speed of 177 km/h, with gusts to 235 km/h. TRO Engineering (2002) conducted a further assessment of TL-214, and recommended that TL-214 be redesigned to withstand gusts to 235 km/h. A central concern was ensuring that conductors had sufficient weight so that they would not be displaced by strong winds towards the cross-arms, as contact between the two would result in design failure. Both studies assumed no substantive change in future wind regime.

Study and Adaptation Needs

Study of issues affecting onshore energy production and distribution are limited in all areas of Newfoundland and Labrador. In addition to studies related to coastal and marine environments, areas where research could be undertaken include:

- Assessment of changes in wind regime
- Assessment of changes in the frequency and severity of freezing rain and ice storm events
- Assessment of the impacts changes in precipitation and temperature under various scenarios for the larger hydroelectric reservoirs

A summarial list of possible adaptations proposed by Bell and Mackenzie (2004) included diversification of energy sources; strengthening of the distribution grid; incorporation of climate change scenarios into modeling for wind, solar, biomass, and tidal energy; and water diversions to increase hydroelectric reservoir size. Introduction of technology new to Newfoundland (such as power generation from biomass consumption or tidal activity), assessment or refinement of existing technology to NL conditions (solar, wind), and/or reconfiguration of the mix of energy sources, will require both re-consideration of socio-economic impact assessment techniques (e.g. Locke, 1996; Bonnell, 1998) and more detailed climate modeling research.

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9. Energy – Page 71

10. Tourism

Study of the implications of climate change for tourism has focused on two aspects (Scott *et al*., 2005): the impacts of changing climate conditions at particular sites; and the role of travel (particularly air travel) in generating climate change, possibly leading some potential tourists to question their vacation choices.

Environmental conditions are an important factor in decisions made by prospective tourists, particularly where the natural environment is among the destination's primary attractions (Bigano *et al.*, 2006; Braun *et al.,* 1999; Jones and Scott, 2006; Moreno and Becken, 2009; Scott and Suffling, 2000; Scott and Jones, 2006a, 2006c; Scott *et al*., 2002, 2008). Tourist feedback indicates that the natural environment in Atlantic Canada, and in Newfoundland and Labrador in Particular, is among the major attractions. Perceived alterations in the environment of southeastern New Brunswick due to climate change, both positive (increased summer temperatures) and negative (increased summer storms) were cited by visitors and operators (Debaie *et al*, 2006).

Increased summer tourism can operate as an economic stimulus, but also may require construction of additional infrastructure, results in increased demand for water during peak season;, and impacts particularly sensitive areas. Balancing visitation with environmental conservation has long been a concern of park and protected area managers, particularly with the stress of changing environmental conditions (e.g. Abegg *et al*., 1998; Anion and Berger, 1996; Browne and Hunt, 2007; deFrietas *et al*., 2001; Gössling and Hall, 2005; Ryan, 1993). Both the impacts of environmental change on tourists (e.g. Coombes *et al*., 2009; Coombes and Jones, 2010) and the impacts of tourists on the environment need to be considered. Geomorphic stresses induced by climate change, in combination with increased visitation, lengthening of the tourist season, and enhanced tourist use of coastal areas, have resulted in accelerated erosion of coastal tourist sites (Catto, 2006), and could have an impact on the long-term sustainability of coastal tourism (Daigle *et al.*, 2006).

The impacts of changing summer climate include increases in temperature; increased potential for forest fires, due both to weather conditions and increased back-country use; increased use of trails, generating erosion; and erosion of beaches and dunes due to tourist pressure. The overall tourism and outdoor recreation climate of Newfoundland and Labrador was evaluated by Peach (1975, 1984), based on suggested optimal ranges of temperature, (limited) precipitation, and (limited) wind speed. Although the optimal" ranges for these variables are based on personal or societal preference, which may differ among people (see Robertson and Porter (1993) for a rebuttal in the NL context), they are widely used. More detailed studies relating to particular tourism activities were undertaken by Rada (2009) in western Newfoundland, following the concepts and methodologies proposed by deFrietas (1990, 2001), Matzarakis *et al*. (2006), Mieczkowski (1985), Scott and Jones (2006b), and Scott and McBoyle (2001).

Rising sea level, increased coastal erosion, beach narrowing and coarsening, and storm activity all have negative impacts in coastal regions (Bigano *et al*., 2008; Catto, 2004, 2006; Catto *et al*., 2003; Debaie *et al*., 2006; Perch-Nielsen, 2009; Weiland and Catto, 2000). Coastal development, and the construction of protective infrastructure, can restrict landward movement of the beaches. As sea level rise continues, the beaches will inevitably become narrower. Wave energy will be focused in progressively smaller areas, resulting in the preferential removal of sand and causing beaches to become coarser. Where coupled with restrictions on sand supply, the result is to produce gravel beaches which are less attractive for most tourists. This will have important economic impacts on the communities that rely on tourism for sustainability. Increased foot traffic and vehicular access to coastal dune complexes dunes has resulted in accelerated erosion in Newfoundland dunes (Catto, 1994, 2002, 2004, 2006; Catto *et al*., 2006; Ingram, 2004; Pittman, 1995; Pittman and Catto, 2001), as elsewhere in Atlantic Canada (e.g. Catto and Catto, 2009, and references therein).

Trail degradation due to combinations of construction techniques, environmental factors, and usage has become notable in several areas of Newfoundland (Norman, 2009; Reid, 2000; Speller, 2001), mirroring observations elsewhere (e.g. Browne and Hunt, 2007; Bryan, 1977; Calais and Kirkpatrick, 1986; Cole, 1995a, 1995b; Gallet and Rose, 2001; Olive and Marion, 2009). Introduction of non-native species (Norman, 2009; also see Fletcher and Westcott, 2009), and damage to native species (Daley, 2002), have both been noted as trail usage increased. The impact of summer dust raised by ATV traffic along the T'Railway through Norris Arm was investigated by Pike (2004).

Impacts on winter tourism are primarily concerned with the quantity and timing of snow cover. There has been abundant study of this factor elsewhere in Canada (Lamothe and Périard Consultants, 1988; Scott *et al*., 2003, 2004, 2008; Scott and Jones, 2006a, 2006b, 2006c; Scott and McBoyle, 2007) and in other countries (e.g. Burki *et al*., 2005; Elsasser and Burki, 2002; George, 1993; Gössling and Hall, 2005; Hill *et al*., 2010; Hoffman *et al*, 2009; Uhlmann *et al*, 2009), focused primarily on downhill skiing. Rada (2009) investigated potential impacts on downhill skiing at Marble Mountain, but noted that the quantity and timing of snow cover in western Newfoundland has remained satisfactory.

Concerning snowmobiling, McBoyle *et al.* (2006, 2007) suggested that climate change will reduce the number of days suitable for snowmobiling between 38% and 62% by the 2020s in eastern North America, compared to conditions in the 1970s. By 2050, the predicted snowmobiling season would be less than one week in Gander (McBoyle *et al.,* 2006, 2007). However, Rada (2009) noted that snow cover remained suitable for snowmobiling and cross-country skiing in western Newfoundland, with the highland areas in particular (see Martin, 2004) showing no marked decline in snow coverage.

Iceberg-related tourism is discussed in the *Marine* section of the review.

The role of travel in accelerating climate change through increased emissions, and possible tourist responses influencing vacation choices, has become a focus of study internationally (e.g. Anthoff *et al*., 2009; Berrittella *et al*., 2006; Bows *et al*., 2009; Dickinson, 2010; Dubois *et al*., 2010; Gössling and Hall, 2005). Research in Canada has been relatively limited, with some observers noting that the Canadian tourism industry has not addressed the matter (Doods and Graci, 2009; Pollock, 2007, 2009). The impact of potential shifts in tourist behaviour was investigated for the cottage-country rural communities of Addington by McLeman (2008). No similar research has been undertaken in Newfoundland and Labrador.

Potential exists for significant tourism-related research in Newfoundland, particularly in central and Avalon, following the style of research conduced for western Newfoundland. Research elsewhere in Canada is of relevance to tourism-related impacts in Newfoundland. Studies of trail design and management undertaken in central Newfoundland and on the Avalon Peninsula are relevant to other areas.

Climate-change impacts have been studied throughout northern and Arctic Canada extensively, but tourism has been a neglected sector. The only available work is linked to transportation through the Northwest Passage. No tourism-related research specific to Labrador was noted.

Study and Adaptation Needs

Tourism studies have been limited on the island of Newfoundland, and no specific tourism-related studies were noted for Labrador. Suggestions for future study include:

- Analysis of the impacts on tourism in other regions of the province outside western Newfoundland

- Analysis focused on particular activities (e.g. snowmobiling, summer trail usage)
- Linkage of surveys of tourism attitudes and reactions to changing environmental conditions
- Consideration of management strategies for parks and protected areas
- Detailed assessment of the socio-economic impacts of tourism for specific communities.

<u>See List of References</u>

10. Tourism – Page 73

11. Health

Impacts, and the necessary adaptations, can result in effects on human health. Study has generally proceeded along three lines: health impacts associated with particular sectors (e.g. Coastal Zone, Water); health impacts associated with community sustainability, adaptation, and adaptive capacity concerns; and specific health-related impacts (Duncan *et al*., 1997; Berry *et al*, 2009; Haines *et al*., 2006; Kristie *et al*, 2006; Lemmen and Warren, 2004; Menne and Ebi, 2006; Seguin, 2006, 2008). References pertaining to the latter are listed here.

Severe events can result in many people being dislocated and temporarily residing in shelters, increasing the chance of disease outbreak. People are also affected by the stress induced by such events (Hutton, 2005; Hutton *et al*, 2007). Mental health impacts can include depression resulting from financial loss, injuries, and/or relocation. Psychological effects commonly persist for several years following a disaster.

Atlantic Canada is recognized as one of four areas of Canada where air pollution is greatest, largely because of air masses from the eastern United States (Labelle, 1998). Ozone is the most common air pollutant. An increase in heat waves, combined with air pollution, can increase the frequency of smog days in urban areas and cause serious health problems, such as asthma and other pulmonary illnesses, as well as heat stress and related illnesses (Haq *et al*, 2008; ; Health Canada, 2005; Kostatsky, 2007; Kostatsky *et al*., 2008; Mao, 2007; McMichael *et al.*, 2003; Ouimet, 2007). Impacts of heat waves, smog events, and the effects of airborne particulates resulting from forest fires (Dominici *et al*, 2006; Stieb *et al*, 1995; Moore *et al*, 2006) may be compounded as a result of climate change.

Several studies linked to community-focused research have been undertaken in communities in Labrador and Nunavik (Fleming *et al*, 2008; Furgal, 2003; Furgal *et al*, 2002; Furgal and Seguin, 2002; Gosselin *et al*, 2006; Martin, 2007; Owens, 2005). Comparatively little work has focused directly on health-related issues in Newfoundland communities.

Study and Adaptation Needs:

- application of outside research to NL conditions, particularly in Newfoundland;
- assessment of linkage of health and water issues in Newfoundland communities;
- assessment of linkage of health and air quality issues (including wildfire);
- assessment of urban community isssues.

See List of References

11. Health – Page 80

12. Communities

In addition to works focusing on particular sectoral issues, the following references consider impacts on particular communities.

In Labrador, research has focused on northern, coastal, and First-Nations communities. Adaptation strategies and techniques developed in consultation with Arctic communities are relevant to Labrador, and have been applied in some communities. Research in northern Labrador communities has typically addressed impacts from a community rather than a sectoral viewpoint, or has emphasized linkages between sectoral impacts and community health and sustainability.

Research gaps exist concerning communities in southern Labrador, and for Happy Valley-Goose Bay, Churchill Falls, and western Labrador. Most Labrador-oriented studies have not considered any issues in these communities.

In Newfoundland, research has focused on rural, primarily fishery-related communities, such as Change Islands, Indian Bay, and those on the Northern Peninsula. Little research has been conducted that is directly pertinent to interior communities, or to those with economies based on resources other than the fishery.

Individual aspects have been studied for urban areas, but no comprehensive study of an urban area has been undertaken. Research in urban areas has focused on sectoral rather than community analysis. Research elsewhere in Canada is of relevance to impacts in urban communities in Newfoundland.

Adaptation strategies and techniques developed elsewhere in Canada are relevant to Newfoundland's urban and rural communities. Future community-focused research should attempt to integrate studies across sectors.

Study and Adaptation Needs

- application of outside research to Newfoundland communities;
- assessment of linkage of health and community issues in Newfoundland communities;
- assessment of community sustainability and adaptation
- assessment of rural Newfoundland community resilience, adaptive capacity, and response to climate change;
- assessment of urban community resilience and response to climate change;
- development and testing of adaptive mechanisms (e.g. environmental assessments, building codes, and integrated decision making tools).

See List of References

12. Communities

Labrador and Adjacent Nunavik – Page 83

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General – Page 88

13. Regional Distribution

This section lists the references which involve research within Newfoundland and Labrador. References are listed by region, beginning with those that involve the entire province, followed successively by works focused on Labrador, and finally on Newfoundland. The implications of the distribution of research efforts are considered in the *Discussion and Conclusions* section.

See List of References

13. Regional Distribution

14. Discussion and Conclusion

a) Regional Distribution of available research on Climate Change and Variation

Table 1 summarizes the results of this review of the available literature concerning impacts and adaptations to climate change and variation in Newfoundland and Labrador. Numbered comments are listed below.

Sector	**Labrador**		**Newfoundland**	
	Locally-focused Research	*Applicable Research from Elsewhere*	*Locally-focused Research*	*Applicable Research from Elsewhere*
Terrestrial Ecosystems	Substantial[1]	Substantial	Moderate-Substantial[2]	Moderate
Marine and Fisheries	Substantial[3]	Substantial	Substantial[4]	Substantial
Coastal Zone	Limited[5]	Moderate-Substantial	Moderate-Substantial[6]	Substantial
Water Resources	Moderate[7]	Moderate	Limited-Moderate[8]	Moderate-Substantial
Freshwater Fish	Substantial[9]	Substantial	Substantial[10]	Substantial
Agriculture	Very Limited[11]	Limited	Very Limited[12]	Moderate
Forestry	Very Limited[13]	Moderate	Limited[14]	Moderate-Substantial
Transportation	Limited[15]	Moderate	Limited[16]	Moderate-Substantial
Energy	Very Limited[17]	Limited	Limited[18]	Moderate
Tourism	None recorded[19]	Very Limited	Limited-Moderate[20]	Substantial
Health	Moderate[21]	Moderate-Substantial	Limited-Moderate[22]	Moderate-Substantial
Rural	Substantial[23]	Substantial	Limited-	Moderate

Communities			Moderate[24]	
Urban Communities	Very Limited[25]	Limited	Moderate[26]	Moderate-Substantial
Adaptation Strategies and Techniques	Limited-Moderate[27]	Substantial	Limited[28]	Substantial

Table 1: Regional Distribution of available research on Climate Change and Variation

1. Substantial research has been conducted on boreal forests, treelines, and tundra areas in northern and central Labrador. Lesser research has been conducted on the boreal forest environment of western Labrador, and on the environments of southeastern Labrador. Caribou have been the subject of research, but other species have not been extensively investigated.

2. A moderate to substantial amount of research has focused on the boreal forests, barrens, wetlands, and lakes of Newfoundland, particularly concerning protected areas. Research on particular species is relatively limited.

3. Marine fisheries have been extensively investigated, with the impacts on cod and capelin being particular foci. Research has also concentrated on oceanography, storm activity, and the North Atlantic Oscillation.

4. Gaps in Newfoundland-oriented marine research include impacts on shellfish, warm-water (Gulf Stream) species, and invasive species.

5. The coastal zone of Labrador has received relatively little attention, although generalized studies have been conducted in communities.

6. The east, southeast, and west coasts of Newfoundland have been investigated in detail, including studies of individual sites. The northeast coast (Cape Bonavista to Cape Onion) has not been as extensively studied.

7. Study of water quality and availability has concentrated on northern and coastal communities. Flooding and avalanching have not been studied in detail.

8. Flooding and avalanching have been studied in several communities. Studies of water quality and availability are relatively limited.

9. Study has concentrated on Arctic Char.

10. Study has concentrated on Atlantic Salmon.

11. Some work has been accomplished pertaining to the Happy Valley-Goose Bay area.

12. Impacts and adaptations concerning agriculture have not been studied extensively, although discussions have begun with federal and provincial agencies. Research elsewhere in Maritime Canada is of relevance to Newfoundland agriculture.

13. Little work has been conducted on forestry in Labrador (compared to the extensive work on terrestrial ecosystems). More research concerning wildland fire is desirable.

14. Research elsewhere in boreal Canada is of relevance to Newfoundland forestry. Additional research is needed concerning regeneration, fire, and management strategies.

15. Research has concentrated on the influence of coastal ice conditions.

16. Research has concentrated on the Gulf Ferry-TCH system in western Newfoundland, and on the impacts of frost wedging on slope failures in western Newfoundland and the Burin Peninsula. Research elsewhere in Canada is of relevance to impacts on roads in Newfoundland.

17. The only available research relates to wind power.

18. In addition to impacts on offshore petroleum extraction, research could focus on ice storm impacts on power lines.

19. In contrast to all other sectors, research on tourism-related impacts in northern and Arctic regions in Canada is virtually non-existent. The only available work is linked to transportation through the Northwest Passage.

20. Potential exists for significant tourism-related research in Newfoundland, particularly in central and Avalon. Research elsewhere in Canada is of relevance to tourism-related impacts in Newfoundland.

21. Health-related research has focused on northern and First-Nations communities. Research in Nunavik is also relevant.

22. Health-related research has focused on rural, primarily fishery-related communities.

23. Research has focused on northern, coastal, and First-Nations communities.

24. Research has focused on rural, primarily fishery-related communities.

25. Very limited research has been conducted on any aspect focused on Happy Valley-Goose Bay or Labrador west.

26. Individual aspects have been studied for urban areas, but no comprehensive study of an urban area has been undertaken. Research elsewhere in Canada is of relevance to impacts in urban communities in Newfoundland.

27. Adaptation strategies and techniques developed in consultation with Arctic communities are relevant to Labrador, and have been applied in some communities.

28. Adaptation strategies and techniques developed elsewhere in Canada are relevant to Newfoundland.

b) Exposure, Sensitivity, Vulnerability, and Adaptive Capacity with respect to Climate Change and Variation for Sectors in Newfoundland and Labrador

Sector	*Exposure*	*Sensitivity*	*Vulnerability*	*Adaptive Capacity*	*Confidence Level*
Terrestrial Ecosystems	Low to Moderate	Low to Moderate	Low to Moderate	Moderate to High	Moderate to High
Marine and Fisheries	High	High to Moderate	High to Moderate	Moderate to Low	Moderate to High
Coastal Zone	High	High	High	Moderate to High	High
Water Resources	Moderate	Moderate to High	Moderate to High	High to Moderate	High
Freshwater Fish	Moderate to High	High	Moderate to High	Low to Moderate	High
Agriculture	Moderate to High	Moderate to High	Moderate to High	Moderate	Moderate
Forestry	Low	Low to Moderate	Low to Moderate	Low to Moderate	Moderate
Transportation	Moderate	Moderate	Moderate	Moderate to High	Moderate
Energy	Low	Low to Moderate	Low to Moderate	Moderate to High	High
Tourism	Moderate	Moderate	Moderate	Moderate	Low to Moderate
Health	Moderate	Moderate	Moderate	Moderate to High	Moderate to High
Rural Communities-Labrador	Moderate to High	High	High	Moderate to Low	High
Rural Communities-Newfoundland	Moderate to High	High	High	Low to Moderate	Moderate
Urban Communities-Newfoundland	Moderate to High	Moderate	Moderate to High	Moderate	Moderate

Table 2: Exposure, Sensitivity, Vulnerability, and Adaptive Capacity with respect to Climate Change and Variation for Sectors in Newfoundland and Labrador

Table 2 summarizes the exposure, sensitivity, and vulnerability of the sectors in Newfoundland and Labrador discussed in this report. *Exposure* refers to the physical conditions affecting a sector, location or community. It is directly related to the likelihood that a particular phenomenon will occur.

Sensitivity is the potential degree to which a sector, location, or community could be affected by climate change and variation. It is related to both the severity of the exposure and the potential consequences. For sectors other than the natural terrestrial ecosystems and marine climate (but not forestry or marine fisheries), sensitivity refers to the ability of the ecological community to respond, adapt, and evolve in the face of exposure to climate conditions. For the other, human-influenced sectors (including those using biological resources), sensitivity refers to the potential severity of the consequences of change. Whereas exposure to climate change and variation could only be reduced by changing the climate again through mitigation, sensitivity can be reduced through sectoral, community, or governmental action. Those which are either familiar with the problems or have taken measures to reduce their impacts are less sensitive than others that have no prior experience or have taken no action.

Vulnerability is the degree to which a person, community, or sector is adversely affected by change and/or variation. Vulnerability is the combined function of exposure and sensitivity. The frequency of occurrence (exposure) is not the only factor influencing vulnerability. If the effects of the change are too great, any sector may be vulnerable. Communities or sectors that have fewer resources to cope are more vulnerable than those with greater resources, even if the degree of exposure is less. The necessary resources include money, expertise, trained emergency response personnel, medical facilities, previous experience, adaptive capacity, social networks (local people helping each other), and assistance from other communities, ranging from adjacent towns to national governments to world-wide appeals for aid.

Adaptive capacity refers to the ability to cope with or adapt to a change. Newfoundland and Labrador communities generally have substantial exposure to snow, but both the sensitivity and vulnerability are low because people have developed well-practiced strategies to cope. If a heat wave struck, with temperatures rising to 40°C, the same communities would be more sensitive: people without prior experience (low previous exposure) to heat waves would have more difficulty coping, and would be more vulnerable.

For natural terrestrial and marine ecosystems, adaptive capacity and vulnerability to change are directly related: an ecosystem which has a relatively greater capacity to evolve is also relatively less vulnerable. Most natural systems have moderate to high exposure to climate change impacts, when considered over a *ca*. 50 year period. Terrestrial ecosystems in Newfoundland and Labrador have evolved in response to the climate since deglaciation, and a sudden shift in climate conditions will adversely impact them. Differences in lifespan and size of individual organisms influence the degree to which each species is exposed, as well as the immediacy of the reaction to changed conditions. In forests, the larger, older trees will be more able to tolerate progressive changes in climate to a greater extent than will smaller, shorter-lived organisms. Insect species respond more rapidly to climate variation and change, both in terms of survival and migration, than do trees and large mammals. Migration of tree species in response to historical changes in climate (such as warming following deglaciation) requires time, and there is some time lag between the development of suitable climate conditions and the establishment of a forest. Unless the species are planted or introduced by humans, the time required for migration will slow the response to climate change in forested areas.

Terrestrial ecosystems in both parts of the province are less exposed, sensitive, and vulnerable than those elsewhere in Canada (e.g. Maritime Canada). Insular Newfoundland is surrounded by water, which limits the ability of new species to migrate and colonize. Most new species have arrived due to human agency, either accidently (e.g. shrew, white daisy) or deliberate introduction (e.g. moose, snowshoe hare, Austrian pine). The single major exception is the coyote, which has replaced the extinct wolf. Species which could colonize the island under present climate conditions cannot reach Newfoundland without human assistance or in the absence of human monitoring.

Terrestrial ecosystems in Labrador are connected to the remainder of Canada, but migration and ecological change in the northern boreal forest proceeds at a slower pace than in more temperate regions. Changes are ongoing, however, as indicated by treeline migration in the Mealy Mountains and the arrival of new species in westernmost Labrador. Isolated natural ecosystems in coastal and alpine areas, and those where assemblages are geologically restricted, will be more vulnerable to climate change and have a limited adaptive capacity, as suitable terrain and substrate conditions are confined to restricted areas.

Marine ecosystems are also capable of evolving, but the interconnectedness of marine environments is a counterbalancing factor. Seasonal temperature variations in marine waters are less than the variations in air temperature, but many marine species are highly sensitive to temperature changes. Marine waters require longer times to respond to climate changes, but also require longer times to revert to previous conditions. Marine ecosystems in the northwest Atlantic Ocean and Gulf of St. Lawrence have been subjected to greater pressure from human activities than have many terrestrial environments in Newfoundland and Labrador, which has substantially reduced their ability to adapt to changes in the short term (ca. 20-50 years).

For human-related sectors considered in a climate change context, adaptive capacity not only involves the potential (or latent) ability, but also the success at mobilization in response. In a community or sector, the potential adaptive capacity involves comparing the available resources (financial, technical, and human) with the scope and magnitude of the issue to be addressed. A realistic assessment of adaptive capacity, however, must also consider the practicality and/or societal attitudes and/or political willingness to proceed with the initiative. A community may have the fiscal resources to fund extensive public transit for all its residents if this was the top priority for municipal spending, but a realistic assessment would indicate that citizens may not accept this usage of taxation. Climate change and variation will not operate in isolation of other human influences.

Confidence level refers to the confidence that the foregoing assessments are supported by both quantity and quality of the available data. The confidence of the assessment also is influenced by the amount of previous and ongoing human modification to the environment, as well as by the uncertainties in the scenarios resulting from climate modeling. Confidence levels are highest for sectors with large amounts of data that directly pertain to the issues and impacts felt in Newfoundland and Labrador. The review of literature for this project has substantially increased the confidence level for most sectors in Newfoundland and Labrador since the last attempt at assessment (Vasseur and Catto, 2008). For the natural terrestrial ecosystems, the restrictions on confidence are due to the limited research undertaken on some components in Newfoundland. Confidence levels for marine ecosystems are affected primarily by uncertainties pertaining to further human interventions (e.g. impacts of harvesting of marine resources).

Numerous facets in coastal zones are impacted by climate change and variation, both directly by waves, tides, and storms, and indirectly by winds and weather systems generated over marine waters. Changes in precipitation, winds, and storm activity will have more direct influences in coastal environments than will changes in air temperature. The available research indicates that the coastal zones are highly exposed, sensitive, and vulnerable to climate change and variation. The potential adaptive capacity is high, due to the available knowledge and successful adoption of previous established principles or "best practices". Construction of residences in areas exposed to coastal erosion, for example, represents a maladaptive response. The existing potential adaptive capacity is sufficient to define areas subject to coastal erosion and preclude residential construction through application of zoning regulations. The actual success in adaptation, however, depends upon application of the knowledge and principles.

Surface water forms the dominant source of supply for Newfoundland and Labrador residents. Changes in precipitation, particularly seasonal variations, can have limiting effects on water availability, especially where compounded by water quality issues. Sensitivity and vulnerability range from moderate to high, depending upon community size, options for water supply from new surface sources or groundwater sources, and treatment facilities. The use of water in agricultural and urban settings has recently come under review, but continuing research efforts are required.

Flood susceptibility, another facet of water management, has been investigated in numerous communities in Newfoundland, but has received relatively little attention in Labrador. Adaptations include floodplain mapping and assessment of flood probabilities and magnitudes (future exposure), but also involve comprehensive land-use planning, restrictions on construction in floodplains, engineering measures, and preparation for future events. Emergency management, response, and preparation are key adaptations to cope with any climate-related natural hazard. Avalanche risks could be reduced by information directed at the specific demographic population at risk.

Agriculture will be impacted by climate change and variation in Newfoundland and Labrador. For most agricultural activities, variation is more critical than long-term change: a single frost, drought, or rainstorm can eliminate all the theoretical advantages resulting from an overall long-term 'change'. The necessity for suitable growing conditions for crops and forage, and the requirement for seasonal availability of water, increases the sensitivity of this sector. Human factors, including the comparatively small scale of individual farms, the volatility of economic factors, competition from outside food supplies, difficulties in transportation, and the demographics of the farming community, all increase vulnerability and reduce adaptive capacity.

Additional research is required on impacts and adaptations for agriculture in Newfoundland and Labrador.

Forestry operations are less vulnerable than agriculture, due to the life-span and nature of the forest assemblages, although pathogens and pests represent a somewhat uncertain threat. Uncertainties exist with respect to fire as well, accentuated by the difference in fire regime between Newfoundland (where most fires are human-related) and Labrador (where lightning strikes have a much larger role). The time lag between the introduction of a new species and its growth to marketability, and that between development of a successful pathogen-control strategy and the recovery of the affected forest, limit adaptive capacity in forestry. Although research on impacts to Newfoundland and Labrador forestry is limited, boreal forests elsewhere in Canada have undergone more detailed study, allowing a moderate confidence level to be assigned.

The transportation sector is moderately vulnerable to climate change and variation, with concerns focusing around ferry services and road maintenance (including susceptibility to slope failures and coastal erosion). The lack of a road network with multiple transit routes increases vulnerability throughout the province. The dependence on the Gulf ferry service is a major influence on vulnerability. Adaptive capacity is high with respect to possible measures and technical ability (new roads, ports, and ferries; mitigation of slope failures, etc.), but is restricted by financial resources and human constraints. The confidence level is restricted by the lack of specific research focused on highways in Newfoundland and Labrador.

The energy sector is perhaps the least exposed in Newfoundland and Labrador, although it is not immune. Ice storms continue to disrupt power distribution in the province. Recognition of the suite of existing hazards by designers, engineers, and maintenance personnel, a form of adaptation, have reduced the sensitivity and hence the vulnerability of the energy sector. Unlike the challenges facing other sectors, those facing transportation and energy can be localized, and adaptations are already underway. Adaptive capacity is limited primarily by technical and financial considerations.

Tourism in Newfoundland and Labrador has come under increasing study, particularly in western Newfoundland, but much additional work needs to be done (particularly in central Newfoundland and Labrador). The degree of exposure depends on the style of tourism (e.g. nature-based vs. cultural-historical), the seasonality, and the influence of other factors (e.g., climate-related impacts on transportation and water resources). Assessment potentially is easiest where the focus is entirely on natural features, or where snow conditions are critical. Summer tourism is more difficult to assess, as the climate regime is only one factor among many influencing tourist decisions. Additional research is required across Newfoundland and Labrador.

Health-related issues are frequently combined with water quality concerns, and with assessments of rural (particularly First-Nations) and urban communities. Although vulnerability is ranked as moderate overall, this conceals substantial variation among communities, and also variations over time associated with individual events (such as contamination resulting from floods or hot, dry weather). Adaptive capacity represents the ability of health-care professionals and emergency measures personnel to respond to events. As treatments and procedures that prove successful in one region of Canada can generally be applied in others, the bank of available research outside Newfoundland and Labrador is valuable for adaptation within the province.

Communities differ widely demographically and socio-economically, with substantial differences existing between rural and urban communities and within each of these categories. Adjacent communities may be exposed to a particular climate-related hazard to the same degree, but differences in their available human and economic resources may result in great differences in sensitivity, and hence in vulnerability and adaptive capacity. Generally, rural communities throughout the province have fewer fiscal and human resources, and are more likely to be facing economic difficulties resulting from their dependence on a single natural resource. Climate change places additional pressure on communities already under substantial stress. Change should not be seen as an independent, solely-dominant actor, but as one of several stressors acting on communities. Resilience and community spirit are also important concerns influencing the success of adaptation efforts and reducing vulnerability.

As each community is different, the confidence level depends upon the amount of study undertaken in somewhat comparable communities. As Labrador coastal communities are fewer in number and are comparable to communities elsewhere in the north, the confidence level in assessing impacts (informed by research elsewhere in the North and in First-Nations communities) is relatively high. In contrast, although some Newfoundland rural communities have been studied in detail, it is more difficult to transfer experience and ‘lessons’ to other communities with different physical settings, resource bases, and demographic compositions.

Work in Hopedale can inform discussion and analysis of Makkovik, but there is less transferability between work in Change Islands or Indian Bay to Buchans or Whitbourne.

Urban centres have the same degree of exposure to climate, but theoretically less sensitivity than adjacent rural communities, due to their larger availability of human and institutional resources and larger, more diversified economies. The greater variety of challenges, however, may act as a counterweight. Some adaptation research has been undertaken in urban communities in Newfoundland, but more work is needed, as well as in Happy Valley-Goose Bay and Labrador West.

Summary of Future Research Needs
Terrestrial ecosystems:

- development of integrated land use management strategies and policies;
- inventory of species numbers and health;
- protection of key habitats and species;
- baseline studies in protected areas;
- analysis of invasive species;
- development of adaptive measures to protect biodiversity;
- assessment of the sustainable level of human use of species;
- promotion of effective public involvement;
- incorporation of climate change and variability analysis into species recovery and management plans.

Marine and Fisheries:

- focus on broadly-based community adaptation;
- analysis of implications for operational concerns;
- analysis of implications for occupational health and safety concerns;
- protection of key habitats and species in marine and estuarine environments;
- analysis of invasive species;
- adjustment of regulatory regimes to account for ongoing changes in marine conditions;
- development of adaptive measures to protect biodiversity;
- study of impacts and opportunities for aquaculture operations.

Coastal Zone

- ongoing monitoring of sensitive coastal areas;
- establishment of base-line data for coastal erosion, using LiDAR surveys and other techniques;
- investigation of the effects of storm surge activity;
- continuing analysis of storm-surge dynamics and synoptic climatology;

- assessment of the current rates of sea level change in coastal Labrador;
- baseline survey of coastal Labrador;
- consideration of the effectiveness of adaptation strategies;
- analysis of the rates and processes of marine coastal bluff erosion.

Water

- investigation of the impacts of weather and climate events on water quality and quantity in communities, particularly in Newfoundland;
- study of water usage by sector;
- flood mapping and infrastructure assessment;
- assessment of potential geological contaminants in water supplies;
- investigation of impacts on aquatic species (in addition to salmonids);
- systematic assessment of avalanche exposure, sensitivity, and vulnerability;
- linkage between water quality and quantity and impacts to other sectors.

Agriculture

- soil mapping and assessment;
- assessment of impacts on forage production and/or outside supply;
- consideration of climate-related impacts (not limited to crop production) in analysis of agricultural issues;
- issues impacting livestock production;
- issues impacting berry production;
- study of water usage;
- analysis of invasive species and pathogens;
- assessment of impacts and opportunities in central Labrador;
- application of outside research to NL conditions.

Forestry

- focus on specific pathogens, such as hemlock looper, wooly adelgid, balsam fir sawfly, and pine sawfly;

- detailed analysis of fire frequency and contributing factors in various regions;
- analysis of the potential for adaptation strategies in NL forests;
- study of the regional frequency and severity of wind damage, in conjunction with fire and insect disturbance;
- analysis of the impact of changing climate on regeneration rates;
- study of implications for forest resources in Labrador;
- application of outside research to NL conditions.

Transportation

- impacts on road and bridge design;
- economic impacts of interruptions to ferry and road transportation;
- dependency on transportation for food supply;
- impacts of slope failures and coastal erosion;
- application of outside research to NL conditions.

Energy

- assessment of changes in wind regime;
- assessment of changes in the frequency and severity of freezing rain and ice storm events;
- assessment of the impacts changes in precipitation and temperature under various scenarios for the larger hydroelectric reservoirs;
- study of effectiveness of new technologies for energy generation in NL;
- application of outside research to NL conditions.

Tourism

- analysis of the impacts on tourism in other regions of the province outside western Newfoundland;
- analysis focused on winter activities;
- analysis focused on summer trail usage, impacts, and design;
- linkage of surveys of tourism attitudes and reactions to changing environmental conditions;

- consideration of management strategies for parks and protected areas;
- detailed assessment of the socio-economic impacts of tourism for specific communities;
- application of outside research to NL conditions.

Health and Communities

- application of outside research to NL conditions;
- assessment of linkage of health and water issues in Newfoundland communities;
- assessment of linkage of health and air quality issues (including wildland fire);
- assessment of community sustainability and adaptation
- assessment of rural Newfoundland community resilience, adaptive capacity, and response to climate change;
- assessment of urban community resilience and response to climate change;
- development and testing of adaptive mechanisms (e.g. environmental assessments, building codes, and integrated decision making tools).

Labrador

- assessment of the current rates of sea level change in coastal Labrador;
- baseline survey of coastal Labrador;
- flood mapping and infrastructure assessment;
- systematic assessment of avalanche exposure, sensitivity, and vulnerability;
- assessment of impacts and opportunities related to agriculture in central Labrador
- detailed analysis of fire frequency and contributing factors
- analysis of the potential for adaptation strategies in forests;
- study of implications for forest resources in Labrador
- impacts on Trans-Labrador Highway
- dependency on transportation for food supply
- assessment of changes in wind regime
- assessment of the impacts changes in precipitation and temperature under various scenarios for Smallwood reservoir
- analysis of the impacts on tourism

- analysis focused on winter activities
- assessment of linkage of health and air quality issues (including wildland fire);
- assessment of community resilience and response to climate change

Western Newfoundland

- establishment of base-line data for coastal erosion, using LiDAR surveys and other techniques;
- adjustment of regulatory regimes to account for ongoing changes in marine conditions;
- investigation of the impacts of weather and climate events on water quality and quantity in communities
- study of water usage by sector;
- flood mapping and infrastructure assessment;
- systematic assessment of avalanche exposure, sensitivity, and vulnerability;
- soil mapping and assessment;
- consideration of climate-related impacts (not limited to crop production) in analysis of agricultural issues;
- focus on forestry-related pathogens
- detailed analysis of fire frequency and contributing factors
- analysis of the potential for adaptation strategies in forests;
- impacts on road and bridge design
- economic impacts of interruptions to ferry and road transportation
- impacts of slope failures and coastal erosion
- assessment of changes in wind regime
- assessment of the impacts changes in precipitation and temperature under various scenarios for Cat Arm reservoir
- analysis focused on summer trail usage, impacts, and design
- assessment of linkage of health and water issues in communities
- assessment of linkage of health and air quality issues (including wildland fire);
- assessment of rural community resilience, adaptive capacity, and response to climate change

- assessment of urban community resilience and response to climate change

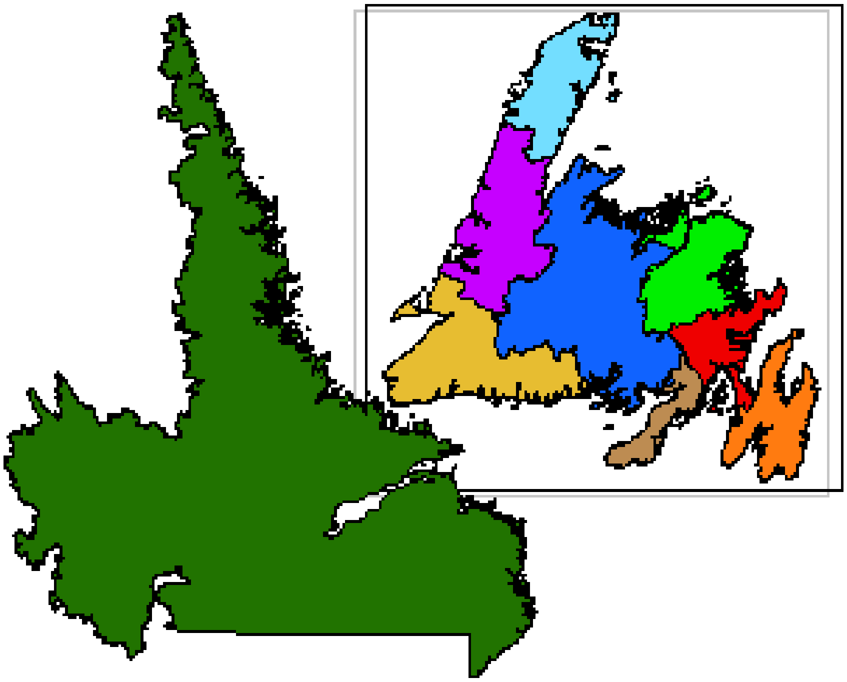
Central and Eastern Newfoundland

- analysis of invasive species;
- analysis of implications for marine operational concerns;
- adjustment of regulatory regimes to account for ongoing changes in marine conditions;
- investigation of the impacts of weather and climate events on water quality and quantity in communities
- study of water usage by sector;
- flood mapping and infrastructure assessment;
- soil mapping and assessment;
- consideration of climate-related impacts (not limited to crop production) in analysis of agricultural issues;
- focus on forestry-related pathogens
- detailed analysis of fire frequency and contributing factors
- analysis of the potential for adaptation strategies in forests;
- impacts on road and bridge design
- economic impacts of interruptions to ferry and road transportation
- assessment of changes in wind regime
- assessment of changes in the frequency and severity of freezing rain and ice storm events
- assessment of the impacts changes in precipitation and temperature under various scenarios for Bay d'Espoir reservoir
- analysis of the impacts on tourism
- analysis focused on winter activities
- analysis focused on summer trail usage, impacts, and design
- assessment of linkage of health and water issues in communities
- assessment of linkage of health and air quality issues (including wildland fire);
- assessment of rural community resilience, adaptive capacity, and response to climate change
- assessment of urban community resilience and response to climate change

Avalon Peninsula

- analysis of invasive species;
- analysis of implications for marine operational concerns;
- adjustment of regulatory regimes to account for ongoing changes in marine conditions;
- establishment of base-line data for coastal erosion, using LiDAR surveys and other techniques;
- investigation of the impacts of weather and climate events on water quality and quantity in communities
- study of water usage by sector;
- soil mapping and assessment; consideration of climate-related impacts (not limited to crop production) in analysis of agricultural issues;
- detailed analysis of fire frequency and contributing factors
- impacts on road and bridge design
- economic impacts of interruptions to ferry and road transportation
- impacts of slope failures and coastal erosion
- assessment of changes in wind regime
- assessment of changes in the frequency and severity of freezing rain and ice storm events
- analysis of the impacts on tourism
- analysis focused on summer trail usage, impacts, and design
- assessment of linkage of health and water issues in communities
- assessment of rural community resilience, adaptive capacity, and response to climate change
- assessment of urban community resilience and response to climate change

Appendix: Sectoral Issues in Rural Secretariat Regions



This section outlines the status of investigations within each of the Rural Secretariat Regions, as illustrated on the map above. Labrador is subdivided into *Coastal and Northern Labrado*r" (including all the coastal areas with the exception of Lake Melville), and *Interior and Western Labrador* (including the Lake Melville area and the Mealy Mountains). The other divisions follow the terminology for the Rural Secretariat Regions.

Within each Rural Secretariat Region, the vulnerability (as derived from the exposure and sensitivity) and the adaptive capacity (considering the magnitude and extent of vulnerability, and the capacity of the region to respond) are listed. The research directly applicable to each sector within each region, including both research conducted within each region and that conducted in other areas which is directly applicable, is indicated as *Available Research. Potential Focal Areas for Research* are suggested on the bases of perceived vulnerability, lack of existing applicable research, and potential for substantive increases in adaptive capacity.

Avalon Peninsula

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Low to Moderate	Moderate to High	Moderate	Invasive species Impacts on threatened/vulnerable sp.
Marine and Fisheries	High to Moderate	Moderate	Substantial	Implications for marine operations Adjustment of regulatory regimes
Coastal Zone	High	Moderate to High	Substantial	Coastal erosion base-line data Impacts of coastal erosion
Water Resources	Moderate to High	High to Moderate	Limited-Moderate	Water quality and quantity Water usage by sector
Freshwater Fish	Moderate	Low	Substantial	---
Agriculture	Moderate	Moderate	Limited-Moderate	Soil mapping and assessment Climate-related impact analysis
Forestry	Low	Low	Limited-Moderate	Fire frequency Impact of Invasive species
Transportation	Moderate	High	Limited-Moderate	Road, street, and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low	High	Limited-Moderate	Changes in wind regime Freezing rain & ice storm events
Tourism	Moderate	Moderate	Moderate	Impacts on tourism Trail usage, impacts, design
Health	Moderate	High	Moderate	Linkage of health & water issues Air quality issues
Rural Communities	High	Moderate	Moderate	Resilience, Adaptive capacity, response to change
Northeast Avalon	Moderate to High	Moderate	Moderate	Resilience, Adaptive capacity, response to change

The coastal and marine sectors exhibit substantial vulnerability due both to the physical factors and the concentration of population and economic interests along the Avalon coastline. Water resources are a concern, particularly in Northeast Avalon (balancing supply and requirements) and in communities where the chemistry of bedrock-hosted waters should be investigated before surface water supplies are replaced. Potential opportunities and problems existing in the agriculture and tourism sectors could be investigated. As in all areas of Newfoundland, interior communities, and urban and suburban communities, have not been studied in detail.

Clarenville - Bonavista

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Low to Moderate	Moderate to High	Moderate	Invasive species Impacts on threatened/vulnerable sp.
Marine and Fisheries	High to Moderate	Low	Substantial	Implications for marine operations Adjustment of regulatory regimes
Coastal Zone	High	Moderate	Substantial	Coastal erosion base-line data Impacts of coastal erosion
Water Resources	Moderate	Moderate	Moderate	Water quality and quantity Water usage by sector Flood mapping Infrastructure assessment
Freshwater Fish	Moderate	Low	Substantial	Impacts on salmon angling
Agriculture	Moderate	Moderate	Limited	Soil mapping and assessment Climate-related impact analysis
Forestry	Moderate	Low to Moderate	Moderate	Fire frequency Pathogens Impact of Invasive species
Transportation	Moderate	Moderate to High	Limited	Road and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low to Moderate	Moderate to High	Limited-Moderate	Changes in wind regime Freezing rain & ice storm events
Tourism	Moderate	Moderate	Limited-Moderate	Impacts on tourism Trail usage, impacts, design Snow availability for winter tour. Impacts on Terra Nova NP
Health	Moderate	High	Limited-Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Moderate	Moderate	Resilience, Adaptive capacity, response to change

The coastal and marine sectors exhibit substantial vulnerability. The water resources, agriculture, and forestry sectors are moderately vulnerable. Flood mapping is absent for several of the region's communities. Transportation andf energy infrastructure is vulnerable to freeze-thaw events, ice storms, and wind impacts. The potential opportunities and problems in the tourism sector, particularly in the areas adjacent to Terra Nova National Park, should be investigated.

Burin Peninsula

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Low	Moderate	Moderate	Invasive species
Marine and Fisheries	High	Low	Substantial	Implications for marine operations Adjustment of regulatory regimes Invasive species (Gulf Stream) Changing fog regime
Coastal Zone	High	Moderate to Low	Substantial	Coastal erosion base-line data Impacts of coastal erosion Impacts on aquaculture
Water Resources	Moderate	Moderate	Limited	Water quality and quantity Water usage by sector
Freshwater Fish	Low	Low	Substantial	---
Agriculture	Low to Moderate	Low to Moderate	Limited	Soil mapping and assessment Climate-related impact analysis
Forestry	Low to Moderate	Low	Moderate	Fire frequency
Transportation	Moderate to High	Moderate to High	Limited-Moderate	Road and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low to Moderate	Moderate to High	Limited-Moderate	Changes in wind regime Freezing rain & ice storm events
Tourism	Moderate	Moderate	Limited-Moderate	Impacts on tourism Trail usage, impacts, design
Health	Moderate	High	Limited-Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Moderate to Low	Moderate	Resilience, Adaptive capacity, response to change

Research on the Burin Peninsula has largely focused on the coastal and marine sectors, and on flood hazard mapping. Less work has been accomplished in other sectors, notably terrestrial ecosystems, water resources, and tourism. Forestry and agriculture have also received less attention, due to their perceived lesser importance in much of the region. Burin Perninsula communities have not been explicitly studied in detail.

Gander-New-Wes-Valley

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Low to Moderate	Moderate	Moderate	Invasive species Impacts on threatened/vulnerable sp.
Marine and Fisheries	High to Moderate	Low	Substantial	Implications for marine operations Adjustment of regulatory regimes
Coastal Zone	High	Moderate	Substantial	Coastal erosion base-line data Impacts of coastal erosion
Water Resources	Moderate	Moderate	Moderate	Water quality and quantity Water usage by sector Flood mapping Infrastructure assessment
Freshwater Fish	Moderate	Low	Substantial	Impacts on salmon angling
Agriculture	Moderate	Moderate	Limited	Soil mapping and assessment Climate-related impact analysis Impacts on berry growth
Forestry	Moderate	Moderate	Moderate	Fire frequency Pathogens Impact of Invasive species Adaptation strategies for forestry
Transportation	Moderate	Moderate to High	Limited	Road and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low to Moderate	Moderate to High	Limited-Moderate	Changes in wind regime Freezing rain & ice storm events
Tourism	Moderate to Low	Moderate	Limited	Impacts on tourism Trail usage, impacts, design Snow availability for winter tour. Impacts on Terra Nova NP
Health	Moderate	High	Limited-Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Moderate	Moderate	Resilience, Adaptive capacity, response to change
Gander	Moderate	Moderate	Limited-Moderate	Resilience, Adaptive capacity, response to change

Potential opportunities and problems existing in the agriculture, forestry, freshwater fish (salmon), and health sectors could be investigated, building upon research conducted in similar settings elsewhere. Ongoing research is examining natural hazards in the Gander area.

Grand Falls-Windsor-Baie Verte-Harbour Breton

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Low to Moderate	Moderate	Moderate	Invasive species Impacts on threatened/vulnerable sp.
Marine and Fisheries	High to Moderate	Low	Substantial	Implications for marine operations Adjustment of regulatory regimes Invasive species (Gulf Stream) Changing fog regime
Coastal Zone	High to Moderate	Moderate	Substantial	Coastal erosion base-line data Impacts of coastal erosion Impacts on Aquaculture
Water Resources	Moderate	Moderate	Limited-Moderate	Water quality and quantity Water usage by sector Flood mapping Infrastructure assessment
Freshwater Fish	Moderate	Low	Substantial	Impacts on salmon angling
Agriculture	Moderate to Low	Moderate	Limited	Soil mapping and assessment Climate-related impact analysis Impacts on berry growth Impacts on forage product/transport
Forestry	Moderate to Low	Moderate to Low	Moderate	Fire frequency Pathogens Impact of Invasive species Adaptation strategies for forestry
Transportation	Moderate	Moderate to High	Limited	Road and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low to Moderate	Moderate to High	Limited-Moderate	Changes in wind regime Freezing rain & ice storm events Impacts on Bay d'Espoir Reservoir
Tourism	Moderate to Low	Moderate	Limited	Impacts on tourism Trail usage, impacts, design Snow availability for winter tour.
Health	Moderate	High	Limited-Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Moderate to Low	Limited-Moderate	Resilience, Adaptive capacity, response to change
Grand Falls-Windsor	Moderate	Moderate	Limited-Moderate	Resilience, Adaptive capacity, response to change

No work has been specifically undertaken in the Grand Falls-Windsor area. Coastal and marine issues have been investigated in the Coast of Bays area, but updating of the baseline coastal erosion data would be desirable.

Stephenville-Port aux Basques

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Moderate	Moderate to Low	Moderate	Invasive species Impacts on threatened/vulnerable sp.
Marine and Fisheries	Moderate	Low	Substantial	Implications for marine operations Adjustment of regulatory regimes Invasive species (Gulf Stream) Changing fog regime
Coastal Zone	High	Moderate	Substantial	Coastal erosion base-line data Impacts of coastal erosion Impacts on Aquaculture
Water Resources	Moderate	Moderate	Limited-Moderate	Water quality and quantity Water usage by sector
Freshwater Fish	Moderate to Low	Low	Substantial	Impacts on salmon angling
Agriculture	Moderate	Moderate	Limited	Soil mapping and assessment Climate-related impact analysis Impacts on forage product/transport
Forestry	Moderate	Moderate to Low	Moderate	Fire frequency Pathogens Impact of Invasive species Adaptation strategies for forestry
Transportation	Moderate to High	Moderate	Moderate	Road and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low	Moderate to High	Moderate	Changes in wind regime Freezing rain & ice storm events
Tourism	Moderate	Moderate	Moderate-Substantial	Impacts on tourism Trail usage, impacts, design
Health	Moderate	High	Limited-Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Moderate to Low	Limited-Moderate	Resilience, Adaptive capacity, response to change
Stephenville	Moderate	Moderate	Moderate	Resilience, Adaptive capacity, response to change

The coastal and marine sectors exhibit substantial vulnerability due both to the physical factors and the concentration of population and economic interests along the coastline. Transportation and tourism have been investigated to a greater degree here than elsewhere in the province. Potential exists for investigations in the agriculture sector. Stephenville has been investigated from the viewpoint of flooding, but no work specifically focused on resilence has been undertaken.

Corner Brook-Rocky Harbour

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Moderate	Moderate to Low	Moderate-Substantial	Invasive species Impacts on threatened/vulnerable sp. Impacts on Main River
Marine and Fisheries	Moderate	Low	Substantial	Implications for marine operations Adjustment of regulatory regimes Invasive Species (Gulf)
Coastal Zone	Moderate to High	Moderate	Substantial	Coastal erosion base-line data Impacts of coastal erosion
Water Resources	Moderate	Moderate	Limited-Moderate	Water quality and quantity Water usage by sector Infrastructure assessment Avalanches
Freshwater Fish	Low	Low	Substantial	Impacts on salmon angling
Agriculture	Moderate to High	Moderate	Limited	Soil mapping and assessment Climate-related impact analysis Impacts on berry growth Impacts on forage product/transport
Forestry	Moderate	Moderate to Low	Moderate	Fire frequency Pathogens Impact of Invasive species Adaptation strategies for forestry
Transportation	Moderate to High	Moderate	Moderate	Road and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low	High	Moderate-Limited	Changes in wind regime Freezing rain & ice storm events
Tourism	Moderate	Moderate	Moderate-Substantial	Impacts on tourism Trail usage, impacts, design Snow availability for winter tour. Impacts on Gros Morne NP Avalanches
Health	Moderate	High	Limited-Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Moderate to Low	Limited-Moderate	Resilience, Adaptive capacity, response to change
Corner Brook Deer Lake	Moderate	Moderate	Moderate	Resilience, Adaptive capacity, response to change

Research efforts undertaken in Gros Morne National Park support work in the region, but additional research in the forestry sector in particular is desirable.

St. Anthony-Port au Choix

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Moderate	Low	Moderate-Substantial	Invasive species Impacts on threatened/vulnerable sp.
Marine and Fisheries	Moderate to High	Low	Substantial	Implications for marine operations Adjustment of regulatory regimes Invasive species (Gulf) Changing sea ice regime
Coastal Zone	Moderate to High	Moderate	Moderate	Coastal erosion base-line data Impacts of coastal erosion Impacts on Aquaculture
Water Resources	Moderate to Low	Moderate	Limited	Water quality and quantity Water usage by sector Flood mapping Infrastructure assessment Avalanches
Freshwater Fish	Low	Low	Substantial	Impacts on salmon
Agriculture	Moderate to Low	Moderate to Low	Limited	Soil mapping and assessment Impacts on berry growth
Forestry	Moderate to Low	Moderate to Low	Moderate-Limited	Fire frequency Pathogens Impact of Invasive species Adaptation strategies for forestry
Transportation	Moderate	Moderate	Limited	Road and bridge design Econ. Impacts of interruptions Slope failure frequency & impacts
Energy	Low	Moderate	Moderate-Limited	Changes in wind regime Freezing rain & ice storm events Impacts on Cat Arm Reservoir
Tourism	Moderate	Moderate	Limited	Impacts on tourism Trail usage, impacts, design Snow availability for winter tour. Avalanches
Health	Moderate	Moderate	Limited-Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Low	Moderate	Resilience, Adaptive capacity, response to change

The coastal and marine sectors exhibit substantial vulnerability. Water availability has limited development of tourism-related businesses in the L'Anse-aux-Meadows area. Changing sea ice distribution and the impact on the Strait ferry service could be investigated. Coastal communities have been studied through the "Coasts under Stress" and other initiatives of Memorial University faculty.

Coastal & Northern Labrador

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Moderate	Moderate	Substantial	Continuing ongoing research Permafrost ablation
Marine and Fisheries	Moderate	Low	Substantial	Implications for marine operations Changing sea ice regime
Coastal Zone	Moderate	Moderate	Limited	Coastal erosion base-line data Sea level change
Water Resources	Moderate to High	Moderate	Moderate	Water quality and quantity Flood mapping Infrastructure assessment Avalanches
Freshwater Fish	Moderate to High	Low to Moderate	Substantial	Continuing ongoing research
Agriculture	---	potential	None recorded	
Forestry	Low	Low	Very Limited	Fire frequency Adaptation strategies for forestry in Aurora Economic zone
Transportation	Moderate	Moderate	Limited-Moderate	Impacts on Trans-Labrador Highway Slope failure frequency & impacts
Energy	Low	Moderate	Very Limited	Changes in wind regime
Tourism	Moderate (?)	Moderate	None Recorded	Impacts on tourism
Health	Moderate	Moderate	Moderate	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Low to Moderate	Substantial	Resilience, Adaptive capacity, response to change

Substantial research has been conducted in communities in Nunatsiavut and adjacent Nunavik, in part due to funding through ArcticNet and other research initiatives focused on northern and Arctic Canada. Straits and southern Labrador coastal communities have been studied through the “Coasts under Stress” and other initiatives of Memorial University faculty. Geomorphic studies of the coastal zone (eroson, sea level change, stotrm impacts) are limited in comparison to the research on nearshore and marine biological communities and organisms. Health studies, including focus on water resources, have also been conducted in Nunatsiavut. Studies of sea ice distribution have implications for transportation, as well as for the marine and coastal environments.

Interior & Western Labrador

Sector	*Vulner-ability*	*Adaptive Capacity*	*Available Research*	*Potential Focal Areas For Research*
Terrestrial Ecosystems	Low to Moderate	Moderate to High	Moderate-Substantial	Continuing ongoing research
Water Resources	Moderate	High to Moderate	Limited-Moderate	Water quality and quantity Water usage by sector Flood mapping Infrastructure assessment
Freshwater Fish	Moderate	Low to Moderate	Substantial	Continuing ongoing research
Agriculture	Moderate	Moderate	Very Limited	Impacts and opportunities for agriculture in central Labrador
Forestry	Low to Moderate	Low to Moderate	Limited-Moderate	Fire frequency Pathogens Impact of Invasive species Adaptation strategies for forestry
Transportation	Moderate	Moderate to High	Very Limited	Impacts on Trans-Labrador Highway Slope failure frequency & impacts
Energy	Low to Moderate	Moderate to High	Very Limited	Changes in wind regime Impacts on Smallwood Reservoir
Tourism	Low (?)	Moderate (?)	None recorded	Impacts on tourism
Health	Moderate	High	Moderate-Limited	Linkage of health & water issues Air quality issues (wrt fire)
Rural Communities	High	Low to Moderate	Limited	Resilience, Adaptive capacity, response to change
Urban Communities	Moderate to High	Moderate	Very Limited	Resilience, Adaptive capacity, response to change

In contrast to northern Labrador, central interior Labrador (except for North West River) and western Labrador have received limited attention. Although research elsewhere in boreal Canada concerning ecosystems, freshwater fish, forestry, agriculture, health, and community adaptation is relevant, there has been little detailed study of any sector in this region.

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