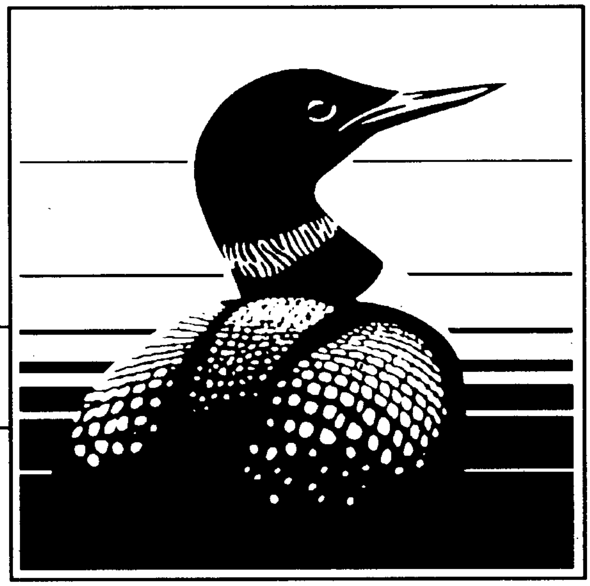
A PRELIMINARY IDENTIFICATION OF PROCESSES AND PROBLEMS AFFECTING MARINE BIRDS IN COASTAL AND OFFSHORE AREAS OF BRITISH COLUMBIA

Alan E. Burger,
Jacqueline A. Booth and
Ken H. Morgan

Pacific and Yukon Region 1997
Canadian Wildlife Service
Environmental Conservation Branch



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ABSTRACT

This report reviews the physical and biological processes and the human-related problems affecting marine birds in British Columbia. The focal groups are *Procellariiformes* (albatrosses, fulmars, shearwaters and storm-petrels), *Phalacrocoracidae* (cormorants), *Charadriiformes* (phalaropes, jaegers, skuas, gulls, kittiwakes, terns and alcids), with some information provided on *Gaviiformes* (loons), *Podicipediformes* (grebes) and *Anseriformes* (waterfowl). Most *Scolopacidae* (shorebirds), *Ciconiiformes* (herons) and *Coraciiformes* (kingfishers) are not included. Colonies and critical foraging areas are mapped. The prey requirements of the birds are reviewed, and prey concentrations are mapped, focusing on macrozooplankton, salmonids, Pacific herring *Clupea harengus*, and sandlance *Ammodytes hexapterus*. The effects of coarse-scale physical ocean processes on the distribution of seabirds are reviewed, including bathymetry, the continental shelf break, underwater canyons, shallow banks, upwelling plumes, the Juan de Fuca gyre, seamounts, tides and currents. There is very little local information on the effects of these features or the effects of fine-scaled features like small convergent fronts. Overall there has been very little research on the interactions of birds with physical ocean features off British Columbia. Potential problems affecting marine birds are reviewed, including chlorinated hydrocarbons, heavy metals, oil spills (both catastrophic and chronic), aquaculture, recreational and commercial vessel traffic, shoreline development, and fishing (particularly gillnetting). The intensity of survey effort is mapped for the entire coast, with aerial and vessel surveys in each of the four seasons mapped separately. Most parts of the coast have been surveyed once or not at all, and only a handful of areas have been monitored more than five times. Changes in populations and distributions are unlikely to be reliably detected from these samples. Additional observations from shore-based observations (sight-record cards, systematic shore surveys, Christmas Bird Counts and beached bird surveys) are reviewed.

Recommendations for future research and monitoring include the following:

* increased sampling of bird densities relative to oceanic parameters in pelagic surveys;
* studies of the effects of gillnet and seine fishing;
* research on the distribution of sandlance and its role as a prey base;
* studies on the winter distribution of offshore and inshore marine birds;
* at-sea studies of breeding seabirds around colonies;
* multi-seasonal investigations of the seabirds at the shelf break and the importance of macro-zooplankton aggregations there;
* surveys of the birds in fjords and inside passages on the central and northern coast;
* investigation of the role of fisheries discards on seabirds;
* studies of the effects of seamounts on pelagic seabirds;
* increased research on the marine distribution of Marbled Murrelets *Brachyramphus marmoratus*;
* continued monitoring of the effects of toxins and oiling with beached bird surveys;
* monitoring of the effects of recreational and commercial boating;
* testing of the accuracy of aerial surveys for marine birds in inshore and offshore waters.

RÉSUMÉ

Le présent rapport traite des processus physiques et biologiques ainsi que des problèmes anthropiques qui affectent les oiseaux marins en Colombie-Britannique. Les groupes visés sont les *Procellariiformes* (albatros, fulmars, puffins, pétrels et océanites), les *Phalacrocoracidae* (cormorans), les *Charadriiformes* (phalaropes, labbes, goélands, mouettes, sternes et alcidés), et on donne certaines informations sur les *Gaviiformes* (plongeons), les *Podicipediformes* (grèbes) et les *Anseriformes* (sauvagine). La plupart des *Scolopacidae* (oiseaux de rivage), des *Ciconiiformes* (hérons) et des *Coraciiformes* (martins-pêcheurs) ne sont pas pris en considération. Les colonies et les aires d'alimentation critiques sont cartographiées. Les besoins des oiseaux en matière de proies sont examinés, et les concentrations des proies sont cartographiées, l'accent étant mis sur le macrozooplancton, les salmonidés, le hareng du Pacifique *Clupea harengus* et le lançon *Ammodytes hexapterus*. Les effets des paramètres océaniques physiques à grande échelle sur la répartition des oiseaux marins sont examinés, dont la bathymétrie, la rupture de pente du plateau continental, les canyons sous-marins, les bancs peu profonds, les panaches de remontées d'eau profonde, le gyre de Juan de Fuca, les monts sous-marins, les marées et les courants. On dispose de très peu d'information locale sur les effets de ces paramètres, ou sur les effets des paramètres à petite échelle comme les petits fronts convergents. Somme toute, très peu de recherches ont été effectuées sur les interactions des oiseaux avec les caractéristiques océaniques physiques au large de la Colombie-Britannique. Les problèmes potentiels affectant les oiseaux marins sont examinés, dont les hydrocarbures chlorés, les métaux lourds, les déversements de pétrole (accidentels et chroniques), l'aquaculture, la circulation de bateaux de plaisance et commerciaux, le développement du littoral et la pêche (surtout celle aux filets maillants). L'intensité de l'effort de recensement est cartographiée pour l'ensemble de la côte, les recensements aériens et réalisés en bateaux de chacune des quatre saisons étant cartographiés séparément. La plupart des secteurs de la côte ont été recensés une fois ou pas du tout, et seulement quelques secteurs ont été couverts plus de cinq fois. Il est peu

probable que les changements dans les populations et les distributions soient détectés de façon fiable à partir de ces échantillons. Des observations additionnelles faites sur le littoral (fiches d'observation, relevés systématiques réalisés sur le littoral, Recensements des oiseaux de Noël et relevés des oiseaux échoués) sont examinées.

Pour les activités de recherche et de surveillance futures, on fait les recommandations suivantes :

* échantillonnage accru des densités d'oiseaux en rapport avec les paramètres océaniques dans les relevés pélagiques;
* études des effets de la pêche aux filets maillants et à la senne;
* recherche sur la distribution du lançon et sur l'importance de ce dernier comme proie;
* études sur la répartition hivernale des oiseaux marins au large et sur la côte;
* études en mer des oiseaux marins nicheurs aux colonies;
* études multi-saisonnières des oiseaux marins à la rupture de pente du plateau continental et de l'importance des agrégations de macrozooplancton à cet endroit;
* relevés des oiseaux dans les fjords et les passages intérieurs dans les zones centrale et septentrionale de la côte;
* étude de l'impact sur les oiseaux marins des captures de pêche rejetées;
* études des effets des monts sous-marins sur les oiseaux marins pélagiques;
* recherche accrue sur la répartition en mer du Guillemot marbré *Brachyramphus marmoratus*;
* surveillance continue des effets des toxines et du mazoutage par l'entremise de relevés des oiseaux échoués;
* surveillance des effets de la navigation récréative et commerciale;
* vérification de la précision des relevés aériens des oiseaux marins dans les eaux côtières et du large.

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1. Introduction

With increasing population growth in the Georgia basin and other coastal areas of British Columbia, conflicts between marine birds and human activities (development, industry, recreation, fishing, etc.) are likely to increase. In addition, there is growing evidence that since approximately 1990, several species of seabirds have declined dramatically off much of the west coast of North America (T.R. Wahl, pers. comm.). Most notable has been the decrease in Sooty Shearwaters *Puffinus griseus*, estimated to have declined by 90% within the California Current system (Veit *et al.* 1996). The impacts of global warming and periodic El Niño events on marine birds are largely unknown, but may likely negate most of what we currently understand about seasonal distribution and abundance, as well as breeding performance.

Research and monitoring of marine and shoreline birds in British Columbia have been undertaken by several agencies, universities, museums and individuals. Although there has been a wide variety of topics covered by this work, much of it has not been co-ordinated towards a common goal. The purpose of this report is to review past and present work on marine birds, identify critical gaps in our knowledge, identify areas of known (or suspected) importance to these birds, and recommend some priorities for research and monitoring. The ultimate goal is to help direct research and monitoring efforts towards the areas and avian groups where attention is most needed.

We have concentrated on the marine foraging and staging areas of marine birds, with consideration given to links between these areas and the birds' breeding sites. The primary focus of this review is on the following groups: pelagic seabirds (albatrosses, fulmars, shearwaters, storm-petrels, phalaropes, skuas, jaegers, alcids, gulls); with some information, but not a comprehensive review, on terns, cormorants, waterfowl, loons and grebes in the marine environment. The level of information available for these groups and for the various geographic regions of British Columbia varies considerably.

We also focused on the processes and problems affecting seabirds in the marine environment. Those affecting the birds at breeding colonies, such as introduced mammalian predators (Bailey and Kaiser 1993), were not reviewed in detail. In this analysis we first identified and mapped critical areas likely to be important to marine birds, and those areas in which birds might be at risk from human activities. We then reviewed the survey efforts covering the British Columbia coast and offshore waters, involving aerial, vessel and ground surveys. This allowed us to identify areas of concern, such as areas with seasonally high concentrations of birds, or areas where birds might be at risk, and in which there had not been adequate investigation.

Marine areas in British Columbia were classified according to a modified version of Kessel's (1979) Alaskan system. ***Inshore waters*** are defined as coastal waters generally within 10 km of shore and less than 100 m deep. In this zone, seas within 1 km of exposed shores, or within protected inlets and sounds are classified as ***nearshore waters***. ***Offshore waters*** are those more than 10 km from the coast and generally deeper than 100 m. Some flexibility was used in applying these boundaries, because bird distributions and oceanic processes vary with seasons and along the coastline. Species normally associated with offshore waters (e.g. albatrosses, shearwaters and fulmars) use inshore waters quite extensively at times.

Throughout this report, the ***continental shelf*** (or ***shelf***) refers to the portion of the continental margin between the coast and the 200 m isobath (Figs. 1a and 1b); and the ***shelf edge*** or ***shelf break*** is generally demarcated by the 200 m isobath (R.E. Thomson, pers. comm.). The locations of all places mentioned in the text are shown in Figures 1a and 1b.

2. Methods

Initially, information on the distribution and densities of birds was extracted from published books and papers, unpublished reports and databases and, in a few cases, from raw field notes. To augment the above, unpublished information and personal knowledge of (assumed) important areas were obtained from staff of the Canadian Wildlife Service (CWS) (A. Breault, R. Butler, G. Kaiser, M. Lemon, K. Morgan) and others who have worked extensively with marine and shoreline birds (A. Burger and J. Clowater).

Information used in the mapping of birds, resources and survey effort were obtained from databases on file with the CWS and with Booth and Associates. Seabird colony information came from the CWS data summarised in Rodway (1991), supplemented by recently collected data from a few colonies.

For the mapping of pelagic bird survey effort by season we used the following dates (from Morgan *et al.* 1991): Winter - 16 December through 15 March, Spring - 16 March through 15 June, Summer - 16 June through 15 September, Fall - 16 September through 15 December. For all other seasonal mappings we used the following dates: Winter - 1 December through 28 February, Spring - 1 March through 31 May, Summer - 1 June through 31 August, Fall - 1 September through 30 November.

Information on mudflats and sandflats was derived from the 1992 Coastal Tourism Resource Inventory (British Columbia Ministry of Tourism) using 18 different sources. Shoreline types were included if they were classified as intertidal mudflats or sandflats, sand beaches with intertidal flats, or beaches (undefined) with intertidal flats.

Euphausiid densities on the west coast of Vancouver Island were obtained from D. Mackas, Institute of Ocean Sciences, Department of Fisheries and Oceans (DFO), Sidney, and formed the basis of several previous publications (Mackas 1992, 1995, Mackas and Galbraith 1992). Densities were classified and mapped as either concentrated (2.5 - 4.0 g dry mass of euphausiids m^{-2}) or highly concentrated (>4 g m^{-2}).

Information on Pacific herring *Clupea harengus* spawn was provided by D. Hay and B. McCarter of the Stock Assessment Division, Pacific Biological Station (DFO), Nanaimo. Coastal segments of 1 km were assigned a spawn index, calculated as:

$$\text{spawn index} = \sum(\text{length x width x layers})/1000$$

The index varied from 0 - 14,450, with a mean value of 334 (SD = 904). Coastal segments were mapped as having either a low index (<1000) or a high (>1000) index value.

Salmonid escapement was mapped from a database of estuaries linked to the DFO stream number using escapement data provided by DFO for the period 1981-1989. The maximum escapement assigned to each estuary was used.

We were unable to find any data on the provincial distribution of sandlance *Ammodytes hexapterus*, but since this is an important prey for many marine birds, we attempted to plot likely areas for this fish. Potential habitats were defined as sandy subtidal seas with depths <200 m. Bathymetric and substrate data for this analysis came from digital files provided to the provincial Land Use Co-ordination Office in association with the report by Wainwright *et al.* (1995), and were primarily derived from Canadian Hydrographic Service charts.

The distribution and effort of gillnet and seine fishing was mapped by plotting the information summarised in Carter *et al.* (1995) for the DFO coastal fisheries statistical areas.

3. Critical areas (known or potential)

3.1 Identification of areas critical to marine birds

3.1.1 Seabird colonies

Fifteen species of seabirds breed on the British Columbia coast, including two storm-petrels, three cormorants, one gull and nine alcid species (Rodway 1991). With the exception of California Gulls *Larus californicus*, other species of gulls and terns that breed inland (Campbell *et al.* 1990), are not considered here. There have been several census programs of these colonies, including a preliminary inventory by Drent and Guiguet (1961), an intensive search and census by the Provincial Museum in 1974-1979 (Campbell *et al.* 1990), and a more comprehensive census covering most of the known colonies by the CWS in the 1980s (Ewins *et al.* 1994, Rodway 1988, 1990, Rodway and Lemon 1990, 1991a,b, Rodway *et al.* 1988, 1990a,b, 1994, Vermeer 1992, Vermeer and Lemon 1986, Vermeer and Rankin 1984, Vermeer and Devito 1989, Vermeer *et al.* 1989a, 1992a, 1993b). Many of the CWS reports include detailed descriptions and maps of the colonies, and locations of the census transects, and these data are not repeated here. Much of this information was summarised by Rodway (1991), who also mapped the locations of the larger colonies.

Figure 2 shows the distribution of seabird colonies across the entire British Columbia coast. Details for three coastal subsections are shown in Figures 3-5 (Fig. 3 - the Queen Charlotte Islands, Fig. 4 - the North Coast [mainland], Fig. 5 - the South Coast [+ Vancouver Island]). These maps are included to allow discussion of related at-sea processes and sampling efforts. Over 5.6 million birds are estimated to nest at 503 sites (Rodway 1991). Large proportions of these birds are concentrated in a few colonies, notably those on the west coast of Graham Island, on the east coast of Moresby Island, on the Scott Islands off northwestern Vancouver Island, and at Pine and Storm islands at the mouth of Queen Charlotte Strait. These large concentrations of hundreds of thousands of birds are dominated by Leach's *Oceanodroma leucorhoa* and Fork-tailed *O. furcata* storm-petrels and burrowing alcids, including Cassin's Auklets *Ptychoramphus aleuticus*, Ancient Murrelets *Synthliboramphus antiquus*, Tufted Puffins *Fratercula cirrhata* and Rhinoceros Auklets *Cerorhinca monocerata*. British Columbia supports an estimated 80%, 74%, and 56% respectively, of the world's breeding populations of Cassin's Auklets, Ancient Murrelets and Rhinoceros Auklets (Rodway 1991).

Cormorants, Glaucous-winged Gulls *Larus glaucescens*, Pigeon Guillemots *Cepphus columba* and Marbled Murrelets *Brachyramphus marmoratus* have more widespread breeding distributions, usually in small colonies or scattered nests (see Campbell *et al.* 1990, Rodway 1991 and Vermeer *et al.* 1992c, 1993b for more detailed information).

3.1.2 Important foraging and staging areas at sea

Table 1 lists the coastal and pelagic areas that were identified as known or suspected to be important to marine and shoreline birds during some stage of the year. Figures 6, 7 and 8 show the locations of these important marine areas to seabirds, waterfowl and Marbled Murrelets, respectively.

Table 1 is obviously not an exhaustive list of all critical areas used by these birds, but it does provide a preliminary overview of marine bird distributions and densities.

The critical foraging or staging areas of most marine birds are still poorly known, particularly for the fall, winter and spring seasons (Morgan *et al.* 1991). However, based primarily upon locations where high concentrations of seabirds have been noted, several (potentially) important areas in deep oceanic waters more than 100 km offshore are indicated (Fig. 6). Other, more nearshore areas (e.g. the east coast of Moresby Island, large patches in Hecate Strait and Queen Charlotte Sound, and the shallow shelf off southwest Vancouver Island, especially La Perouse and Swiftsure banks) are also shown. Several of these areas are close to large colonies.

Important marine areas used by waterfowl, loons and grebes comprise nearshore sheltered waters of the straits of Georgia and Juan de Fuca, along with additional sheltered waters on the outer coast (e.g. Barkley and Clayoquot sounds) and Queen Charlotte Islands (e.g. Masset and Skidegate inlets) (Fig. 7). The highest concentrations occur at the Fraser River delta during winter (Butler and Campbell 1987, Butler and Vermeer 1994).

Marbled Murrelets were selected as a sample focal species, because it is a threatened species in Canada and has been the impetus for numerous recent marine censuses. Relative densities of Marbled Murrelets have not been measured for most coastal areas in British Columbia, but some areas supporting seasonal concentrations are shown in Figure 8. Important areas include nearshore waters of the Queen Charlotte Islands and Vancouver Island, and some of the mainland fjords. For a quantitative review of the coastal densities of Marbled Murrelets during the breeding season, based on vessel surveys, see Burger (1995a). The distribution of Marbled Murrelets during the moulting period (August-September) and during winter, is poorly known (Burger 1995a, Rodway *et al.* 1992).

3.2 Identified areas of prey concentrations

3.2.1 Macrozooplankton

Macrozooplankton, notably euphausiids *Thysanoessa spp.*, *Euphausia pacifica* and large copepods (e.g. *Neocalanus spp.*), and to a lesser extent salps, medusae and hyperiid amphipods, are important food for certain seabird species in British Columbia (Mackas and Fulton 1989, Mackas and Galbraith 1992, Vermeer 1992, Vermeer *et al.* 1987b). Information on the seasonal and spatial distribution of these prey is patchy for most of British Columbia. Off the west of Vancouver Island, the densities of macrozooplankton are highest from April through September, but euphausiids are still available in significant quantities in winter (Fulton and LeBrasseur 1984, Mackas 1992, 1995, Mackas and Fulton 1989, Mackas and Galbraith 1992, Simard and Mackas 1989). The large numbers of Cassin's Auklets which breed (Rodway 1991) and winter (Ford *et al.* 1991, Vermeer *et al.* 1983, 1987a) off this coast are largely dependent on these euphausiids. Additionally, many piscivorous alcids, such as Common Murres *Uria aalge*, Rhinoceros Auklets, Ancient Murrelets and Marbled Murrelets, eat significant quantities of macrozooplankton outside the breeding season (Burkett 1995, Vermeer *et al.* 1987b, A.J. Gaston, pers. comm.).

High concentrations of euphausiids off the west coast of Vancouver Island occur along the shelf break 20-70 km offshore, and in the upwelled waters associated with the gyre at the mouth of the Strait of Juan de Fuca (Fig. 9). These areas also support concentrations of planktivorous Cassin's Auklets (Ford *et al.* 1991, Morgan *et al.* 1991).

Table 1. Coastal and pelagic areas known or suspected to be important to marine and shoreline birds during some stage of the year.

No	Location	Importance[1]	Ref[2]
1	Outer shore Southern Vancouver Is. - Sooke Inlet to Sidney	Important wintering concentrations of ANMU, WEGR, HOGR, THGU, GWGU + many waterfowl spp.	AEB
2	Sooke Harbour	Waterfowl concentrations	KM
3	Witty's Lagoon & Esquimalt Lagoon	Waterfowl, shorebirds, wintering gulls	AMB
4	Sidney Is. & Sidney Channel	Shorebirds, waterfowl, seabirds, MAMU	RB
5	Saanich Inlet - Goldstream estuary, Mill & Pat Bays, Boatswain Bank	Overwintering waterfowl & gulls, WEGR migration staging area & winter roost site	JC, AEB
6	Sansum Narrows	Feeding area for PALO, WEGR, COMU, cormorants & other marine birds, winter roost site for WEGR	JC, AEB
7	Cowichan Estuary & Cowichan Bay	Wintering & migrating waterfowl, grebes	AEB, AMB
8	Stuart Channel - Vesuvius to Shoal Is.	WEGR winter roost location	JC
9	Fulford Harbour - Jackson Rocks	WEGR winter roost location	JC
10	Ganges Harbour - Captain Passage	Seasonal upwelling, important feeding area for marine birds, WEGR winter roost site	JC
11	Active Pass	Significant portion of world's population of PALO	RB
12	Montague Harbour	Wintering marine birds, BAGO, scoters	JC
13	Porlier Pass	Significant portion of world's population of PALO	RB
14	Roberts Bank & Boundary Bay	Largest concentration of waterfowl in B.C.	AEB
15	SW. coast Bowen Is. & coast West of Pt. Atkinson	Scoters, goldeneye, WEGR wintering site	AMB
16	Nanoose Bay, Little Qualicum R. Estuary, Parksville - Qualicum	Winter waterfowl especially BRAN, grebes, loons, gulls, herring spawn area	AMB, KM
17	Squamish Estuary	Waterfowl concentrations	RB

No	Location	Importance[1]	Ref[2]
18	Pender Harbour	Wintering waterfowl, MAMU concentrations winter & summer	AMB
19	Coast from Campbell R. to Qualicum	Wintering waterfowl, gulls, herring spawn area	AMB
20	South end Baynes Sound	MAMU concentrations early summer, marine birds during spring migration	ML
21	North coast Hornby Is.	Wintering HADU	AMB
22	St. John Point	Moulting & wintering waterfowl especially HADU, PECO	AMB
23	Rocks off Powell R.	Winter concentrations of OLDS & other diving ducks	GK
24	Skookumchuk Narrows	MAMU concentrations	GK
25	Okeover, Malaspina & Theodosia Inlets, Desolation Sound	MAMU concentrations breeding season, wintering MAMU at Twin Islets, goldeneye & scoters winter	GK
26	South end Discovery Passage	MAMU summer concentrations	ML
27	Menzies Bay	Large eelgrass bed	AMB
28	Head of Queen Charlotte Strait - Blackney Passage	Seabirds especially phalaropes feeding during migration, MAMU concentrations north side of Harrison Is.	ML
29	Kingcome Inlet	Unexplored but suspected MAMU concentrations	GK, ML
30	Knight Inlet	Unexplored but suspected MAMU concentrations	GK, ML
31	Mouth of Queen Charlotte Str., Pine & Storm Is. area	Seabird feeding concentrations, migrating phalaropes & shorebirds, MAMU concentrations	ML, KM
32	Waters around Scott Islands	Important feeding areas for seabirds	ML
33	Brooks Bay	MAMU & feeding concentrations of seabirds	ML, KM
34	Nootka Sound, West coast Nootka Is.	MAMU, scoters and seabirds in summer	ML
35	Clayoquot Sound (to Grice Bay & Tofino flats)	MAMU concentrations winter & summer, important wintering area for waterfowl & staging area for BRAN & shorebirds	GK, AEB

No	Location	Importance[1]	Ref[2]
36	Pacific Rim Park (Florencia Bay to Clayoquot Sound)	Important MAMU in May - Aug., waterfowl in winter & shorebirds in migration	AEB
37	Barkley Sound & Uchucklesit Inlet	MAMU concentrations winter & summer, PECO & other marine birds all year, important concentrations of waterfowl & grebes	GK, KM, AEB
38	Alberni Inlet & Somass Estuary	Important wintering area for waterfowl, grebes and THGU	AEB, KM
39	Waters near Seabird Rocks	High concentrations of ANMU, MAMU, RHAU, COMU, SOSH	AEB
40	Cape Beale to Owen Pt (to 1km from shore)	High densities of MAMU in May - Aug., high densities of ANMU Nov. - Feb.	AEB
41	Juan de Fuca gyre & Swiftsure Bank	Large concentrations of seabirds (procellarids, alcids & gulls)	GK, KM
42	La Perouse Bank and shelf break	Concentrations of seabirds especially summer & fall (shearwater spp., NOFU, BFAL, FTSP, SAGU, CAGU, GWGU, THGU, BLKI, alcids, phalaropes)	AEB, KM
43	Central coast estuaries	Unexplored but probable waterfowl habitat	AMB
44	Waters near Goose & Gosling Islands, Goose Is. Bank	Seabird feeding concentrations	KM, ML, GK
45	Kynoch Inlet	MAMU concentrations	GK
46	Mussel Inlet	MAMU concentrations	GK
47	Griffin Passage	MAMU concentrations	GK
48	Green Inlet	MAMU concentrations	GK
49	Khutze Inlet	MAMU concentrations	GK
50	Aaltanhash Inlet	MAMU concentrations	GK
51	Klekane Inlet	MAMU concentrations	GK
52	Waters near Aristazabal, Moore & Byers Islands	Important feeding areas for local breeding & migrant seabirds	ML, KM
53	Bonilla Island Banks	Large concentrations of migrant shearwaters	KM

No	Location	Importance[1]	Ref[2]
54	Waters near Joseph Island	PIGU concentrations	ML
55	Waters around Lucy Island	Important feeding area for RHAU & PIGU	ML
56	Waters around Kerouard Island	Important feeding area for local breeding seabirds	ML
57	Waters surrounding Anthony Island	Important feeding area for local breeding seabirds, staging area for PIGU	ML
58	Skincuttle Inlet, waters near Copper Islands & Bolkus Islands	Important staging & feeding areas	ML
59	Waters near Alder Island	Staging area for HADU & spring seaduck concentrations on shore opposite Burnaby Is.	ML
60	Waters near Ramsay & House Islands	Seabird staging concentrations	ML
61	Cumshewa Inlet	RHAU feeding concentrations	ML
62	Waters along East coast Moresby Is.	MAMU concentrations, extensive kelp beds	AEB
63	Gray Bay	HADU concentrations	RB
64	Skidegate Inlet & Sandspit area	PIGU concentrations, migrant BRAN, waterfowl & shorebirds	KM, RB
65	Masset Inlet	Wintering waterfowl especially HADU, MAMU concentrations	ML, AMB
66	Delkatla Slough	Shorebirds & waterfowl	RB
67	Waters off Wiah Point	MAMU concentrations	ML
68	Mouth of Naden Harbour, Virago Sound	MAMU concentrations	ML
69	Parry Passage to Klashwun Point	MAMU concentrations	ML
70	Learmonth Bank	Important feeding area for breeding & migrant seabirds	RB, KM
71	Port Louis, Coates Creek, Coates Lake, Upper & Lower Rainbow Lakes	MAMU concentrations at sea & inland forested areas	ML
72	Rennell Sound	MAMU summer concentrations at sea	ML
73	Long Inlet & Lagin's Creek	MAMU summer concentrations at sea & forest habitat	ML

No	Location	Importance[1]	Ref[2]
74	Government Creek	MAMU summer concentrations at sea & forest habitat	ML
75	Security Inlet	MAMU concentrations at sea	GK
76	Kootenay Inlet	MAMU concentrations at sea	GK
77	Wilson Bay, Botany Inlet & Taso Sound	MAMU concentrations at sea	GK
78	Bowie Seamount	Unexplored but probable seabird concentrations	KM
79	Dellwood Seamount	Unexplored but possible seabird concentrations	KM
80	Union Seamount	Unexplored but possible seabird concentrations	KM
81	Cobb Seamount	Seabird concentrations	KM
82	Warwick Seamount	Unexplored but possible seabird concentrations	KM

[1] Bird Species Abbreviations: ANMU = Ancient Murrelet, BAGO = Barrow's Goldeneye, BFAL = Black-footed Albatross, BLKI = Black-legged Kittiwake, BRAN = Brant, CAGU = California Gull, COMU = Common Murre, FTSP = Fork-tailed Storm-Petrel, GBHE = Great Blue Heron, GWGU = Glaucous-winged Gull, HADU = Harlequin Duck, HOGR = Horned Grebe, MAMU = Marbled Murrelet, NOFU = Northern Fulmar, OLDS = Oldsquaw Duck, PALO = Pacific Loon, PECO = Pelagic Cormorant, PIGU = Pigeon Guillemot, RHAU = Rhinoceros Auklet, SOSH = Sooty Shearwater, THGU = Thayer's Gull

[2] Source of Information: AMB = Andre Breault, AEB = Alan Burger, RB = Rob Butler, JC = James Clowater, GK = Gary Kaiser, ML = Moira Lemon, KM = Ken Morgan

3.2.2 Fish

Fish are important prey for large populations of loons, grebes, cormorants, alcids and gulls off British Columbia (Sealy 1975, Vermeer 1982a, Vermeer *et al.* 1987b). With the exceptions of herring and juvenile salmonids, there have been few detailed studies of the distribution and densities of these fish (Hay *et al.* 1989, 1992).

3.2.2.1 Salmonids.

Pre-smolting salmon are taken in significant numbers in British Columbia's rivers and lakes by diving birds, particularly mergansers (Wood 1984, 1986). Smolts are most likely to be taken by birds within the first few weeks of entering the ocean. By late summer most species are too large to be taken by birds (Hay *et al.* 1992). Salmon escapement data give an indication of the distribution of this food resource (Figs. 10-12).

There are hundreds of rivers and creeks producing salmonids, and in certain locations (e.g. the Fraser Delta, Barkley Sound, east coast of Moresby Island) many millions of smolts are potentially available as prey to seabirds. In Barkley Sound, large numbers of salmon smolts emerge from Alberni Inlet, and yet the summer densities of piscivorous birds are very low (Vermeer and Morgan 1992, A.E. Burger, unpubl. data). Although these prey concentrations do not appear to consistently support large aggregations of piscivorous birds, there are anecdotal accounts of gulls and loons assembling at river mouths in the Queen Charlotte Islands during smolt escapement (A.J. Gaston, pers. comm.).

Most young salmon appear to move away from sheltered inlets and inshore areas into the open ocean where they are probably too deep for most diving birds (Hay *et al.* 1992). Seining surveys made by Hartt and Dell (1986) showed relatively low densities of young salmon within 30 km of the shore, and pink *Onchorynchus gorbuscha* and chum *O. keta* salmon were the most likely species to remain close to Vancouver Island. That study found high concentrations of juvenile salmon near the northern end of Vancouver Island (possibly a staging area). There are very large colonies of Rhinoceros Auklets in this vicinity, and juvenile salmon are a common but not dominant prey item (Bertram and Kaiser 1993, Burger *et al.* 1993, Vermeer 1979, Vermeer and Devito 1986). Overall, it seems that high concentrations of young salmon are not readily available to birds once they leave the rivers.

3.2.2.2 Herring.

Adult herring are too large for all but the largest birds (Common Murres, cormorants and larger loons), but the eggs and juveniles are a major food source for a wide range of birds. Herring spawn is eaten by gulls, waterfowl, shorebirds and alcids. In Barkley Sound and the Strait of Georgia herring eggs are important food for migrating gulls (notably Thayer's Gull *Larus thayeri*), and waterfowl (Haegele and Schweigert 1989, Outram 1958, Robertson 1972, Vermeer 1992). Juvenile (0-year class) herring spend their first summer in shallow inshore waters, and many remain there through winter (Grosse and Hay 1988, Hourston 1958). In British Columbia juvenile herring are important prey for Sooty Shearwaters, gulls (notably resident Glaucous-winged Gulls and migrant California *Larus californicus*, and Mew *L. canus* gulls), alcids (Common Murres, Marbled Murrelets and Rhinoceros Auklets), loons, cormorants and grebes (Robertson 1972, Vermeer 1982a, 1992, Vermeer *et al.* 1987b).

The magnitude of herring spawn on the coast of British Columbia is plotted in Figures 13-15. The maps indicate the availability to birds of herring eggs, and, less precisely, juvenile herring which tend to remain in shallow nearshore waters through their first year. Some of the identified areas are well known to attract tens of thousands of birds (e.g. the southwestern shores of the Strait of Georgia, and northwestern Barkley Sound), but other concentrations have not been thoroughly investigated as a resource for birds (e.g. Milbanke Sound, Hakai Passage and other shores of Queen Charlotte Strait).

3.2.2.3 Sandlance.

Sandlance are extremely important prey of breeding Tufted Puffins, Rhinoceros Auklets, Marbled Murrelets and Glaucous-winged Gulls, as well as the large populations of non-breeding Common Murres, California Gulls and other late-summer migrants (Bertram and Kaiser 1993). All age classes of sandlance are taken by these birds, and the larger 1- and 2-year classes are important as prey delivered to chicks by puffins, auklets and murrelets.

Sandlance of the 0-year class, 30-60 mm in length, were common in a mid-water trawl made in Queen Charlotte Strait in June (Westrheim and Harling 1983). Off the

Queen Charlotte Islands, sandlance were important prey for fish (Westrheim and Harling 1983) and for Ancient Murrelets and Cassin's Auklets (Sealy 1973, 1975). From a collection of 74 Rhinoceros Auklet chick meals collected on Anthony Island, in August 1995, sandlance were the dominant prey item (T. Golumbia, unpubl. data). Post-larval sandlance were important prey for Cassin's Auklets breeding at Reef Island in Hecate Strait (Burger and Powell 1990), but elsewhere they did not make up a large proportion of the auklets' chick meals (Vermeer 1981a, 1985, Vermeer *et al.* 1987b).

Larval sandlance in the North Atlantic tend to be concentrated in the upper 30-40 m of the water column (Reay 1970). Assuming that a similar pattern exists in British Columbia, and since sandlance spend a significant portion of their lives buried in sand or fine gravel (Field 1988), the identification of these substrates (associated with relatively shallow waters [i.e. < 200 m]) could provide some indication of the distribution of this important prey species.

Figure 16 shows the distribution of potential sandlance habitat; this analysis suggests that extensive tracts of suitable habitat could be expected in Hecate Strait, Queen Charlotte Strait and off the west of Vancouver Island. Unfortunately, we suggest that the predictability of this mapping exercise is limited. For example, Figure 16 does not indicate any potential sandlance habitat in the Barkley Sound area, and yet this species is very abundant there, frequently occurring in surface schools (A.E. Burger, pers. obs.). Sandlance are one of the most important prey items for Marbled Murrelets (Carter 1984) and Rhinoceros Auklets (Burger *et al.* 1993, G. Davoren, unpubl. data). Similarly, Figure 16 does not indicate any potential sandlance habitat in the vicinity of Langara Island, where sandlance were important prey for both Ancient and Marbled murrelets (Sealy 1975).

It is likely that the mapping criteria we utilised to generate Figure 16 was too coarse to effectively predict sandlance distribution. In addition, sandlance probably select either additional or alternative criteria (e.g. wave energy, particle size, organic content, etc.). Such large-scale mapping of apparently *suitable* habitat is obviously not detailed enough to act as a reliable habitat indicator, but it may be a useful first step. Side-scan sonar, successfully used to study nearshore benthic foraging habitats of gray whales *Eschrichtius robustus* off Vancouver Island (Kvitek and Oliver 1986) offers one possible method for gathering greater detail.

3.2.2.4 Other fish.

Northern Anchovy *Engraulis mordax*, smelts *Osmeridae* and Eulachon *Thaleichthys pacificus* are all seasonally and patchily common in inshore waters, and are taken by seabirds (Hay *et al.* 1989, 1992, Vermeer *et al.* 1987b). Anchovies are most common on the banks off southwestern Vancouver Island, and in shallow nearshore waters (Hay *et al.* 1989, 1992). Pacific Saury *Cololabis saira*, a fish of warmer oceanic waters, was commonly taken by Tufted Puffin and Rhinoceros Auklets breeding on Triangle Island (Vermeer 1979), and occasionally by Rhinoceros Auklets on Pine Island, but was absent at other colonies (Bertram and Kaiser 1993, Burger *et al.* 1993, Vermeer and Westrheim 1984). Lanternfish (*Myctophidae*), the most common and abundant mesopelagic species collected off British Columbia (Frost and McCrone 1979, Taylor 1968), are important prey of both species of storm-petrels (Vermeer and Devito 1988). Myctophids occur primarily over and beyond the shelf break (Hart 1973).

Most of the small benthic fish taken by birds are species or age-classes which are of no commercial interest. Consequently there are few data on the distribution and densities of these fish and their availability to birds (Hay *et al.* 1989, 1992). Juvenile (young of the year) rockfish *Sebastes spp.* and greenling *Hexagrammids* are taken in large numbers by breeding Rhinoceros Auklets at some locations (Bertram and Kaiser 1993, Burger *et al.* 1993, Vermeer and Westrheim 1984). Recreational fishing of rockfish has intensified in the 1990s, as anglers face reduced salmon limits, and this, in combination with commercial fishing, might reduce the availability of juvenile rockfish in heavily fished areas. Juvenile perches *Embiotocids* are often found near the surface, where they might be vulnerable to birds (Hay *et al.* 1989, 1992).

Pacific hake *Merluccius productus* dominates the fish biomass on the shelf off Vancouver Island in summer (Hay *et al.* 1992). The adults are too large and occur too deep to be taken as prey by birds, but likely compete with birds for some prey types. Offal and fish lost from nets are, however, a significant source of food for tens of thousands of seabirds, principally Black-footed Albatross *Diomedea nigripes*, Sooty, Short-tailed *Puffinus tenuirostris*, and Pink-footed *P. creatopus* shearwaters, Northern Fulmars *Fulmarus glacialis*, Fork-tailed Storm-Petrels and Glaucous-winged, California and Herring *Larus argentatus* gulls, which are attracted to the fishing and processing vessels (Hay 1992, Morgan *et al.* 1991, Vermeer *et al.* 1989b, Wahl *et al.* 1993, A. E. Burger unpubl. data). The amount of food provided by this source has not been estimated, but it is likely to be considerable. Changes in fishing effort and in the proportion of catches discarded would likely have significant effects on the species listed above. Reductions in fisheries discards could potentially have negative consequences as (e.g.) gulls are forced to switch to other food items, such as other species of colonial nesting seabirds (G.L Hunt, pers. comm.). In the North Sea an estimated 2.5-3.5 million seabirds were supported by fishery waste, and might be severely impacted by changes in fishing practices which reduce this food supply (Camphuysen *et al.* 1995, Garthe *et al.* 1996).

3.2.3 Benthic invertebrates

Octopus, bivalves, gastropods, echinoderms, crustaceans and polychaetes are eaten by a large and diverse avifauna. They are particularly important to ducks (Vermeer 1981b, 1982b, Vermeer and Bourne 1984, Vermeer and Levings 1977) and shorebirds, and the aggregations of these birds are likely to reflect the abundance and availability of invertebrate benthos. Most research involving benthic invertebrates as prey of birds has focused on the possible effects of harvesting on birds, or conversely, the effects of birds on cultured invertebrates (Bourne 1989, 1992).

3.2.4 Squid

Seventeen species of squid have been recorded in British Columbia waters. However, because only four species are of commercial interest (opal *Loligo opalescens*, red *Berryteuthis magister*, nail *Onychoteuthis borealijaponica* and flying *Ommastrephes* *bartrami* Bourne 1992), little information is available on the distribution and abundance of this group of invertebrates.

Opal squid are generally found from the intertidal zone to a depth of 250 m; they migrate inshore to mate and spawn, commonly in winter or early spring (Jamieson and Francis 1986, Maupin 1988). Red squid are found from the surface to approximately 4600 m depth, spending most of their time near the ocean floor; nail squid normally occur along the shelf break, from the surface to about 400 m depth; and flying squid are generally restricted to oceanic waters 15-16°C or warmer (Jamieson and Francis 1986).

Opal squid was the dominant prey taken by Rhinoceros Auklets, Sooty and Short-tailed shearwaters, Black-legged Kittiwakes *Rissa tridactyla* and California Gulls in Monterey Bay, California (Morejohn *et al.* 1978). In British Columbia, squid are taken by a wide range of procellarids, gulls and alcids but do not appear to be the dominant prey of any local birds (Vermeer 1979, 1992, Vermeer *et al.* 1987b, Vermeer and Westrheim 1984). However, since the diets of only a few species of seabirds have been adequately examined, squid might be underestimated in the diets of birds feeding off British Columbia.

3.3 Identified areas with favourable physical conditions

3.3.1. Ocean currents and bathymetric effects

Pelagic seabirds are strongly influenced by bathymetric features which affect marine productivity, and more importantly, create concentrations of prey through upwelling, gyres or fronts. These effects can be observed at a range of spatial and temporal scales (Hunt and Schneider 1987). In this review we focus on effects at coarse (1-100 km in size) and fine (0.01 - 1.0 km) scales. Some aspects of processes at other scales affecting birds off the British Columbia coast were discussed by Burger (1993a).

The continental shelf edge forms the boundary between nutrient-rich, upwelled shelf waters and the clear, stratified oceanic waters. The thermal fronts occurring at these boundaries are often visible. Densities of macrozooplankton are often high at these shelf edge fronts (e.g. off Vancouver Island, Fig. 9), and this undoubtedly explains the high densities of planktivorous Cassin's Auklets at the shelf edge, especially outside the breeding season (Briggs *et al.* 1987, Ford *et al.* 1991, Morgan *et al.* 1991). The shelf break also forms the inner boundary of the usual foraging areas of Leach's Storm-Petrels (Briggs *et al.* 1987, Morgan *et al.* 1991, Vermeer *et al.* 1992d). The interactions between physical oceanography, prey distributions and seabird distribution at the shelf break have not been adequately explored off British Columbia (but see Logerwell and Hargreaves 1996).

Shallow banks on the shelf are important foraging areas for a range of seabirds, for several reasons. Shallow seas with a high degree of mixing promote primary productivity; wind-induced coastal upwelling plumes cause advection of nutrient rich waters into the euphotic zone; these plumes and tidal upwelling zones also create convergent fronts which tend to concentrate prey near the surface where seabirds feed. The high productivity generated by upwelling plumes does not necessarily confer immediate benefits to seabirds or other higher trophic level consumers. Denman *et al.* (1989) examined biomass transfer in shelf marine systems and concluded that a pulse in primary productivity would create a peak in the biomass of euphausiids and fish larvae (typical prey of Cassin's Auklets) after 90 days and in a 30 g fish (typical prey of Rhinoceros Auklets and Common Murres) after 270 days. High densities of phytoplankton and zooplankton occur predictably over shallow banks, notably Swiftsure and La Perouse banks off SW Vancouver Island, in summer and winter (Denman *et al.* 1981, Mackas *et al.* 1980, Thomas and Emery 1986), probably as a result of long-lasting upwelling, advection and mixing.

Canyons which cut across the continental shelf off British Columbia modify the deep northward flowing currents to create anticlockwise circling currents or gyres (Hickey 1989). Most of these gyres do not appear at the surface, but can enhance the advection of deep, nutrient-rich waters into the upper ocean (Freeland and Denman 1982, Hickey 1989). During summer there is a large, semi-permanent surface gyre at the mouth of the Strait of Juan de Fuca which entrains cold, nutrient rich waters and enhances local productivity. Dense aggregations of birds occur there in summer and winter (Ford *et al.* 1991, Hay 1992, Morgan *et al.* 1991, A.E. Burger, unpubl. data). Persistent features, such as the Juan de Fuca gyre, might be more important to seabirds than more transient upwelling plumes, but this needs to be examined in more detail.

Seamounts are undersea volcanoes that rise more than 1000 m above the surrounding ocean floor (Thomson 1981). Three shallow seamounts occur off the British Columbia coast in deep ocean waters: Cobb (minimum depth 24 m), Bowie (37 m) and Union (293 m). Two others have deeper pinnacles: Warwick (minimum 468m) and Dellwood (541 m). Seamounts create unique ocean conditions, providing patches of isolated bottom fauna (Parker and Tunnicliffe 1994), and, more importantly to seabirds, modifying the flow of water and bringing epi- and meso-pelagic prey near the surface (Dower *et al.* 1992, Haney *et al.* 1995).

The effect of seamounts on the distribution of seabirds, especially during migration, has rarely been studied. However, Haney *et al.* (1995) reported altered species composition, densities and biomass of seabirds (more Black-footed Albatross and fewer Leach's Storm-Petrels) within 30 km of Fieberling Guyot (minimum depth 438 m, 980 km west of California), compared with the surrounding deep ocean. They attributed these trends to changes in the abundance and/or behaviour of pelagic organisms in the deep scattering layer, perhaps augmented by migrations of seamount residents to the surface. Based upon two surveys (July 1991, June 1992) significantly higher densities of Black-footed Albatross, and Leach's and Fork-tailed storm-petrels were noted over Cobb Seamount than off-seamount (i.e. beyond 1 seamount diameter [~30km], K.H. Morgan, unpubl. data). The relationship between seamounts and seabird distribution requires further study, particularly since there has been renewed interest in commercial exploitation of rockfish at several British Columbia seamounts.

Fine-scale (1-100s m) physical features which are known to influence seabirds' foraging include the following from Brown (1980), Haney (1986) and Hunt and Schneider (1987):

i) concentrations of surface debris and plankton at Langmuir cells or wind-streaks, resulting from spiral, wind-induced circulation in the upper few metres of ocean;

ii) aggregations of debris and surface plankton at tidal slicks formed in relatively calm inshore water;

iii) concentrations of plankton formed at small convergent fronts as strong tidal flows create mini-upwelling;

iv) cells of water (diameter in 100s of m) containing high densities of prey, as a result of advection of deep water over a shallow bank, or because of an eddy that has broken off from a larger current flow.

Fedoryako (1982) showed that small-scale processes, like Langmuir cells, which collect surface debris also produce concentrations of plankton and small fish. These processes might also be important in concentrating floating oil and hence increase the risk of oiling by birds which forage there. All of these processes occur off British Columbia (Thomson 1981), but their influence on seabirds has not been studied.

The shelf region off southwestern Vancouver Island has been the focus of fairly intensive oceanographic research and several studies of pelagic seabirds (see review in Burger 1993a). Other areas are less well known, but deserve attention. In particular, the distribution and dynamics of seabirds around the Scott Islands, Queen Charlotte Strait and the Queen Charlotte Islands, deserves greater attention because they support high densities of breeding and migrant seabirds. The North Coast Oceanic Dynamics Experiment has produced greater understanding of the physical oceanography of the Queen Charlotte Islands (Thomson 1989), but this has not been fully applied to seabird ecology. Upwelling, thermal fronts and persistent gyres are found in these waters, particularly in summer (Thomson 1981, 1989), which may have a strong influence on seabird foraging.

3.3.2 Tides and currents

Large concentrations of seabirds are often attracted to areas of with strong tidal rips and tidal upwelling, e.g. Desolation Sound (Kaiser *et al.* 1991), Jervis Inlet (Vermeer

1989) and Active Pass (Vermeer *et al.* 1987c). While the processes that make prey available to seabirds at tidal narrows have been described (Vermeer *et al.* 1987c), there are no clear criteria available to predict or map the conditions in which these occur.

3.3.3 Estuaries, mudflats and sandflats

Several hundred estuaries, mudflats and sandflats are mapped in Figures 17 and 18. This database is not an inclusive inventory of all of these features: the northern half of Vancouver Island and adjacent mainland have no data, and there are some additional omissions and incorrect inclusions. The database does, however illustrate the large number of potential marine and estuarine habitats which need to be investigated for their avian habitat value. They represent potential foraging habitat for many shorebirds, waterfowl and seabirds. Information on the area, topography, water flow and productivity of these features is needed to determine which are key habitats for birds.

3.4 Identified areas with existing or potential problems for birds

3.4.1 Pulp mills and other point sources of possible toxins

Marine birds in British Columbia are contaminated to varying degrees by industrial and municipal discharges into the ocean (reviewed by Elliott *et al.* 1992, Elliott and Noble 1993, Mahaffy *et al.* 1994). Chlorinated hydrocarbons (Elliot and Noble 1993) and heavy metals (Ohlendorf 1993) are of primary concern. High levels of polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs) contaminants were found in marine birds foraging near pulp mills in the Strait of Georgia (Whitehead *et al.* 1992) and in the Somass Estuary at Port Alberni (Vermeer *et al.* 1993a). Contaminant levels in eggs of marine birds appear to be declining as a result of stricter control of toxic discharges (Elliot and Noble 1993, Elliot *et al.* 1992, Whitehead *et al.* 1993). The distribution of pulp mills and other point sources of potential toxic discharges was reviewed by Kay (1989a,b).

3.4.2 Tanker routes and other areas at risk from oil

Seabirds off British Columbia face threats of both large catastrophic and small chronic oil spills (Burger 1992, Burger and Fry 1993, Mahaffy *et al.* 1994, Vermeer and Vermeer 1975, Vermeer *et al.* 1992b). Each year more than 7000 transits of freighters and tankers occur in British Columbia's waters, including at least 1500 tanker trips to or from Alaska (Shaffer and Associates 1990, Canadian Coast Guard 1991). More than 350 loaded tankers cross the continental shelf to enter the Strait of Juan de Fuca annually (Dickins and Associates 1995). Overall, the annual shipments of crude oil and refined petroleum products in southern B.C. and northern Washington average between 15 and 26 million m^3 (Shaffer and Associates 1990).

Models of the risks of catastrophic oil spills made by Cohen and Aylesworth (1990) suggested that spills exceeding 1000 barrels would be expected every 2.5 years for crude oil, and every 1.3 years for all petroleum products, with longer intervals between larger spills. The actual frequency of large spills affecting the British Columbia coast was fairly close to predicted (Burger 1992): between 1974 and 1991 there were five spills exceeding 1000 barrels which affected the coast of B.C. and northern Washington. The December 1989 *Nestucca* spill was particularly damaging, killing about 56,000 birds off northern Washington and Vancouver Island, and affecting birds along 600 km of coastline (Burger 1992, Ford *et al.* 1991). The mortality of seabirds is generally well documented in spills that affect nearshore areas and impact the coastline, but when spills occur well offshore, such as the Stuyvesant spill of May 1987, little or no information on avian mortality is obtained (Burger 1992).

Small spills can kill tens of thousands of seabirds (Burger 1993b), even though they may not be reported, and may often be of unknown origin. In 1989 the Coast Guard registered 40,000 vessel trips annually off B.C. (including fishing vessels) and considered about 4500 to have 'dangerous' cargo (e.g. tankers and barges). In 1988 Environment Canada registered 574 marine spills (Kay 1989a,b). The origin of most spills was not known and only 22 (4%) exceeded 1 tonne. Many hundreds of smaller spills from fishing vessels, recreational craft, marinas and fuelling barges are never reported. Most of these spills are of volatile fuels which, though highly toxic, evaporate rapidly and tend to pose lower risks to marine birds.

Data from systematic beached bird surveys between 1989 and 1992 showed that a minimum of 6% of the beached carcasses were oiled by small chronic spills (Burger 1993c). Oiled birds were found in most months, with no apparent seasonal pattern. The highest densities were found on the west coast of Vancouver Island (12.6% of 190 carcasses), southern Vancouver Island (10.3% of 29 carcasses) and in the Strait of Georgia and Gulf Islands (17.4% of 23 carcasses). The mean density of oiled birds (0.02 per km surveyed) is among the lowest in the world, but the high volumes of logs and other wrack on local beaches are likely to reduce the chances of finding oiled birds. Studies with drifting carcasses and wooden blocks suggest that only a small proportion (usually less than 10%) of oiled carcasses are likely to be recovered after an offshore spill (Ford *et al.* 1991, Hlady and Burger 1993). Oiling is clearly a significant but poorly documented cause of mortality for local seabirds.

3.4.3 Areas of intensive aquaculture

Aquaculture is a relatively new industry in British Columbia and poses potential threats to birds, through entanglement in nets, and disturbance and habitat changes at foraging and staging areas (Vermeer and Morgan 1989, Rueggeberg and Booth 1989). Entanglement seems to kill few birds, although mortality of herons, kingfishers and diving ducks was reported by 13%, 9% and 12%, respectively, of respondents surveyed by Rueggeberg and Booth (1989). Potential conflicts between birds and aquaculture through disturbance and habitat changes were identified in Sechelt-Sunshine Coast, Campbell River-Desolation Sound, Barkley Sound-Alberni Inlet, Clayoquot Sound, Kyuquot Sound, and Queen Charlotte Strait, but in most of the coast it was difficult to assess the degree of interference (Booth and Rueggeberg 1989, Rueggeberg and Booth 1989).

3.4.4 Human disturbance and shoreline development

The burgeoning human population of southern British Columbia, and the Fraser delta in particular, has a significant impact on coastal ecosystems, including birds (Mahaffy *et al.* 1994). These impacts include increased boat traffic, risk of contaminated runoff, loss of estuarine and other shoreline habitats and increased disturbance from people and dogs. Over 75% of the marshes in the Fraser delta (Butler and Campbell 1987) and 32% of the former estuarine marshland on Vancouver Island (Campbell-Prentice and Boyd 1988) have been impounded by dikes. Most of these impacts affect shorebirds and waterfowl, but alcids, cormorants and other seabirds are likely to be affected in many areas too, particularly by increased recreational boating in or near colonies and foraging areas. For example, housing developments around Glencoe Cove, Victoria threaten the only remaining colony of Pelagic Cormorants *Phalacrocorax pelagicus* on the southern end of Vancouver Island. It is not known whether human disturbances are having a significant impact on seabird populations, and there appear to be few monitoring programs in place which might be able to detect such impacts.

3.4.5 Gillnet and seine fishing

Nearshore gillnets (floating nets usually set near the surface to catch salmon) have not attracted the same level of attention as the destructive offshore drift-nets. Nevertheless, gillnets are known to kill coastal seabirds, sometimes in significant numbers (Atkins and Heneman 1987, DeGange *et al.* 1993, Piatt and Gould 1994, Piatt *et al.* 1984). Off California, gillnet fishing contributed to the decline of Common Murres (Takekawa *et al.* 1990). Public pressure and litigation forced the closure and modification of that fishery to reduce the murre by-catch (Salzman 1989). Marine birds are also known to become entangled and killed or injured in seine-nets.

The listing of the Marbled Murrelet as Threatened in the United States led to the closer examination of mortality of seabirds from gillnets in Puget Sound, Washington (Carter *et al.* 1995, Pierce *et al.* 1994). In a pilot observer program covering 1.5% of the fishing effort, 89 Common Murres, 11 Western Grebes *Aechmophorus occidentalis*, 4

Rhinoceros Auklets and 1 Marbled Murrelet were entangled in gillnets. Two murrelets were entangled in seine-nets but released alive. Pierce *et al.* (1994) cautioned against extrapolation of these preliminary results, but the data clearly show that this fishery could have a serious impact on seabirds near the British Columbia border. Dead murres and auklets are routinely found on beaches and floating at sea in British Columbia during the Washington fishery (Kaiser 1993, A.E. Burger, unpubl. data). The Washington gillnets are monofilament, whereas those used in British Columbia are multifilament, which might reduce seabird bycatch. Efforts are now under way to reduce the avian bycatch in Washington by modifications to fishing gear (Melvin and Conquest 1996).

Carter *et al.* (1995) reviewed the impacts of gillnets and seine-nets on Marbled Murrelets and other seabirds in British Columbia. Mortality was reported from several coastal locations, but the only systematic study was made in Barkley Sound from 11 June to 17 July in 1979 and 1980, when 28 Marbled Murrelets, 10 Common Murres and 1 Rhinoceros Auklet were recovered dead during gillnet openings (Carter and Sealy 1984, Carter *et al.* 1995). Carter and Sealy (1984) estimated that at least 175-250 murrelets were killed in this area in 1980, representing 6.2 percent of the breeding population. This mortality may have contributed to the decline in murrelets observed between 1980 and 1993 in Barkley Sound (A.E. Burger, unpubl. data), even though gillnet openings were not held each year.

Hundreds of Common Murres were recovered from purse-seine fisheries in Barkley Sound in 1979-1980, and from gillnetting near Carmanah Point in August 1979 (Carter *et al.* 1995). Ancient Murrelets and Rhinoceros Auklets were killed in gillnets in 1970-1971 and 1978 near Langara Island (Vermeer and Sealy 1984). Bertram (1995) suggested that commercial fishing operations in the vicinity of Langara Island during the 1950s and 1960s, may have contributed to the decline of the Ancient Murrelet colony.

Figure 19 shows the spatial distribution of gillnet and seining effort off British Columbia (data from Carter *et al.* 1995). The most intensive netting occurred off the Skeena River near Prince Rupert (DFO statistical area 4), off Smith Inlet in Queen Charlotte Strait (area 10) and southern Queen Charlotte Strait and Johnstone Strait (area

12). The last two areas were also within or close to the areas in which Carter *et al.* (1995) reported high concentrations of Marbled Murrelets during the gillnet seasons. Other areas in which netting and large numbers of seabirds are likely to co-occur are the east coast of Moresby Island, the Strait of Georgia, Barkley Sound and the northeastern portion of the Strait of Juan de Fuca (compare Fig. 19 with the distribution of colonies, Fig. 2, and concentrations of birds, Figs. 6, 7 and 8).

There is clearly insufficient information to assess the impacts of gillnet and seine fishing on seabirds in British Columbia, but it is potentially a serious problem in localised areas (Carter *et al.* 1995). We recommend a pilot field study to observe the levels of mortality during gillnet openings in areas where birds are common.

4. Survey effort

4.1 Offshore surveys

4.1.1 Offshore vessel surveys

At-sea surveys have been undertaken on numerous occasions in British Columbia waters (e.g. Hay 1992, Kaiser *et al.* 1990, Logerwell and Hargreaves 1996, Martin and Myres 1969, Morgan *et al.* 1991, Vermeer *et al.* 1983, 1987a, 1989b). Morgan *et al.* (1991) summarised and mapped the results of 45 vessel surveys (covering 20,675 km) made off the British Columbia coast between 1981 and 1990; to date this is the most complete analysis of the spatial and seasonal distribution of pelagic seabirds in the province. Additional surveys have since been made off the west coast of Vancouver Island and around the Queen Charlotte Islands by the CWS (K.H. Morgan, unpubl. data) and off southwestern Vancouver Island (A.E. Burger, unpubl. data, and R. Palm, unpubl. data).

The published pelagic survey effort (from Morgan *et al.* 1991) within each season is shown in Figures 20-23. Large tracts of ocean have never been surveyed and the only area in which year-round systematic surveys have been made is over the shelf waters off southwestern Vancouver Island. Even in this area there has been minimal winter sampling. In an effort to fill some of the spatial and temporal data gaps, seabird surveys along a fixed route to Station Papa (50°N, 145°W) were initiated in May 1996, with three trips scheduled each year (in February, May and August, K.H. Morgan, pers. comm.).

4.1.2 Offshore aerial surveys

There has been very limited use of aerial surveys over offshore waters in British Columbia. Vermeer *et al.* (1983) summarised information from three series of flights made in 1972 and 1973. Ford *et al.* (1991) flew a single series of transects over the continental shelf off southwestern Vancouver Island in January 1990 as part of the investigation following the *Nestucca* oil spill. Aerial surveys provided the core data for the extensive studies of offshore seabirds off California done by Briggs *et al.* (1984, 1987). Boat surveys and satellite imagery were also used, in a protocol that might be applied to British Columbia's shelf and shelf break region.

4.1.3 Offshore stationary counts

Seabirds were systematically counted from the weathership at Station Papa, 900 km off the coast of British Columbia. The seasonal variations in relative densities (birds per day) of albatrosses, shearwaters, fulmars, storm-petrels and two gull species were analysed for the years 1971-1972 and 1974-1977 by Vermeer *et al.* (1983), with some information also given in Campbell *et al.* (1990). There are no other systematic samples from stationary vessels in open oceans off British Columbia.

Opportunities for making stationary counts from hake factory ships over shelf waters off southwestern Vancouver Island might arise if the fisheries observers also had bird identification experience and were provided with standardised data sheets and observation protocol. This might be part of a study on the effects of fisheries discards on local seabirds (see section 3.2.2.4.).

4.2 *Inshore surveys*

4.2.1 Inshore aerial surveys

Aerial surveys are useful for reconnaissance and general mapping of marine birds. However, many small, dark birds, such as alcids, are hard to see from the air and cannot be accurately censused, even in the relatively sheltered inland seas of British Columbia (Burger 1995b, Savard 1982).

Aerial surveys have been used extensively along the British Columbia coast to map the distribution of birds, primarily waterfowl (Savard 1987, Vermeer *et al.* 1983). Aerial surveys are currently being used to monitor seabird densities and distribution in Washington waters (Nysewander *et al.* 1993).

We summarised the number of aerial surveys made (to date) in each season for coastal segments of the Queen Charlotte Islands (Figs. 24-27), the North Coast (Figs. 28-31) and the South Coast (Figs. 32-35). Overall, the coverage is patchy and, because the surveys focused mainly on wintering and moulting waterfowl, provides little information for the summer months.

Despite problems associated with missing small, dark-bodied birds, aerial surveys might provide large-scale information to fill some obvious gaps in distribution information. For example, aerial reconnaissance might help to partially clarify patterns of Marbled Murrelet post-breeding dispersal, which remains very poorly known (Rodway *et al.* 1992, Burger 1995a).

4.2.2 Inshore vessel surveys

Surveys from moving vessels are the standard means of censusing inshore seabirds. Survey effort (to date) by vessel-based observers is summarised for the Queen Charlotte Islands (Figs. 36-39), the North Coast (Figs. 40-43) and the South Coast (Figs. 44-47). Again, the coverage is patchy, with most parts of the coast receiving no vessel surveys and only a very small proportion with more than five. Repeated surveys along fixed routes tend to show considerable seasonal and diurnal variation in inshore waters of

British Columbia (Burger 1995a, Carter 1984, Porter 1981, A.E. Burger unpubl. data), so that even five surveys are probably insufficient to accurately determine the local densities and distributions.

The number of surveys that have been made specifically for Marbled Murrelets is summarised in Figures 48-50. Repeated, multi-year surveys which are likely to provide adequate baseline data on populations of this threatened species have only been made in Laskeek Bay, a small portion of the central mainland fjords, Desolation Sound, Clayoquot Sound, a small part of Barkley Sound and a portion of the coast of southwest Vancouver Island. However, this sample is undoubtedly too small and too geographically restricted to track long-term trends of the entire provincial population.

4.3 Shore surveys and stationary counts

4.3.1 British Columbia sight-record database

Sight-record cards and other opportunistic records of birds formed the basis for the distribution maps produced by Campbell *et al.* (1990). The cards were also analysed to show seasonal and spatial variations in the occurrence of Marbled Murrelets in British Columbia (Rodway *et al.* 1992). The sight-record observation coverage is mapped in Campbell *et al.* (1990: 12-13), but the maps show only the areas visited and not the intensity of sampling. Areas close to larger cities are much more intensively sampled, and observer coverage is more widespread in summer than in the other three seasons. The southern coast is better sampled than the northern, and sight-records from the more remote coastal areas are rare.

4.3.2 Christmas bird counts

Christmas bird counts have been made in 25 coastal count circles (24 km diameter). These are plotted in Figure 51, which also shows the number of years sampled. Christmas count data from British Columbia have been used to estimate long-term declines in local populations and general patterns of winter distribution in

Marbled Murrelets (Rodway *et al.* 1992) and Western Grebes (Burger 1996), and to explain general population and distribution trends in several species (Campbell *et al.* 1990).

4.3.3 Stationary and shore counts of seabirds and waterfowl

Although they provide less information than vessel or aerial surveys, and are biased towards more mobile, nearshore species, counts from the shore can inexpensively provide year-round estimates of occurrence, relative densities and seasonal movements (Burger 1995b). Examples of repeated shore counts include those made from Clover Point, Victoria (Shepard 1992), the Fraser Delta (Butler and Campbell 1987, Vermeer *et al.* 1994a) and the Cowichan estuary (Vermeer *et al.* 1994b).

4.3.4 Beached bird surveys

Systematic beach surveys to count stranded carcasses of marine birds and to check for evidence of oiling have been used in many parts of the world to establish baseline levels of mortality and oiling, track spatial and temporal (seasonal and interannual) variations in bird mortality, and provide samples to determine causes of mortality (e.g. Camphuysen 1989, Stenzel *et al.* 1988). In Europe the method has become widely used to monitor chronic and catastrophic oil pollution (Camphuysen and van Franeker 1991). Typically the surveys are conducted by volunteers trained to identify carcasses and record data, using standardised protocols and data sheets (Ainley *et al.* 1980).

In British Columbia systematic beach surveys were undertaken for three years by the White Rock and Surrey Naturalists in Boundary Bay (M. Schouten unpubl. data), and a province-wide program was launched in 1989, following the *Nestucca* oil spill. The locations of 32 regularly sampled sites, and the sampling effort (number of monthly surveys), are plotted on Figures 52 and 53. The length of beach sampled ranges from 0.5 to 10 km (mean 1.9 km). The only areas of the province adequately sampled are in Boundary Bay, around Victoria, on some of the Gulf Islands (Saltspring and Pender

Islands), and at a few locations on the exposed shores of southwestern Vancouver Island.

It is difficult to get volunteers to commit to long-term year-round beach surveys. A more focused approach might be to sample only the months in which most deaths occur (e.g. August to November on the west coast of Vancouver Island; Burger 1993c), in order to assess multi-year trends.

5. Priorities for future research and monitoring

5.1 Pelagic surveys

Piatt *et al.* (1993) discuss the value of pelagic surveys for estimating seabird populations. The at-sea abundance of 13 species of seabirds, derived from offshore vessel surveys of the Gulf of Alaska, were used to extrapolate seabird populations during the breeding season. Although they found strong correlation's between this data set and population estimates derived from colony surveys (1254 colonies), Piat *et al.* noted large discrepancies for ship followers (gulls and fulmars) and nocturnal species (e.g., Fork-tailed Storm-Petrel, Rhinoceros Auklet).

It is likely unrealistic to expect pelagic surveys to uniformly sample all the ocean within the Canadian economic (fisheries) zone off British Columbia. Even a restricted systematic sampling protocol, such as that used by Briggs *et al.* (1987) off California would be prohibitively costly for all of the British Columbia coast.

A better understanding of the distribution and ecology of pelagic seabirds off our coast might be achieved through a three-phased approach. The first phase would involve a province-wide analysis of existing information on seabird densities and species composition, in relation to ocean features such as bathymetry, bottom topography, sea temperature and salinity, upwelling, fronts and other coarse-scale (10's km) processes. Wahl *et al.* (1993) made some preliminary analyses along these lines for the waters off British Columbia and Washington, and a similar analysis, on a larger scale, was undertaken for the North Pacific by Wahl *et al.* (1989). Ongoing surveys off the west coast of Vancouver Island (by A.E. Burger and K.H. Morgan), the west coast of the Queen Charlotte Islands (K.H. Morgan) and along a fixed route to Station Papa (K.H. Morgan), will likely provide additional insights into the relationships between seabird densities and coarse- and fine-scaled ocean processes.

The second phase would involve applying predictive relationships derived from the analyses to the entire British Columbia shelf and offshore zone, with the assistance of physical and biological oceanographers and the use of GIS.

The third phase would involve testing and improving the distribution/abundance maps through systematic vessel cruises in selected areas. Such selection is likely to be driven by opportunities to join oceanographic cruises, but some of the physical phenomena affecting seabirds should be targeted for intensive surveys. Surveys could also be designed to target specific oceanic features or areas of high risk. For example, surveys made from tankers between Puget Sound and Alaska would show the species and numbers of birds likely to be affected by major spills from such vessels.

5.2 Effects of gillnet and seine fishing

A review of information, followed by field observations and interviews with fishers is needed to assess the risk to seabirds of these fishing methods. It is often dismissed as a trivial problem in British Columbia, yet the only intensive research in this province (Carter and Sealy 1984) revealed serious impacts on Marbled Murrelets (see section 3.4.5.). We suggest that the real problem associated with seabird net drownings is that it is diffuse (i.e. a few birds/boat year) and likely sporadic. A study of the interactions between fisheries operations and Marbled Murrelets was identified as a high priority in that threatened specie's recovery plan (Kaiser *et al.* 1994).

5.3 Distribution of sandlance and its role

Sandlance are one of the most important feed fish for birds, and many other predators, in inshore waters. Unlike herring, another key feed fish, there has been virtually no research on sandlance in British Columbia. Information is needed on the temporal (seasonal and inter-annual) and spatial (relative to depths, substrates and coastal topography) availability and behaviour of sandlance in selected sites. Sampling methods should include hydro-acoustics, nets and SCUBA. The species appears to be sensitive to sea temperature (Field 1988), and is therefore ideal to test the effects of global warming and periodic El Niño events on the inshore marine food webs.

5.4 Winter distribution of offshore and inshore seabirds

The greatest mortality of seabirds (Burger 1993c) and highest risks from oil spills occur in autumn through early spring, but these months have the lowest sampling of offshore seabirds (Morgan *et al.* 1991). Even the occurrence of species is poorly documented, as shown by the discovery of 15 Parakeet Auklets *Cyclorrhynchus psittacula* among the oiled victims of the *Nestucca* spill (Rodway *et al.* 1989). This species was considered by Campbell *et al.* (1990) to be hypothetical in British Columbia; although they have been observed on several occasions (Morgan *et al.* 1991, Sirois and Butler 1994).

Much needs to be learned of the effects of seasonal changes in ocean features on local seabirds, such as the effects of reduced upwelling, and seasonally alternating current systems over the shelf (Thomson *et al.* 1989). This information is needed to assess the varying risks of the birds to oil spills, and the likelihood of being able to detect offshore die-offs.

5.5 At-sea studies around colonies

The diets, parental behaviour, chick growth and energetics of seabirds at colonies are often proposed as indicators of changing marine environments, including the effects of over-fishing or El Niño events (Cairns 1987, Furness and Greenwood 1993, Furness and Nettleship 1991). There have, however, been very few studies comparing these colony-based parameters with concurrent measures of the foraging behaviour and distribution of the birds at sea, and estimates of prey availability (e.g. Ainley and

Boekelheide 1990, Ainley *et al.* 1996). A small-scale study along these lines is in progress on and around the small colony of Rhinoceros Auklets at Seabird Rocks, southwestern Vancouver Island (G. Davoren, unpubl. data). A larger, more comprehensive study should be undertaken in the waters around Triangle Island, to complement the colony-based work on Cassin's and Rhinoceros auklets underway there. Radial transects could be used to measure seabird densities and a wide range of oceanic parameters (e.g. prey densities, sea temperatures and salinity, chlorophyll concentrations, etc.) at varying distances from the colony. Similar studies are also needed in areas with different oceanic regimes, such as around the large colonies in Hecate Strait or Queen Charlotte Strait. Alternatively, colony-based telemetry work would increase our understanding of foraging ranges, preferred areas, etc.

5.6 Seabirds and zooplankton aggregations at the shelf break

The edge of the continental shelf is usually an important foraging area for pelagic birds. Concentrations of macrozooplankton are known to exist at the shelf break off Vancouver Island (see section 3.2.1.). There have been several studies plotting seabird distribution in this area (see section 4.1.1) but other than the study by Logerwell and Hargreaves (1996), there has been little effort to integrate concurrent measures of seabird density, bird species composition, physical oceanography and estimates of prey densities. Elsewhere, this approach when carried out in combination with oceanographic studies, has yielded important insights into the dynamics of seabird foraging and the factors affecting their marine distribution (e.g. Haney and Solow 1992, Hunt *et al.* 1990, 1991).

5.7 Bird use of coastal areas of central and northern B.C.

The convoluted fjords and islands of the central and northern coasts provide huge areas of sheltered ocean with a wide range of depths, currents, tides and topography. The distribution, movements and densities of seabirds have seldom been surveyed there, but there are indications that the area supports large populations of Marbled Murrelets

(Kaiser *et al.* 1991, Prestash *et al.* 1992, J. Kelson pers. comm.). A combination of aerial surveys for reconnaissance and vessel surveys for focused density and oceanographic studies is needed in this area.

5.8 Role of fisheries discards

Recent investigations in the North Sea have revealed that fisheries discards provide huge amounts of food to a variety of seabird species (see section 3.2.2). Discards may be far less important in BC waters, but the hake fishery on the shelf does attract many thousands of seabirds, and requires investigation. Training fisheries observers already stationed on these vessels to do periodic seabird counts would be an inexpensive method of monitoring.

5.9 Importance of seamounts to pelagic seabirds

Considering the renewed interest in the commercial exploitation of rockfish at offshore seamounts, the importance of seamounts to both migrant and resident seabirds needs to be investigated (see section 3.3.1.).

5.10 Distribution of Marbled Murrelets

Despite a surge of recent research, Marbled Murrelets remain one of the most vulnerable and least known of British Columbia's seabirds. Among the priorities identified in the recovery plan (Kaiser *et al.* 1994) are estimates of the abundance and distribution at sea, both provincially and regionally, and identification of seasonal concentrations. Although some important concentrations have been identified in the breeding season (Burger 1995a), the entire coast needs sampling in summer, and efforts should be made to identify important foraging and staging grounds outside the breeding season. Year-round vessel surveys along the entire coast would likely be extremely expensive, but there are at least two relatively inexpensive alternative approaches. One would be a program involving reports from recreational boaters visiting all parts of the coast, using a standardised observation and identification sheet. This could be followed up by intensive vessel surveys in areas identified as potential hot-spots. Alternatively a systematic sampling procedure could be designed with the aid of oceanographers and using GIS mapping of marine habitat types, so that a representative sample of each habitat type in selected lengths of the coastlines could be sampled by vessel transects. Aerial surveys could also be used for reconnaissance and preliminary mapping (Resource Inventory Committee 1995).

5.11 Beached bird surveys

Although concentrations of chlorinated hydrocarbons and heavy metals appears to be declining in marine birds in British Columbia, continued monitoring is essential to detect long-term trends and detect possible increases due to changing industrial and municipal discharges. Similarly, continued monitoring of low-level chronic oiling is required (see section 4.3.4.). The beached bird survey program begun in 1989 which could provide carcasses for pollution monitoring, is effectively moribund but could easily be revived. Surveys covering the late-summer through early-winter would be sufficient to detect long-term trends in mortality and provide specimens for testing. The Centre for Coastal Health, recently established at the University of British Columbia, is interested in participating in such monitoring programs, but cannot fund them.

5.12 Effects of recreational and commercial boating

Increases in recreational boating (including fishing, kayaking, sailing and motor cruising) are likely to escalate disturbances for inshore marine birds. Some birds appear to adapt to vessel traffic, but others (e.g. cormorants) appear more susceptible to disturbance, both on their colonies and in the water. A review of the available information, followed by field studies, would reveal potential problems.

5.13 Accuracy of aerial surveys

Many ornithologists have dismissed aerial surveys as unreliable and inaccurate for estimating densities of seabirds (reviewed by Burger 1995b), but the method has been the cornerstone of some impressive research, notably that of Briggs *et al.* (1987). Although some testing has been done of the accuracy of aerial surveys in British

Columbia (Savard 1982), it has been insufficient to determine where and when the method might be applied, especially along the outer coast. Aerial surveying might be more cost-effective for sampling large areas of coast, and if complemented by satellite imagery and vessel surveys, repeated surveys could provide significant insights into the effects of dynamic ocean processes on local seabirds.

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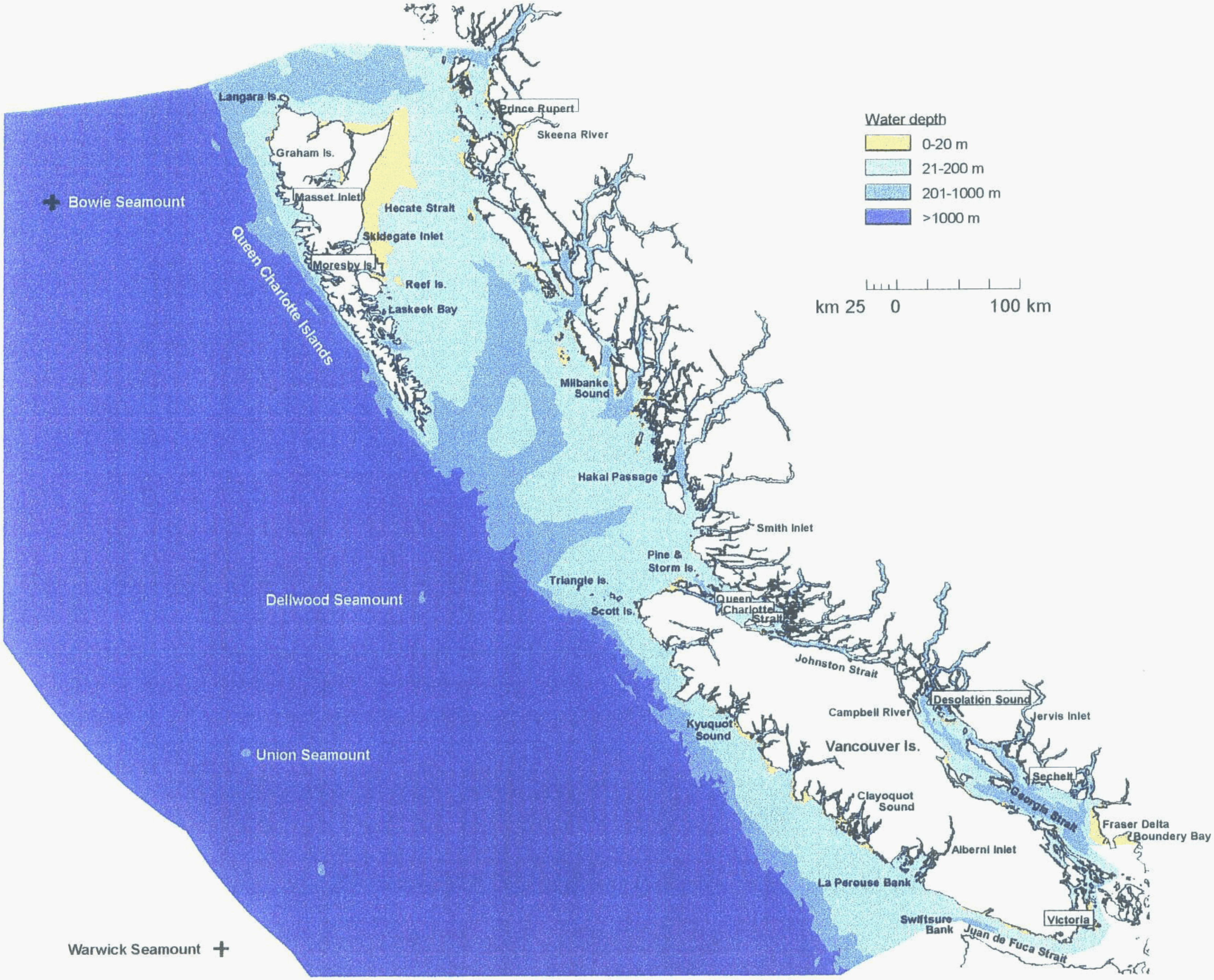


Figure 1a. Coastal and marine areas of British Columbia showing places and features mentioned in text.

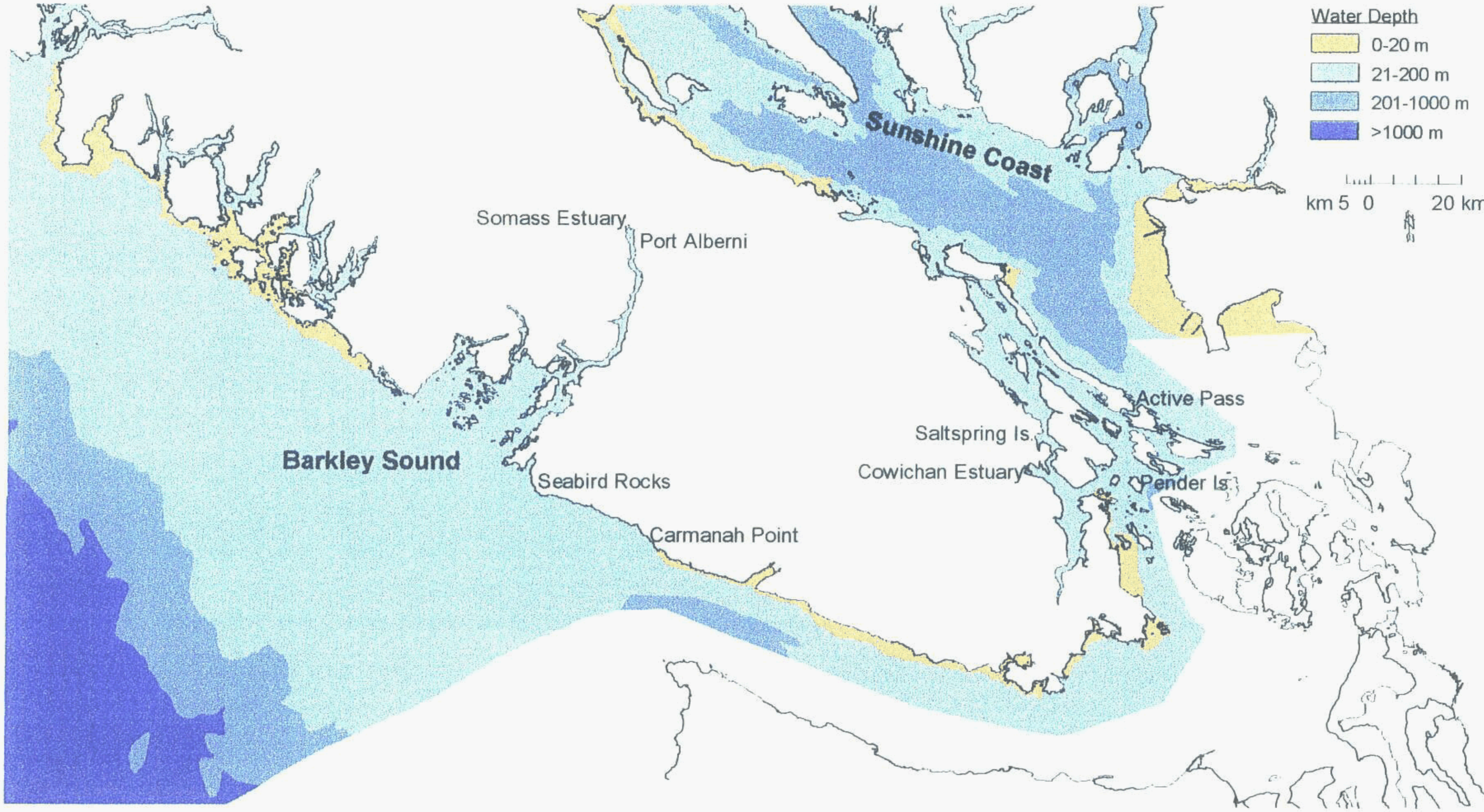


Figure 1b. Coastal and marine areas of southern British Columbia showing places and features mentioned in text.

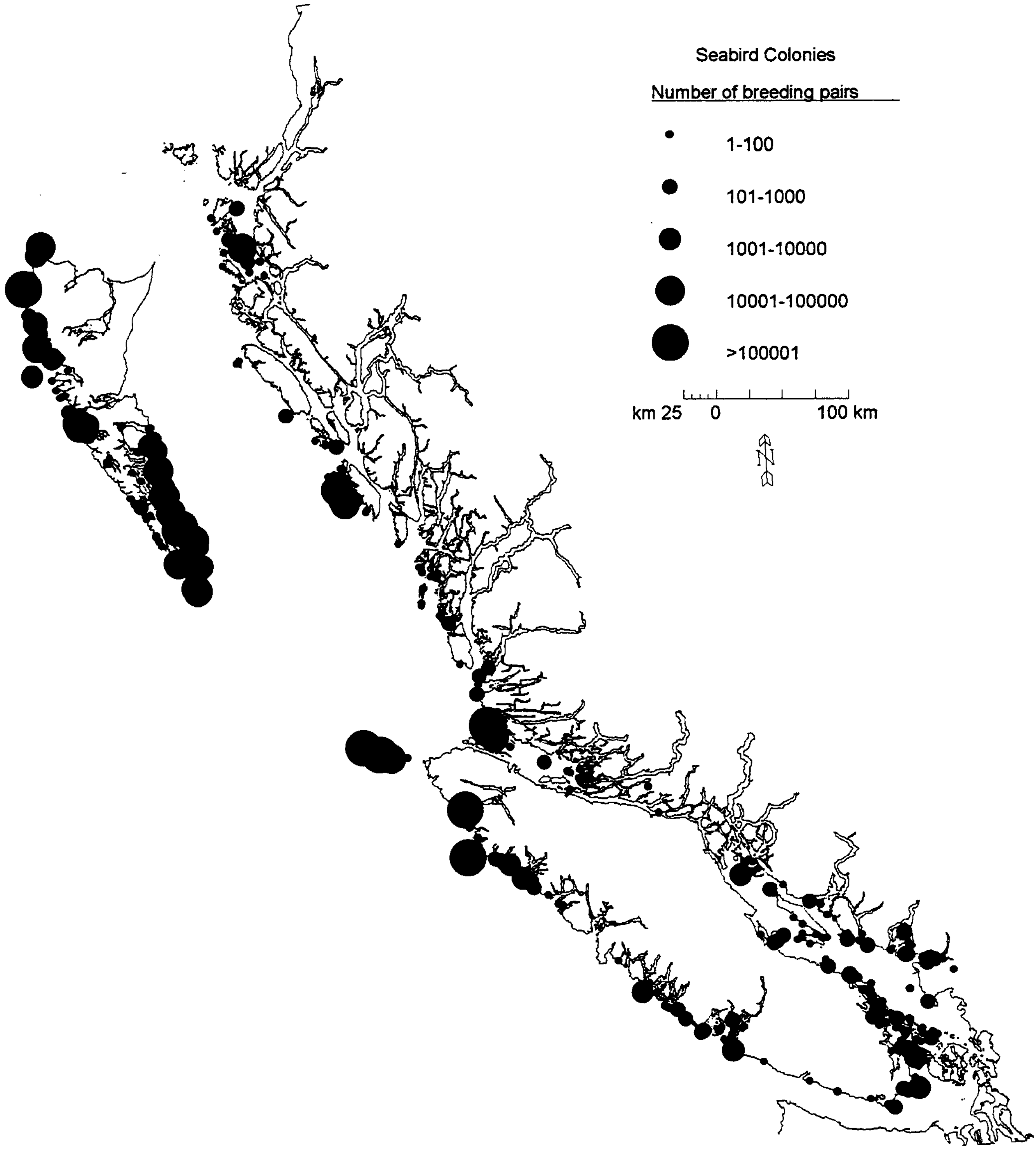


Figure 2. Distribution of seabird colonies in British Columbia.

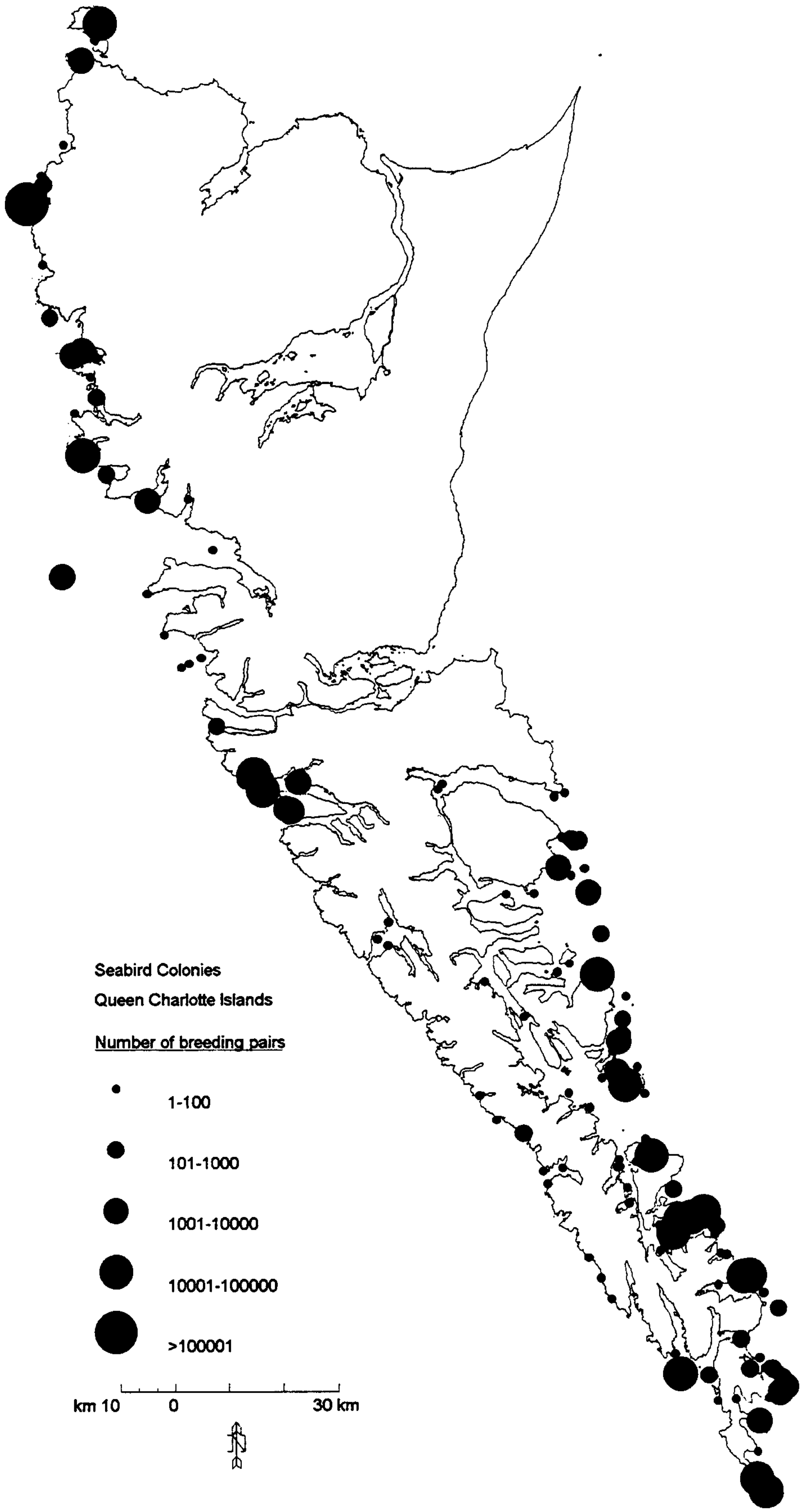


Figure 3. Distribution of seabird colonies in the Queen Charlotte Islands.

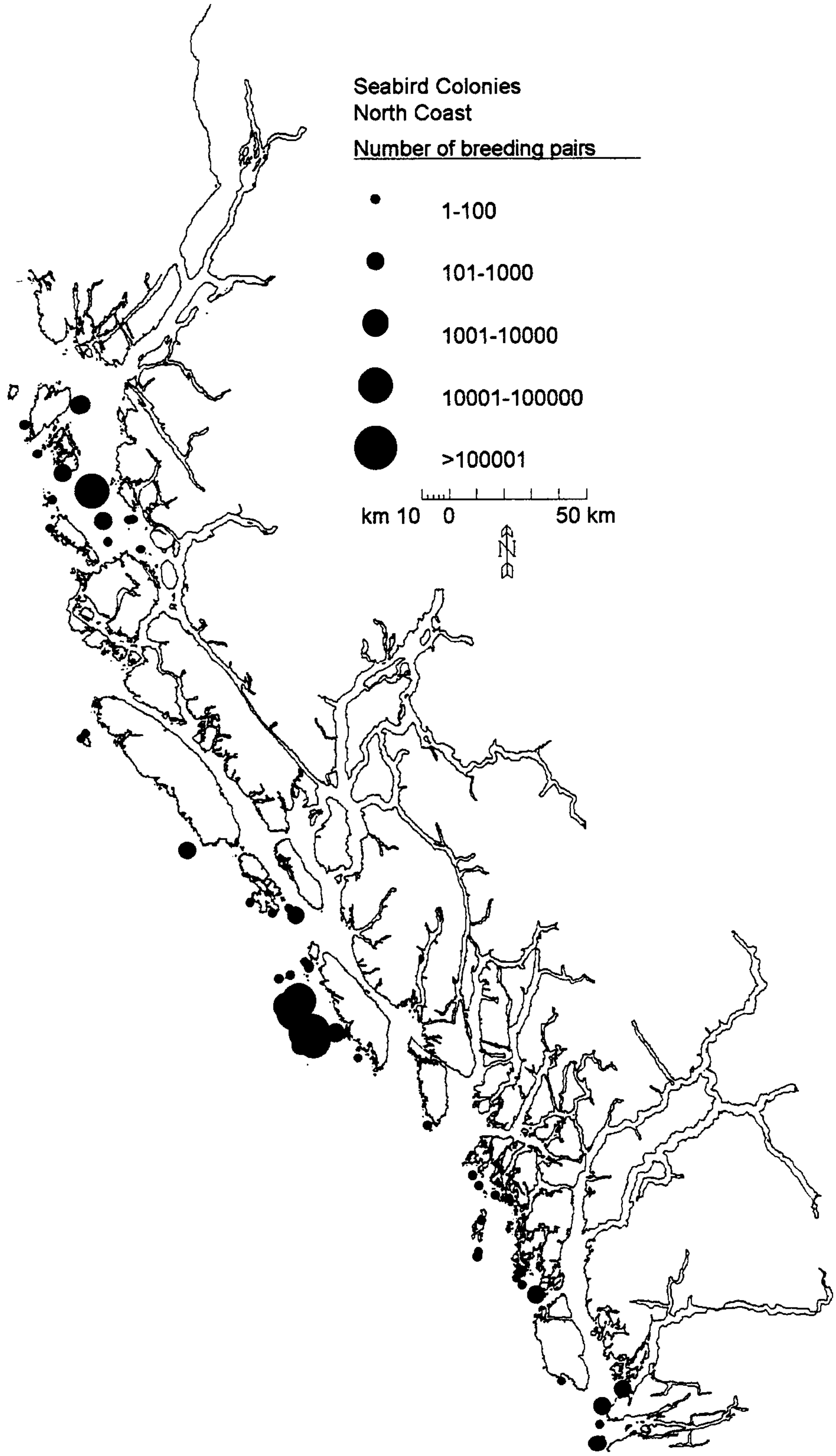


Figure 4. Distribution of seabird colonies along the North coast (of British Columbia).

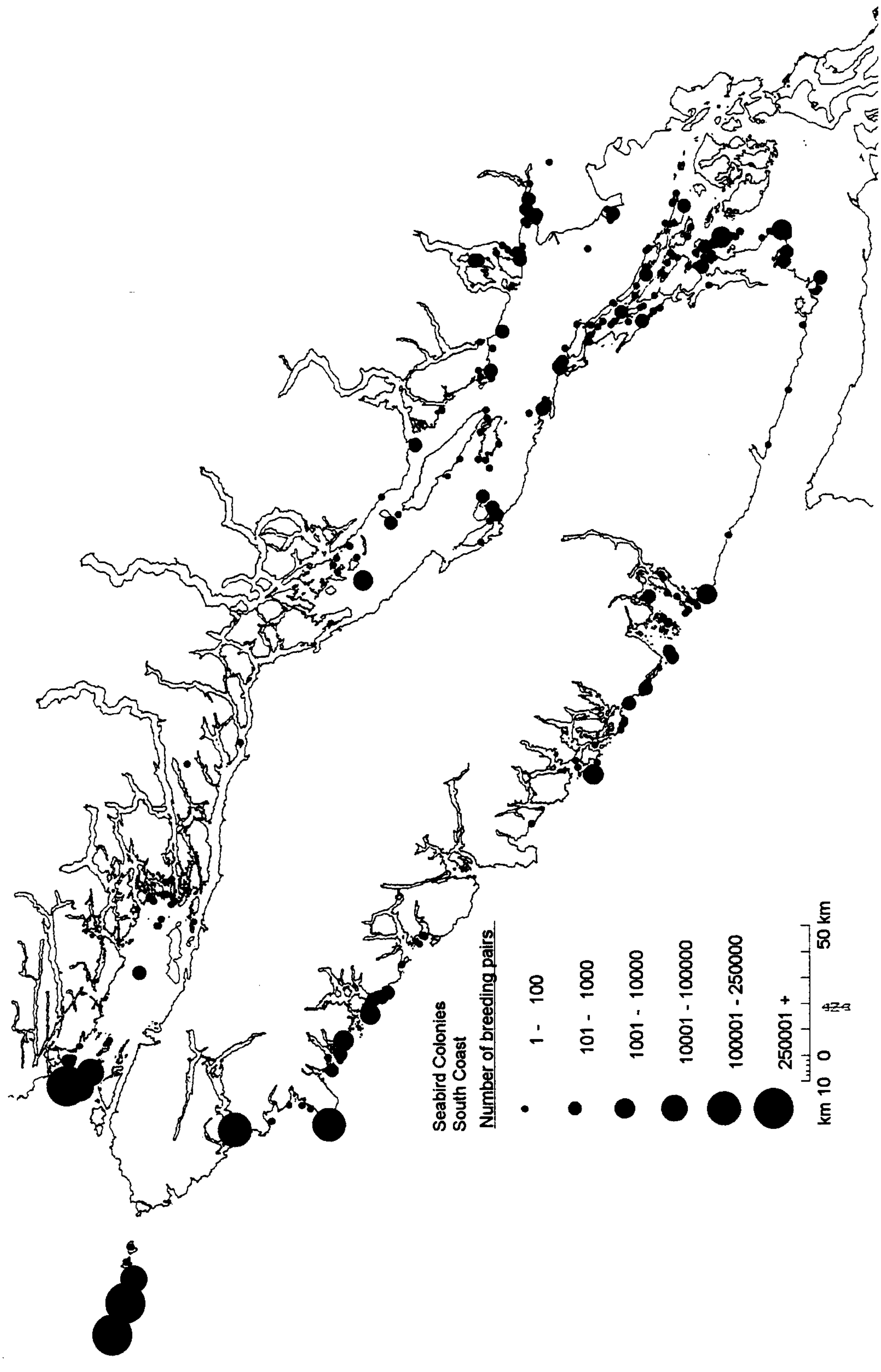


Figure 5. Distribution of seabird colonies along the South coast (of British Columbia).

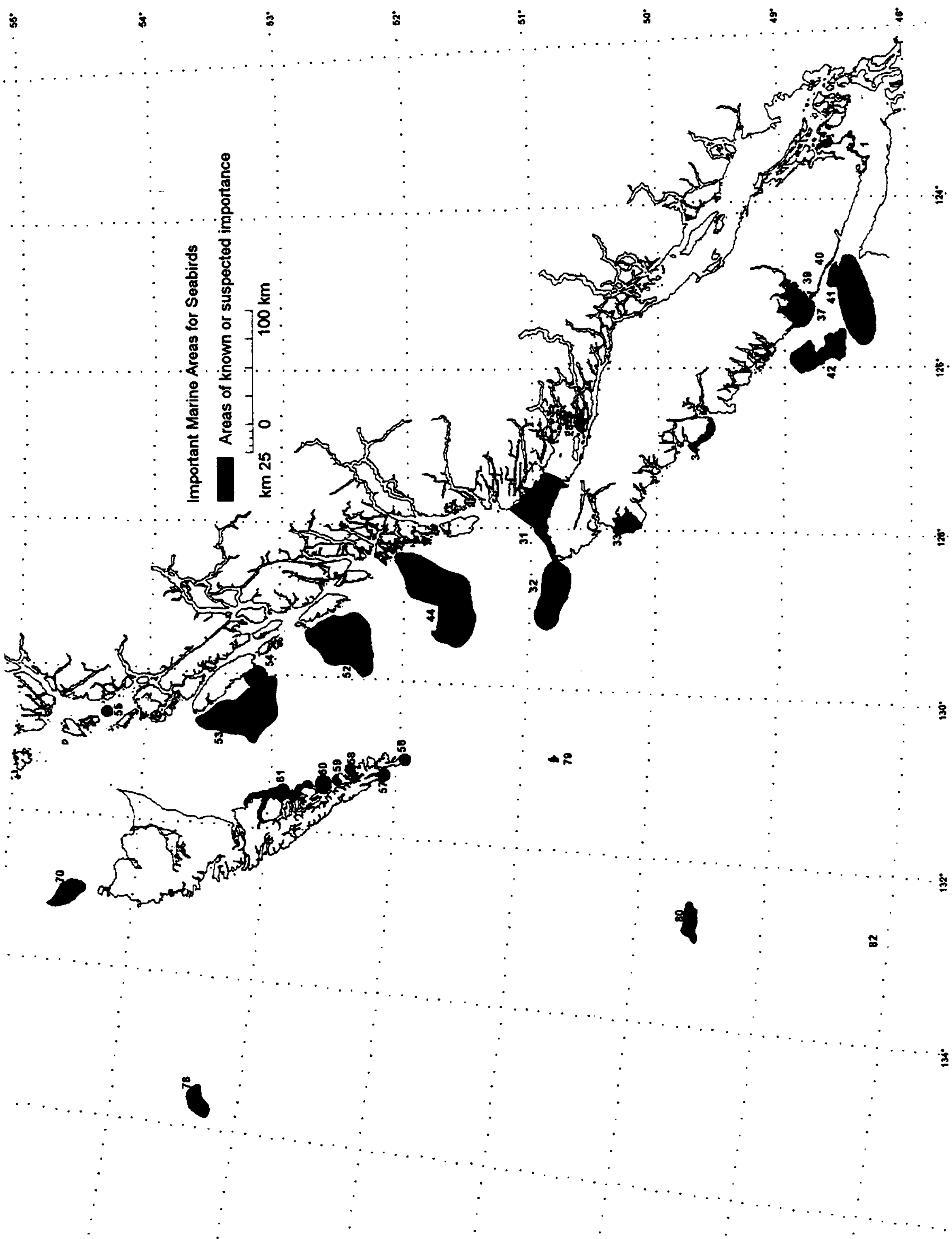


Figure 6. Location of marine areas listed in Table 1 that are known or suspected to be important to seabirds.

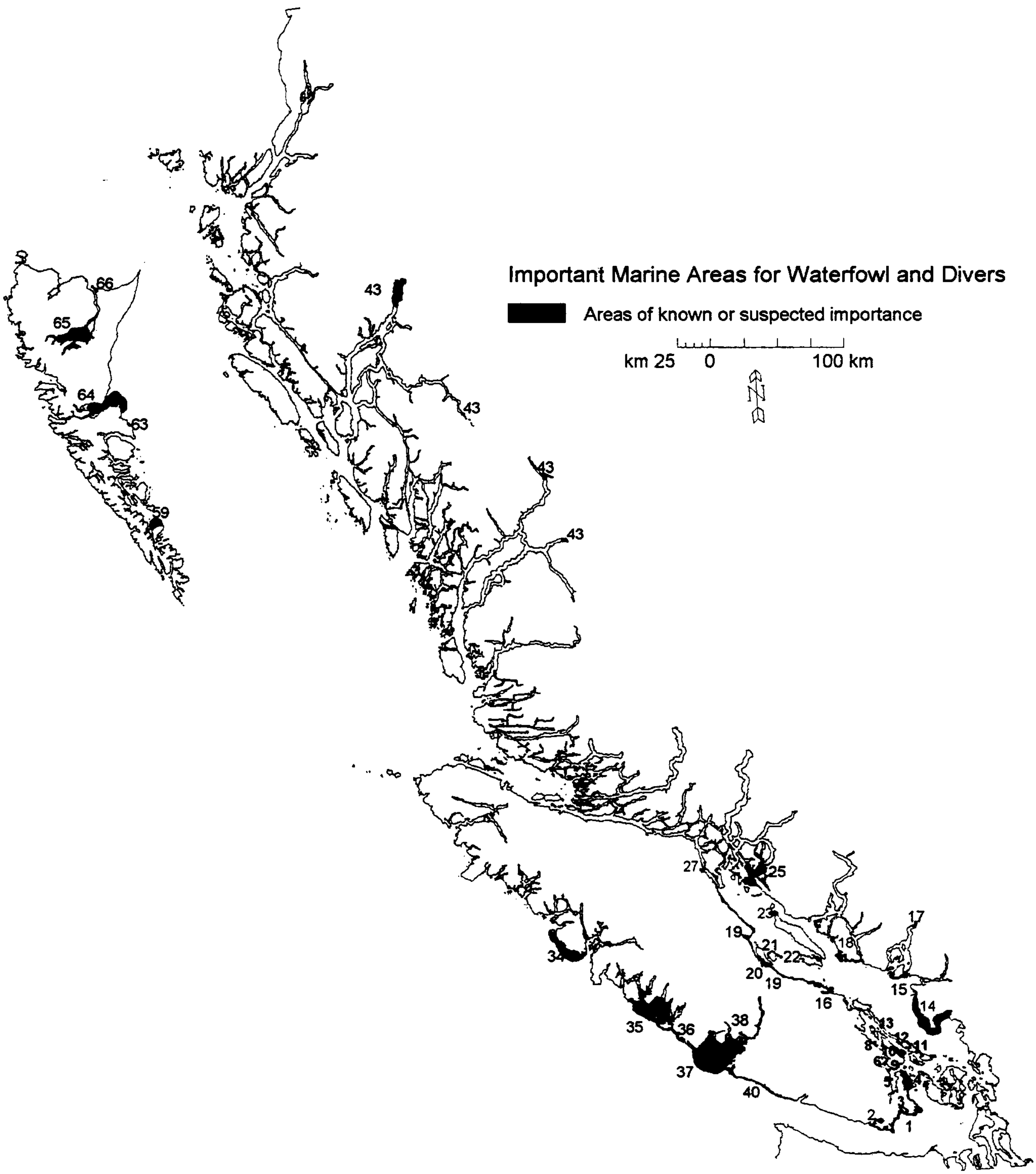


Figure 7. Location of marine areas listed in Table 1 that are known or suspected to be important to waterfowl and divers.

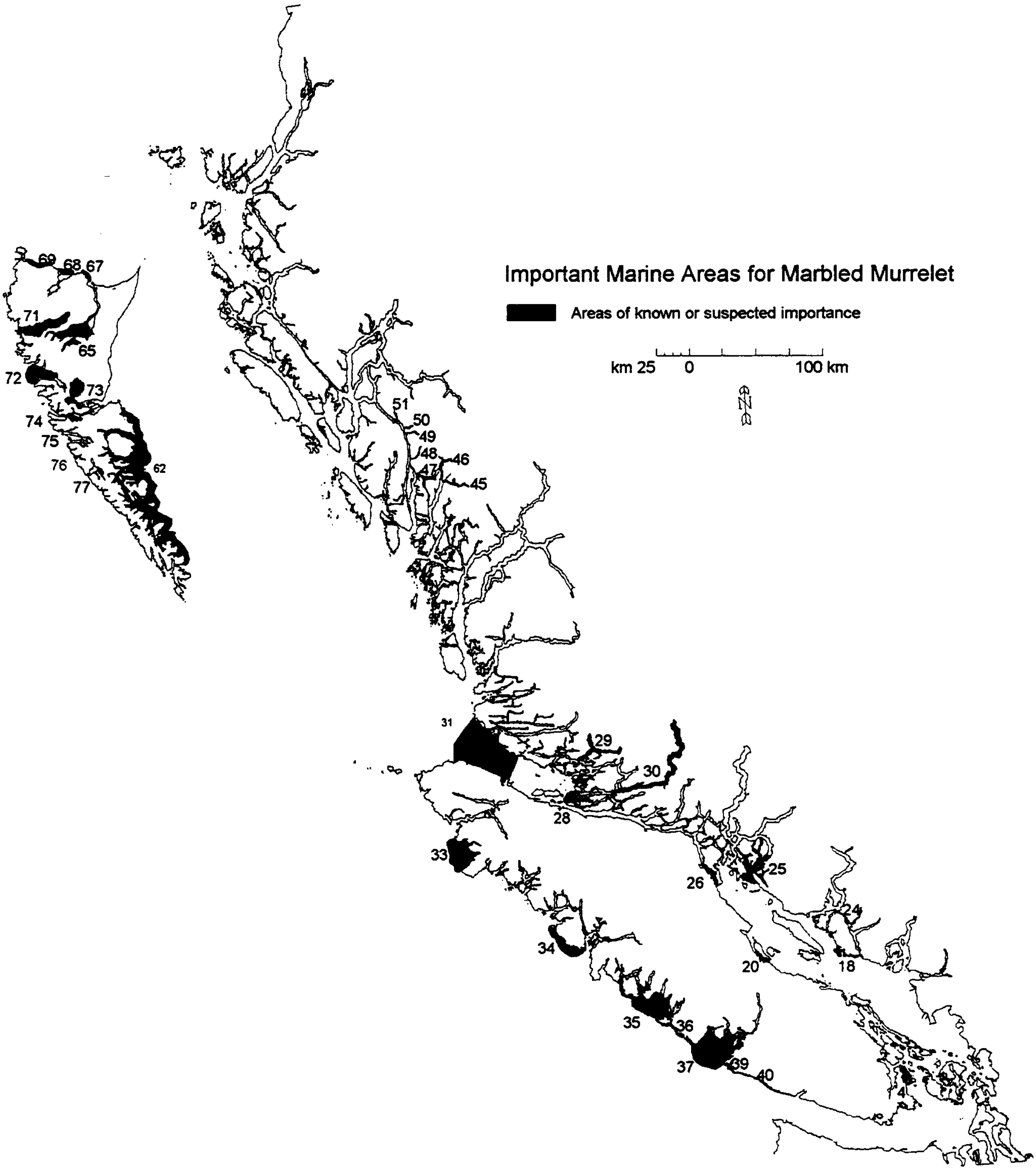


Figure 8. Location of marine areas listed in Table 1 that are known or suspected to be important to Marbled Murrelets.

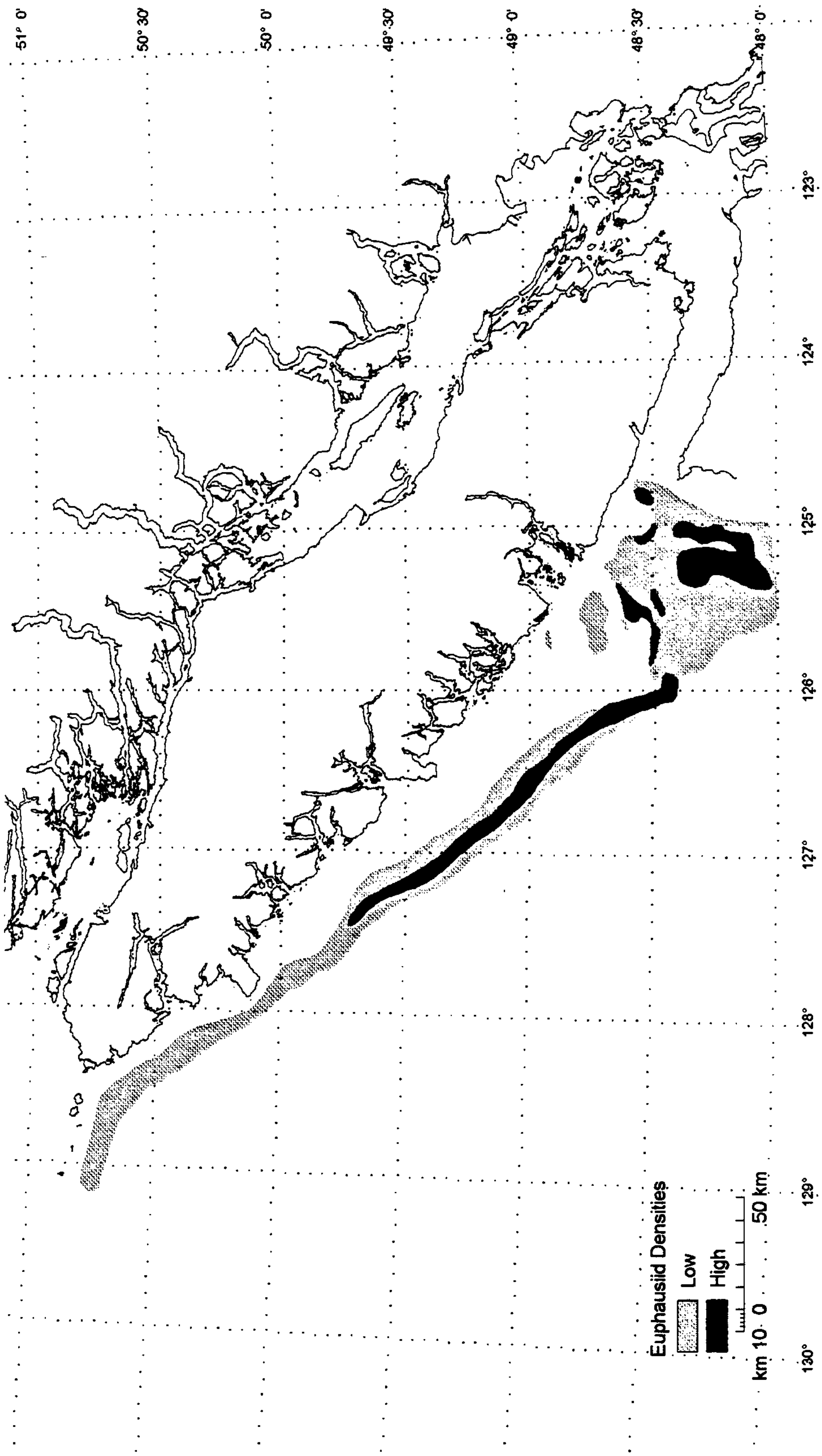


Figure 9. Generalised distribution of euphausiids off the West coast of Vancouver Island.

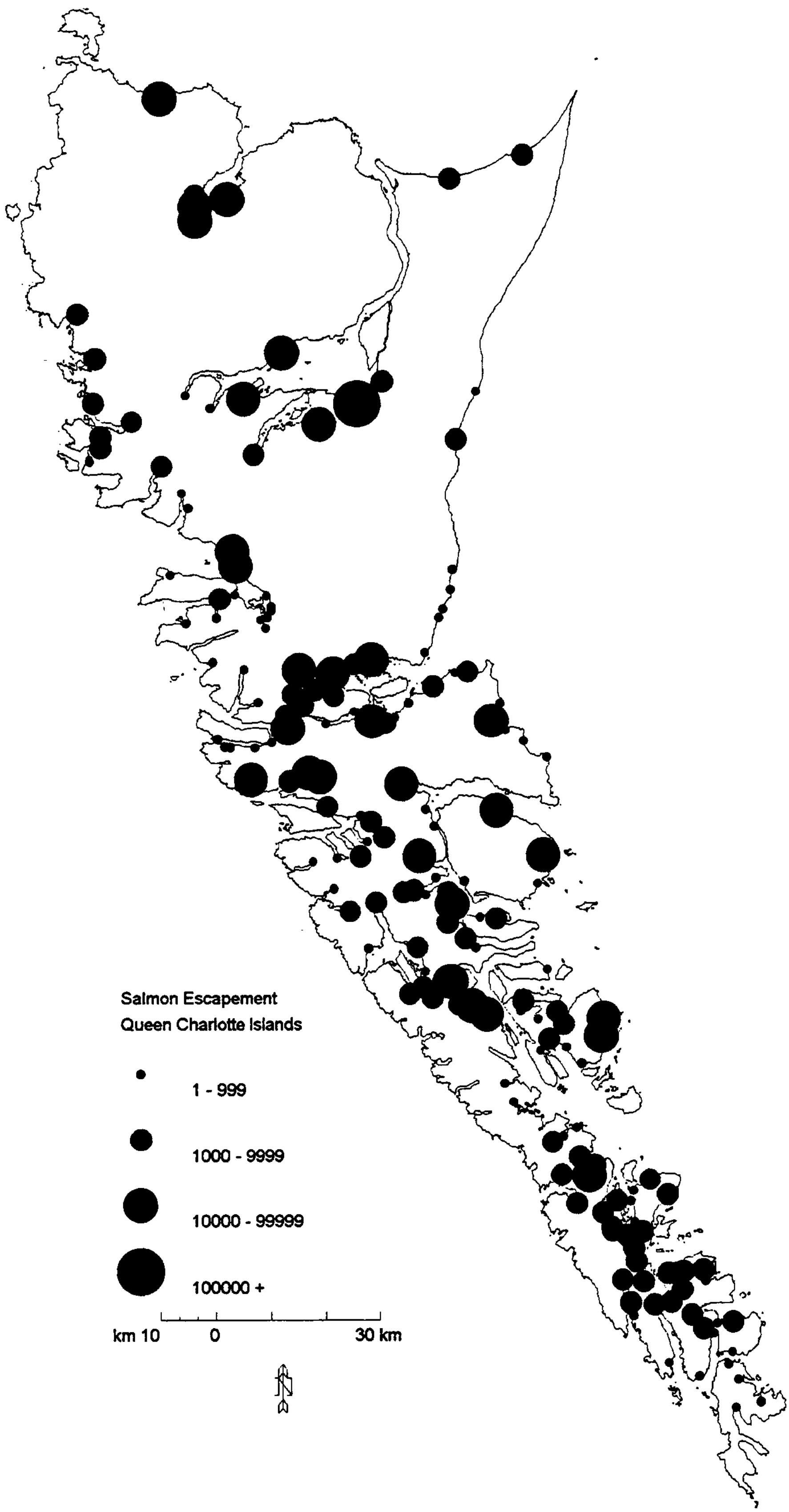


Figure 10. Average annual escapement of salmon smolts in the Queen Charlotte Islands.

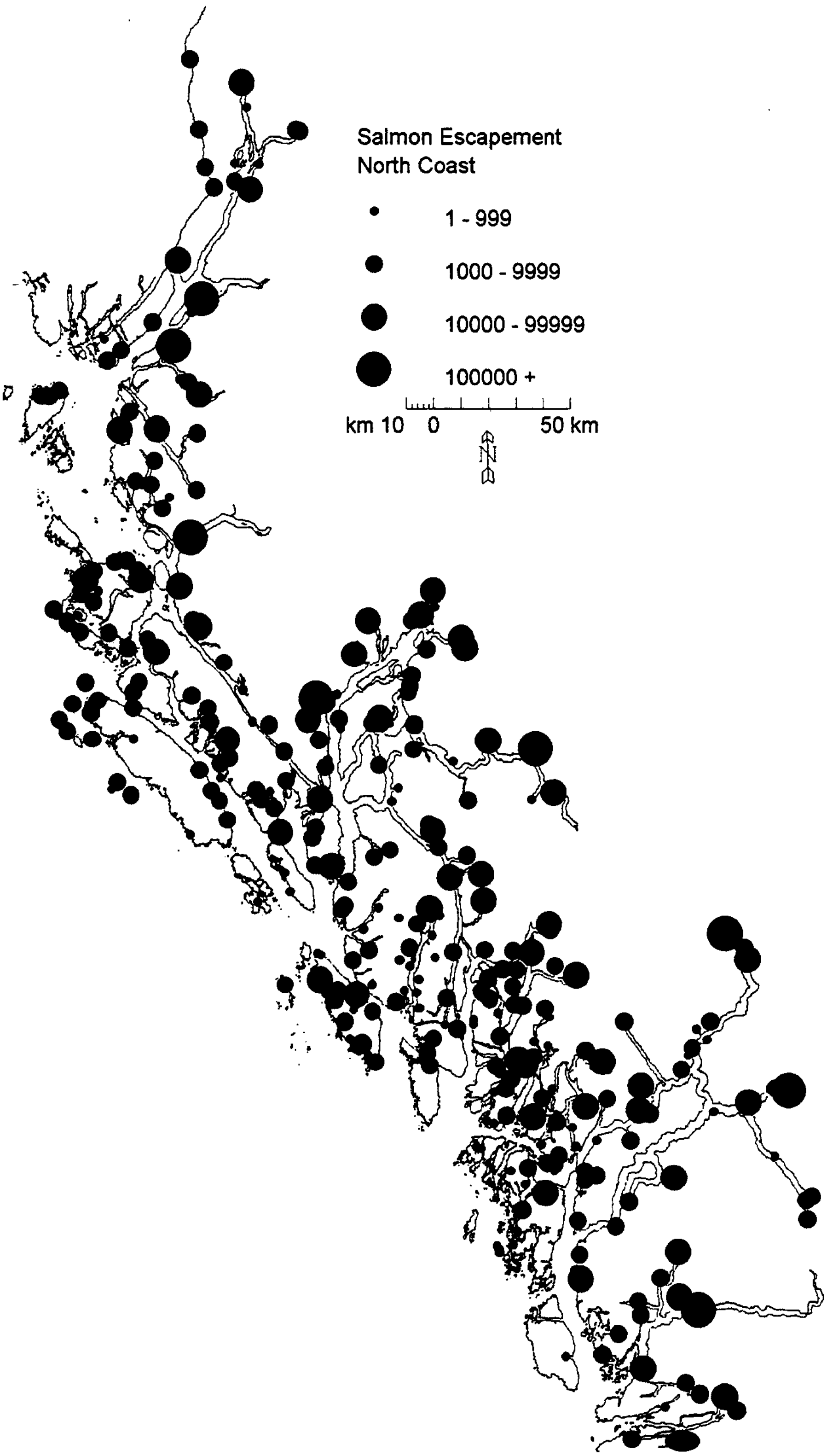


Figure 11. Average annual escapement of salmon smolts along the North coast.

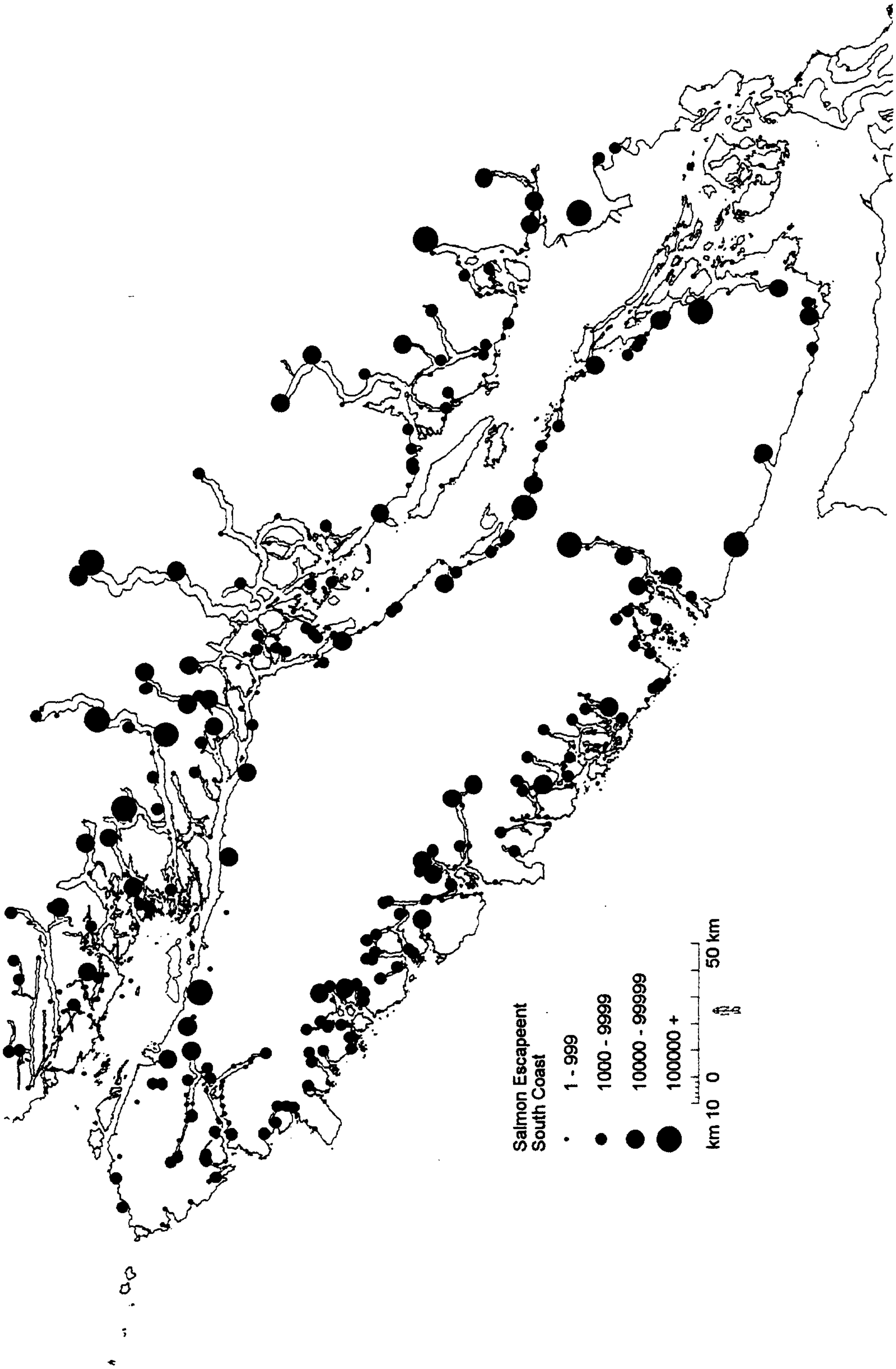


Figure 12. Average annual escapement of salmon smolts along the South coast.

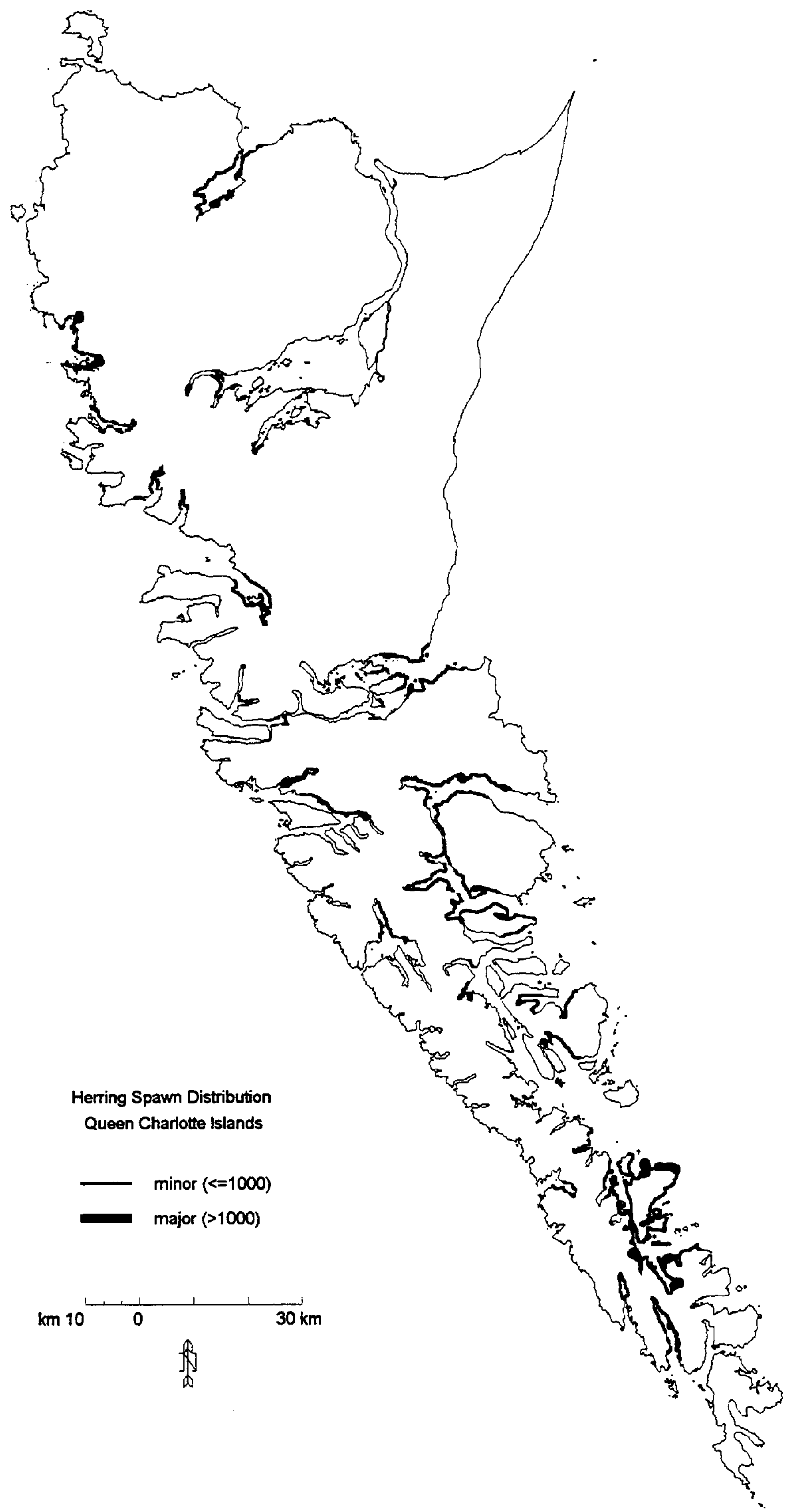


Figure 13. Distribution and magnitude of herring spawn index in the Queen Charlotte Islands.

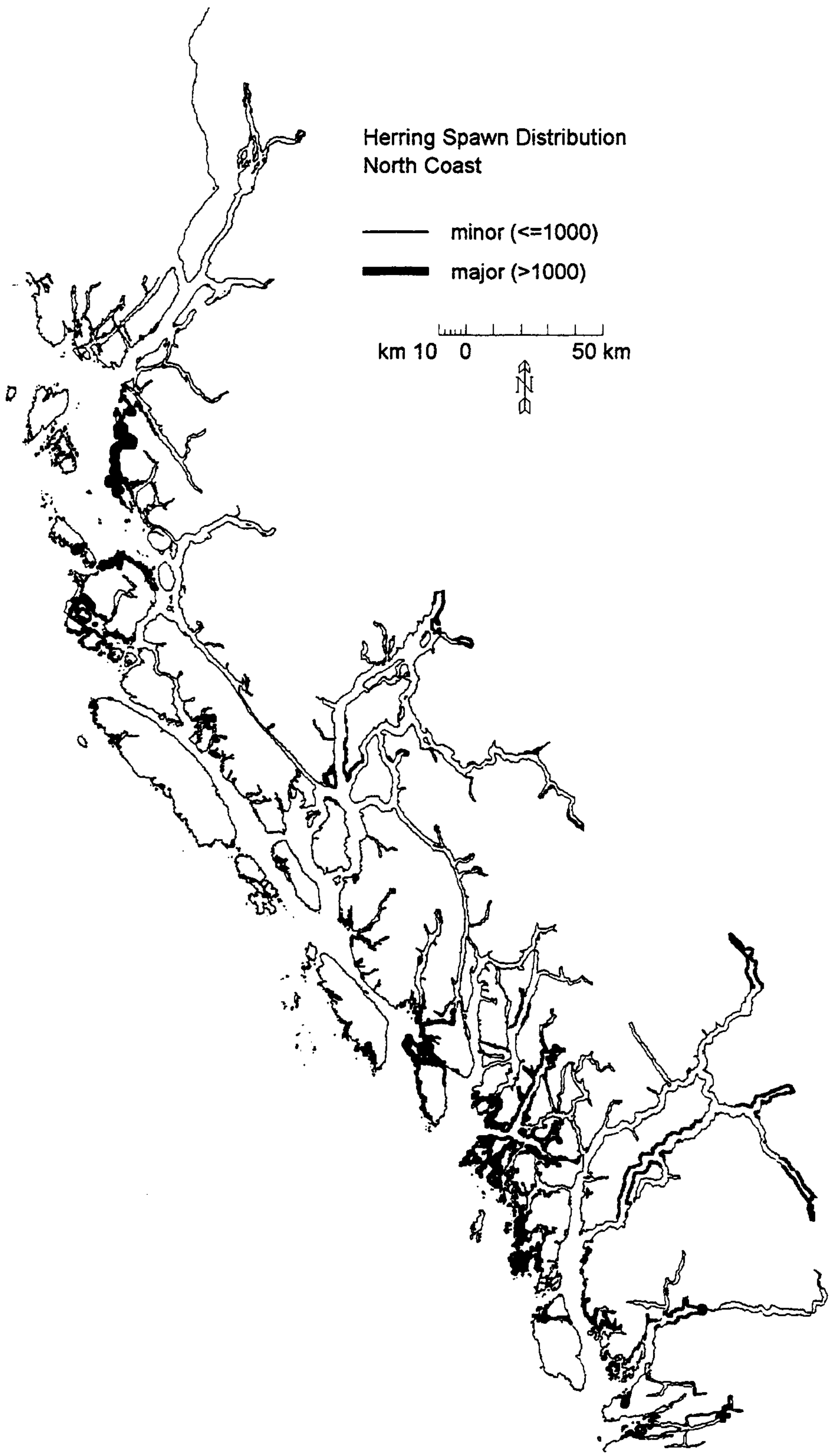


Figure 14. Distribution and magnitude of herring spawn index along the North coast.

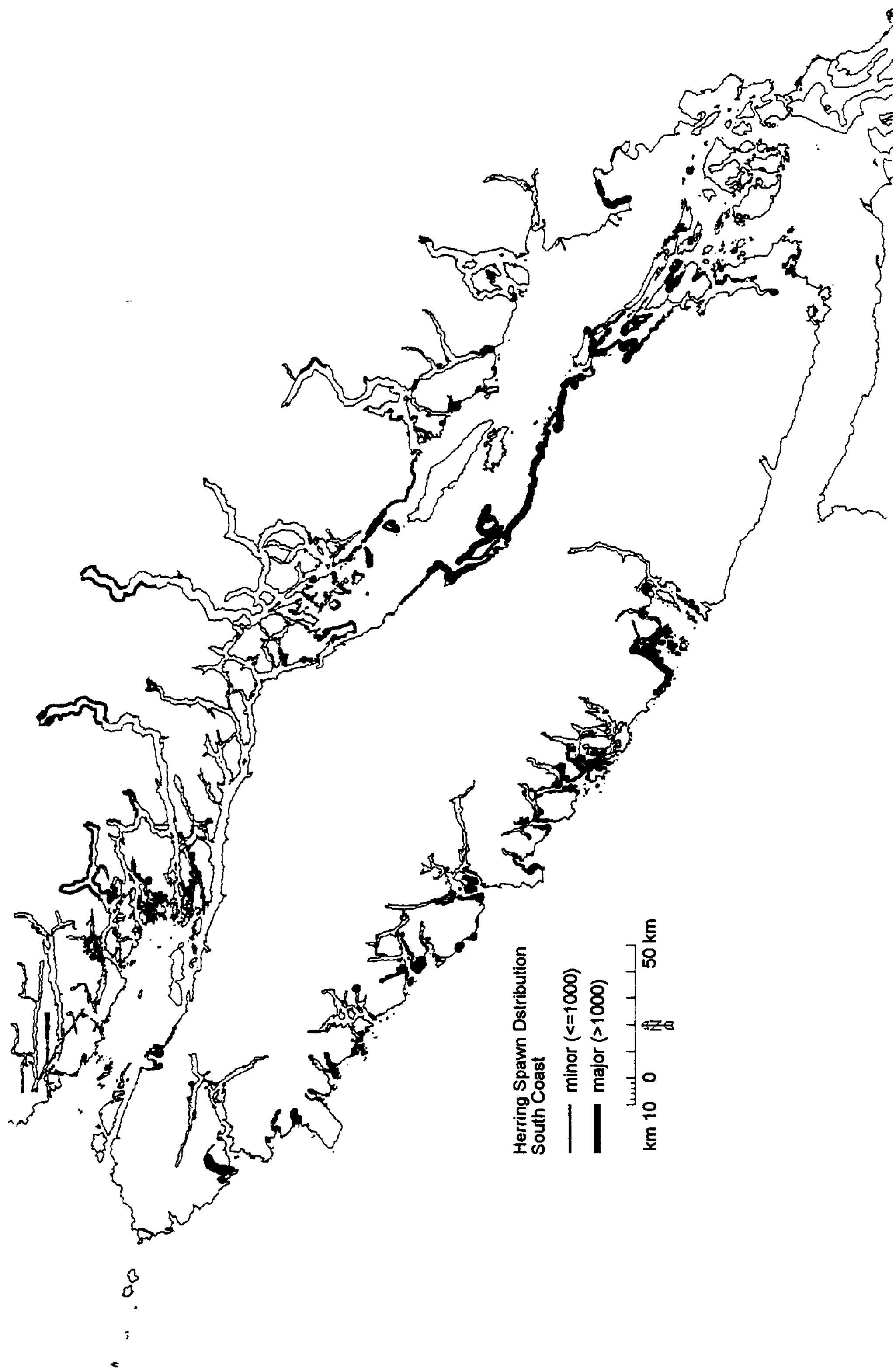


Figure 15. Distribution and magnitude of herring spawn index along the South coast.

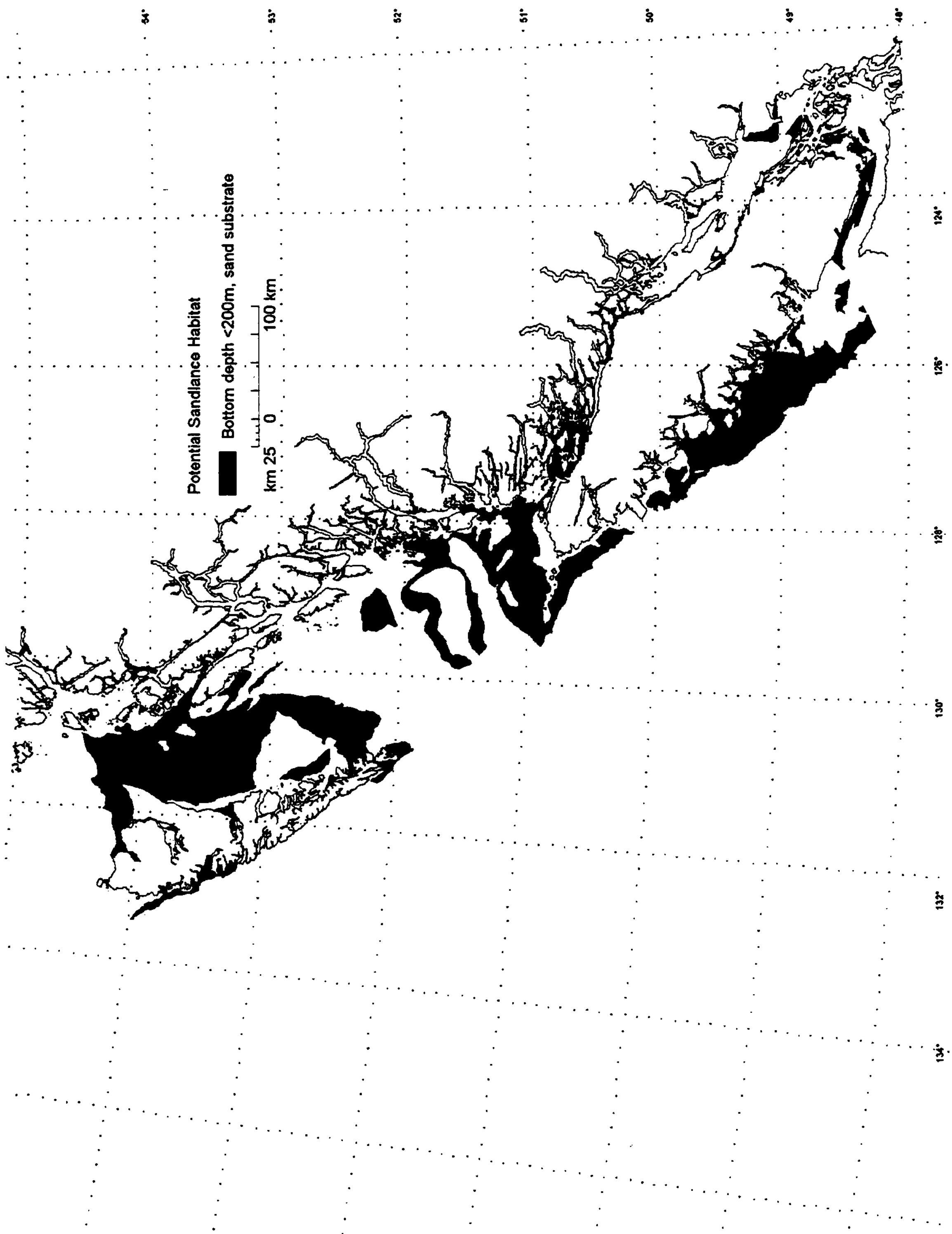


Figure 16. Potential sandlance habitat off the British Columbia coast, based upon water depth (<200m) and the presence of sandy substrates.

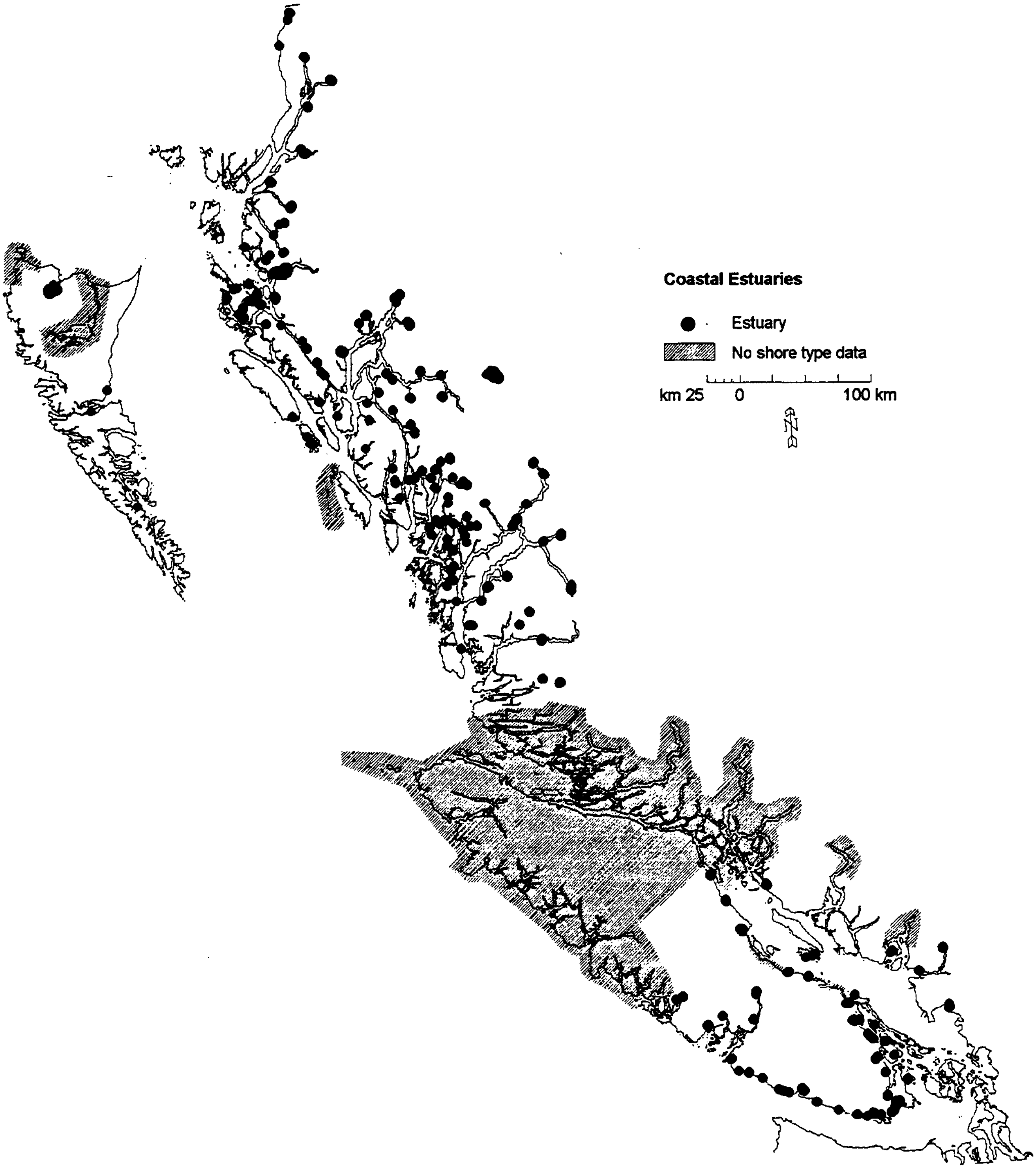


Figure 17. Coastal estuaries of British Columbia.

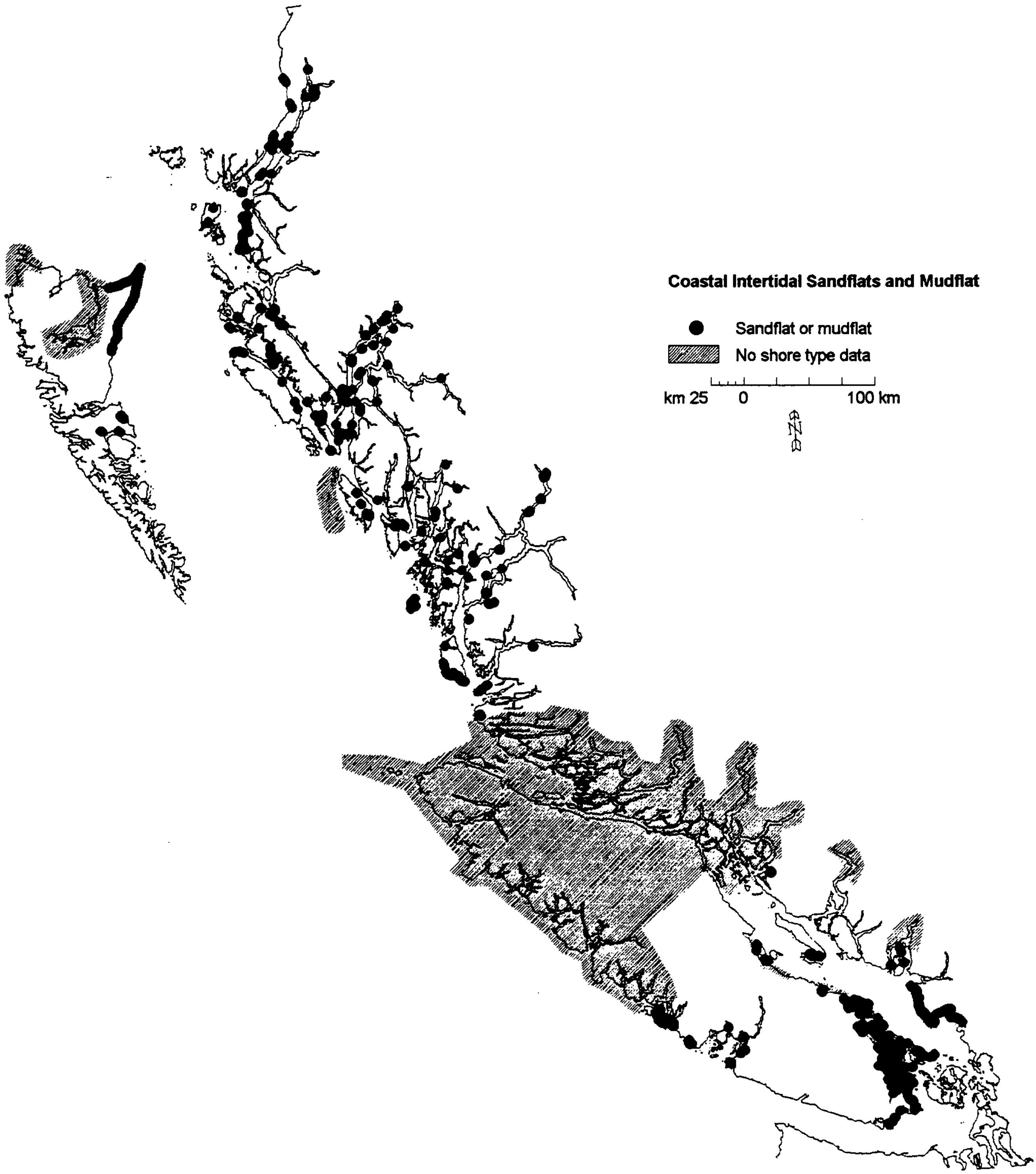


Figure 18. Coastal intertidal sandflats and mudflats of British Columbia.

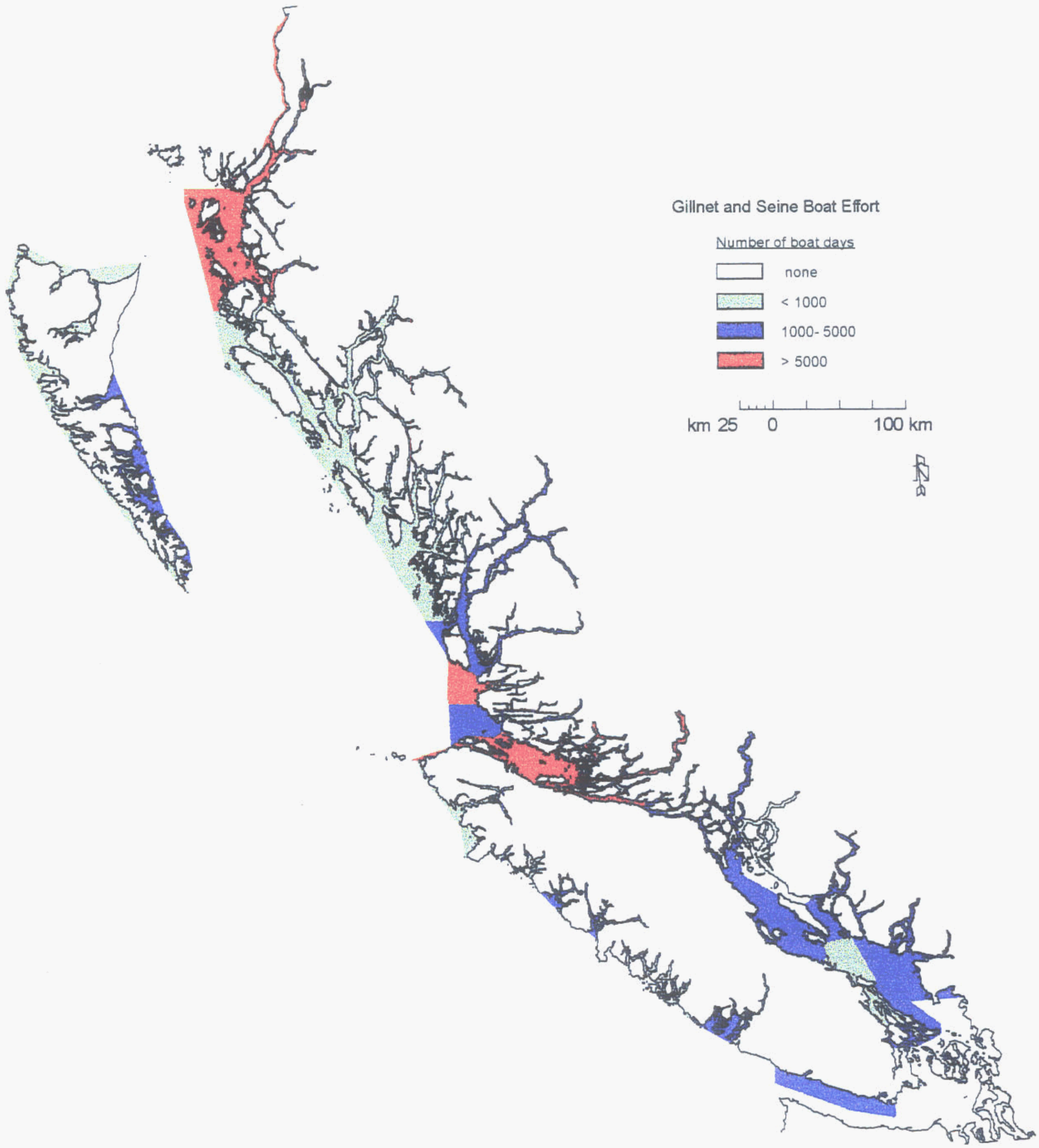


Figure 19. Fishing effort (in boat days) by gillnet and seine boats.

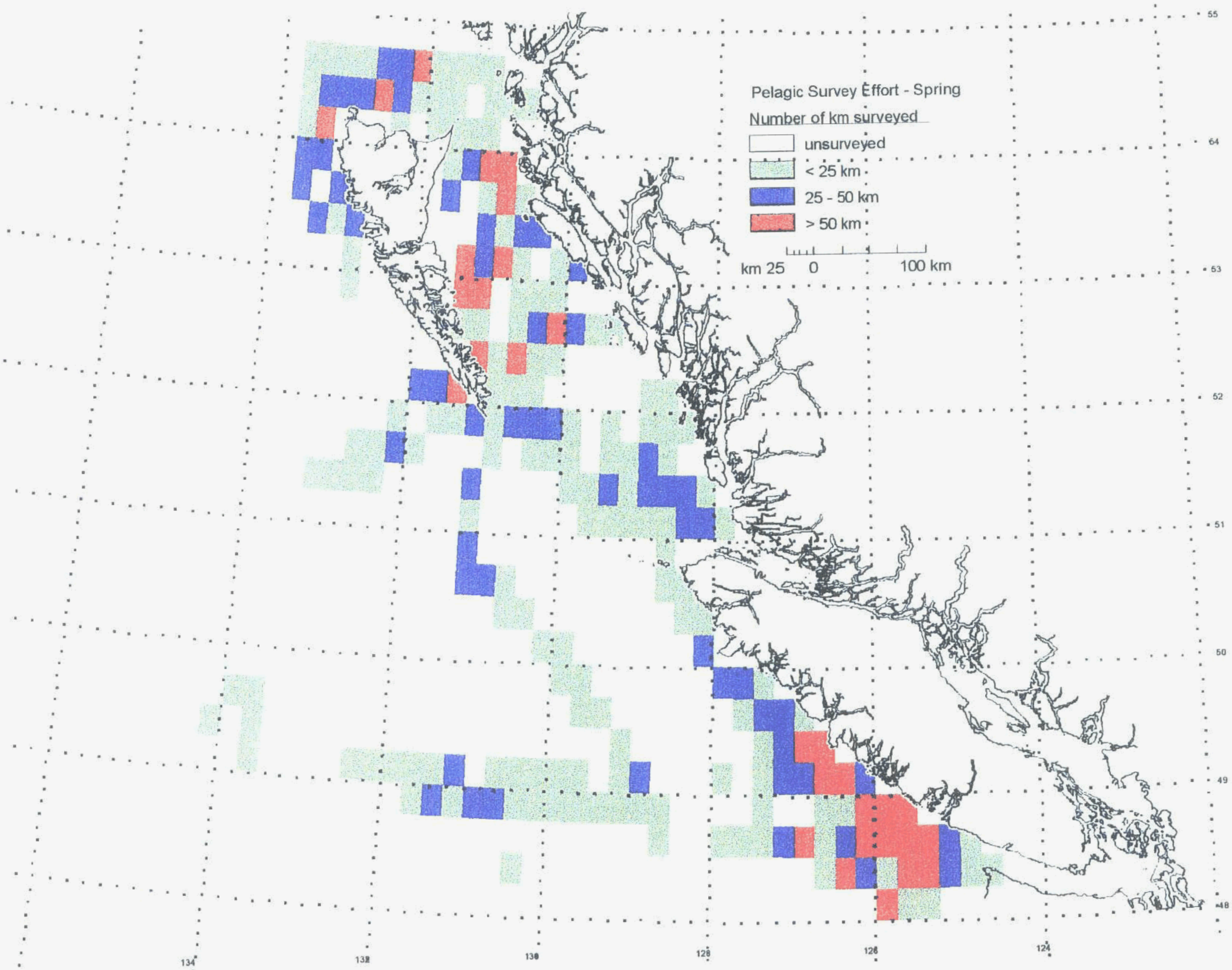


Figure 20. Total pelagic survey effort (1981-1990) during spring (16 March through 15 June).

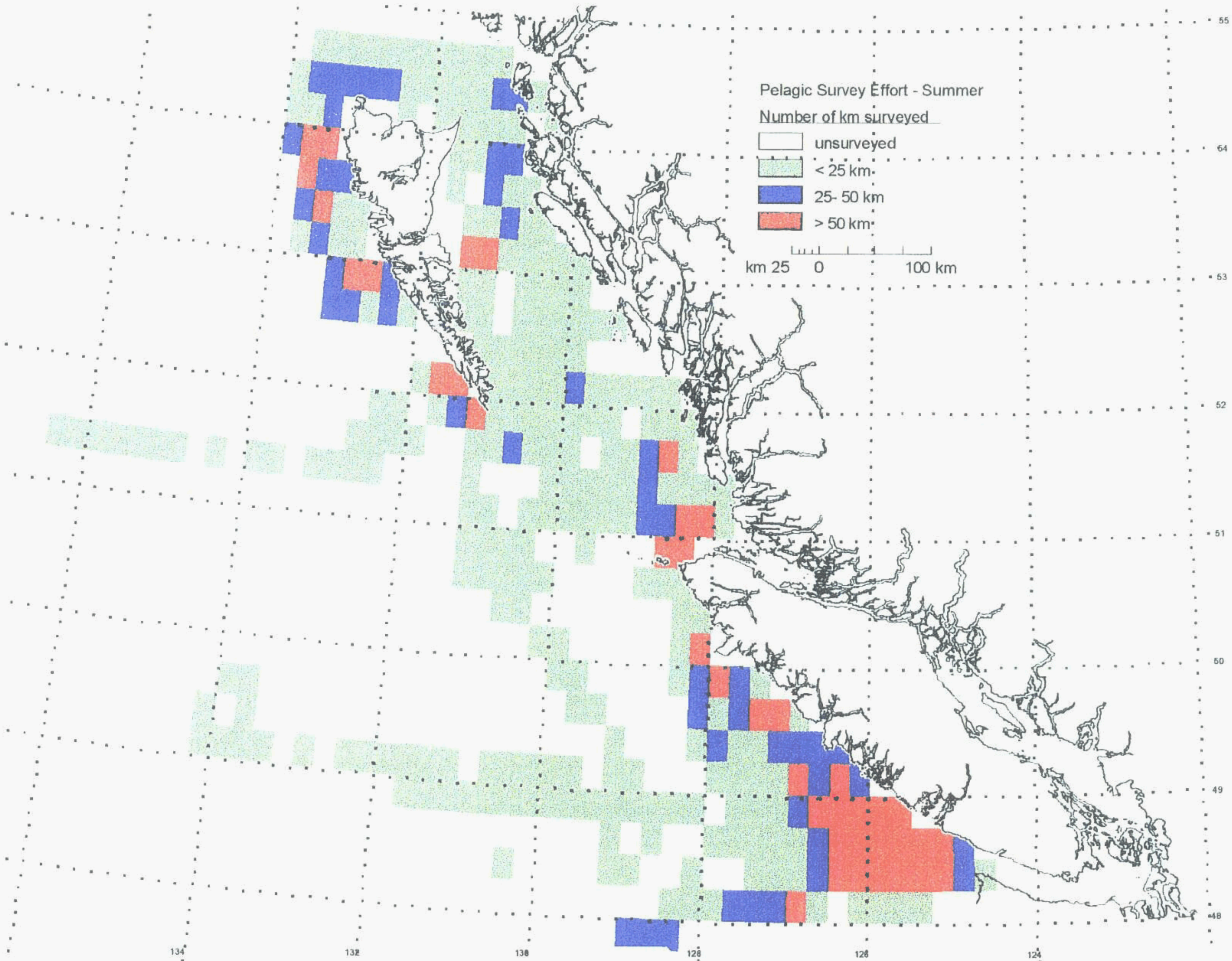


Figure 21. Total pelagic survey effort (1981 - 1990) during summer (16 June through 15 September).

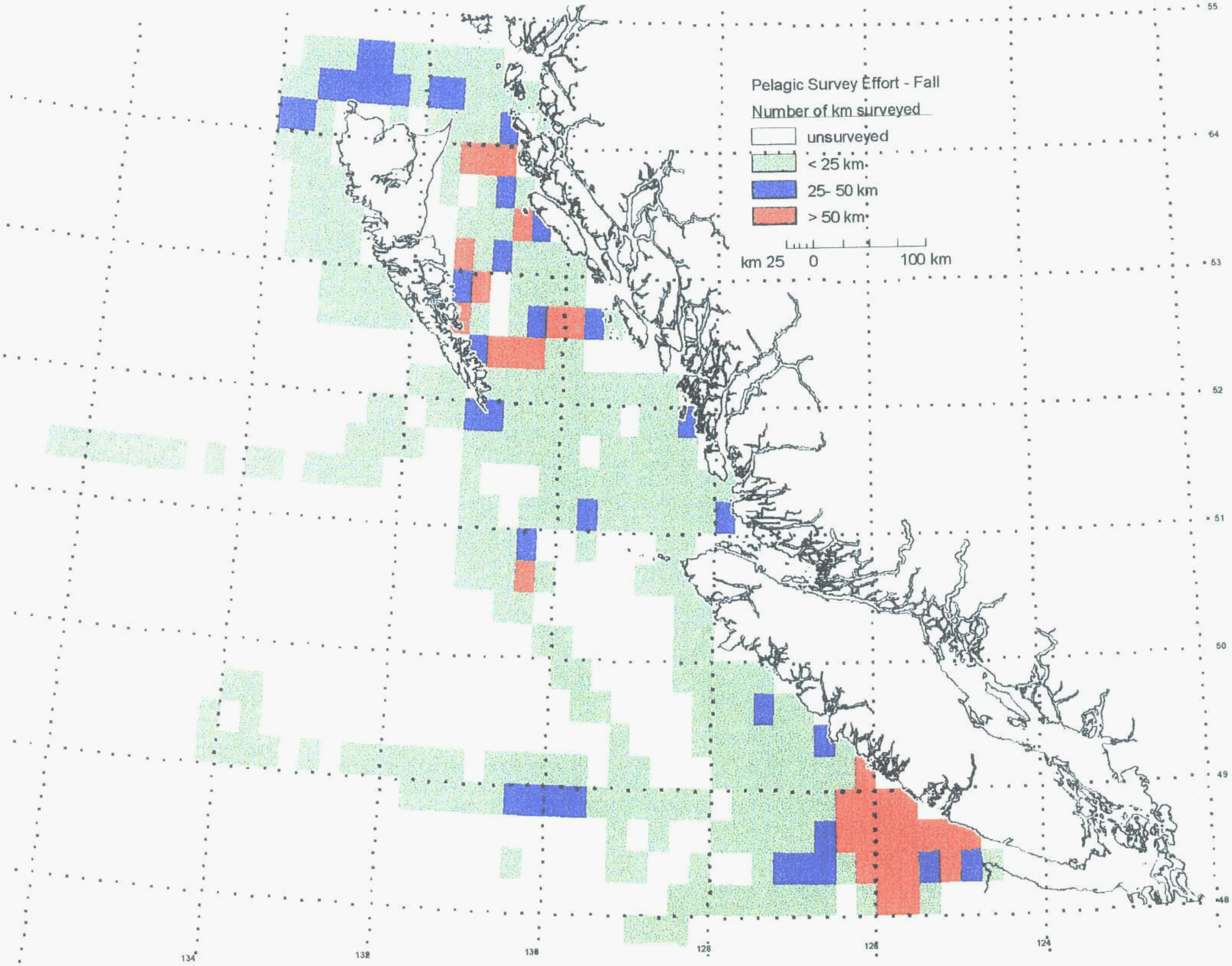


Figure 22. Total pelagic survey effort (1981 - 1990) during fall (16 September through 15 December).

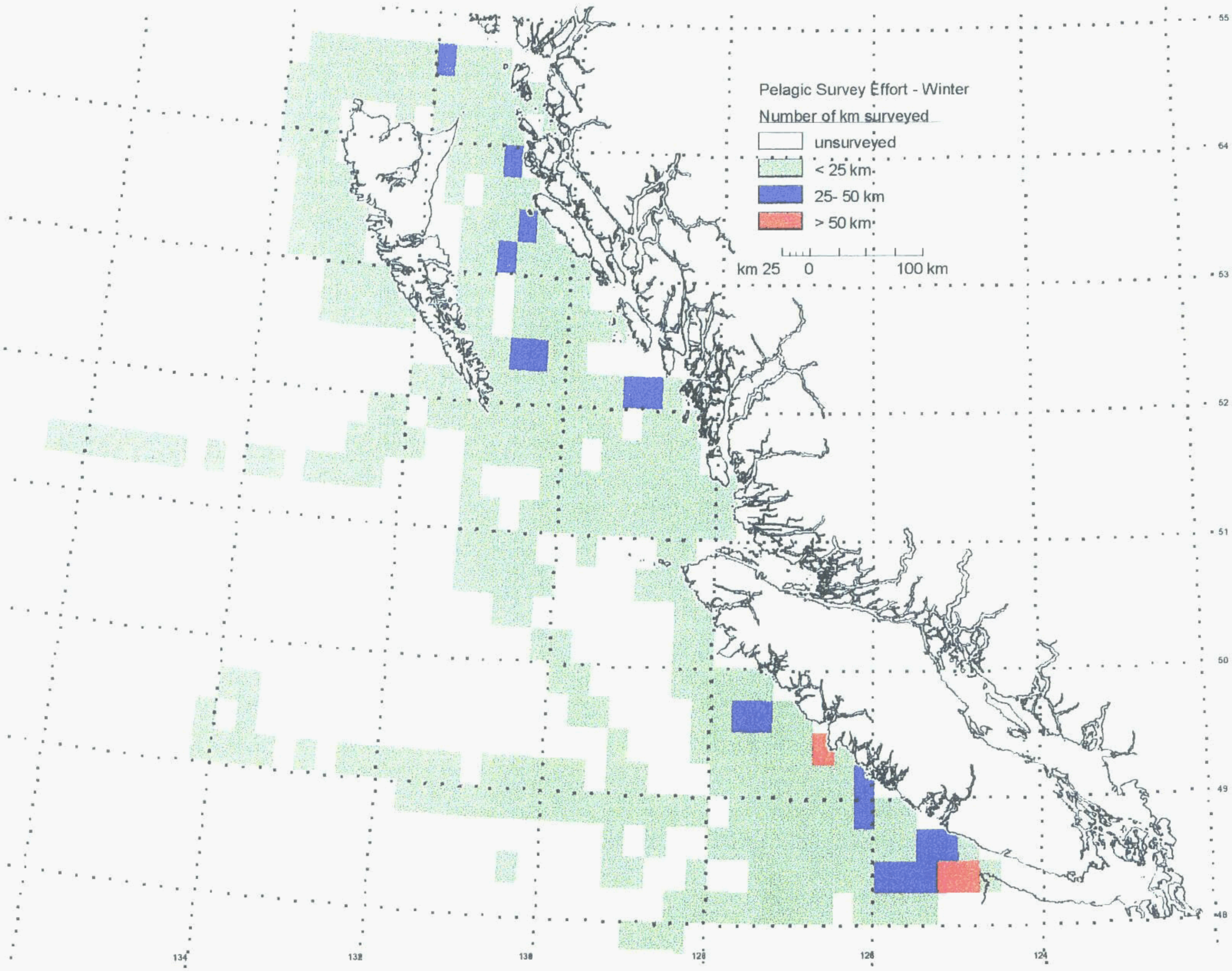


Figure 23. Total pelagic survey effort (1981 - 1990) during winter (16 December through 15 March).

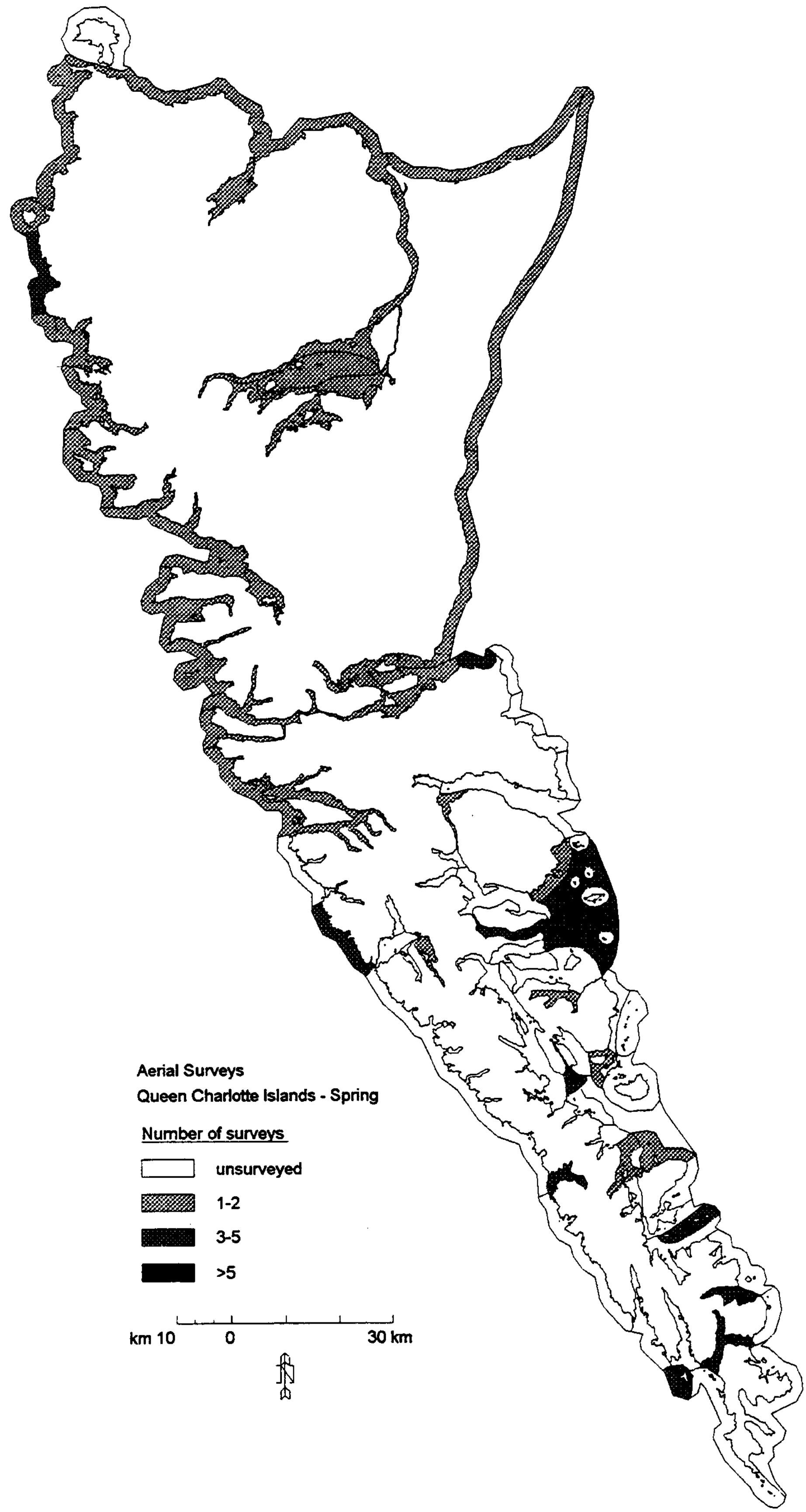


Figure 24. Total number of aerial surveys of the Queen Charlotte Islands during spring (1 March through 31 May).

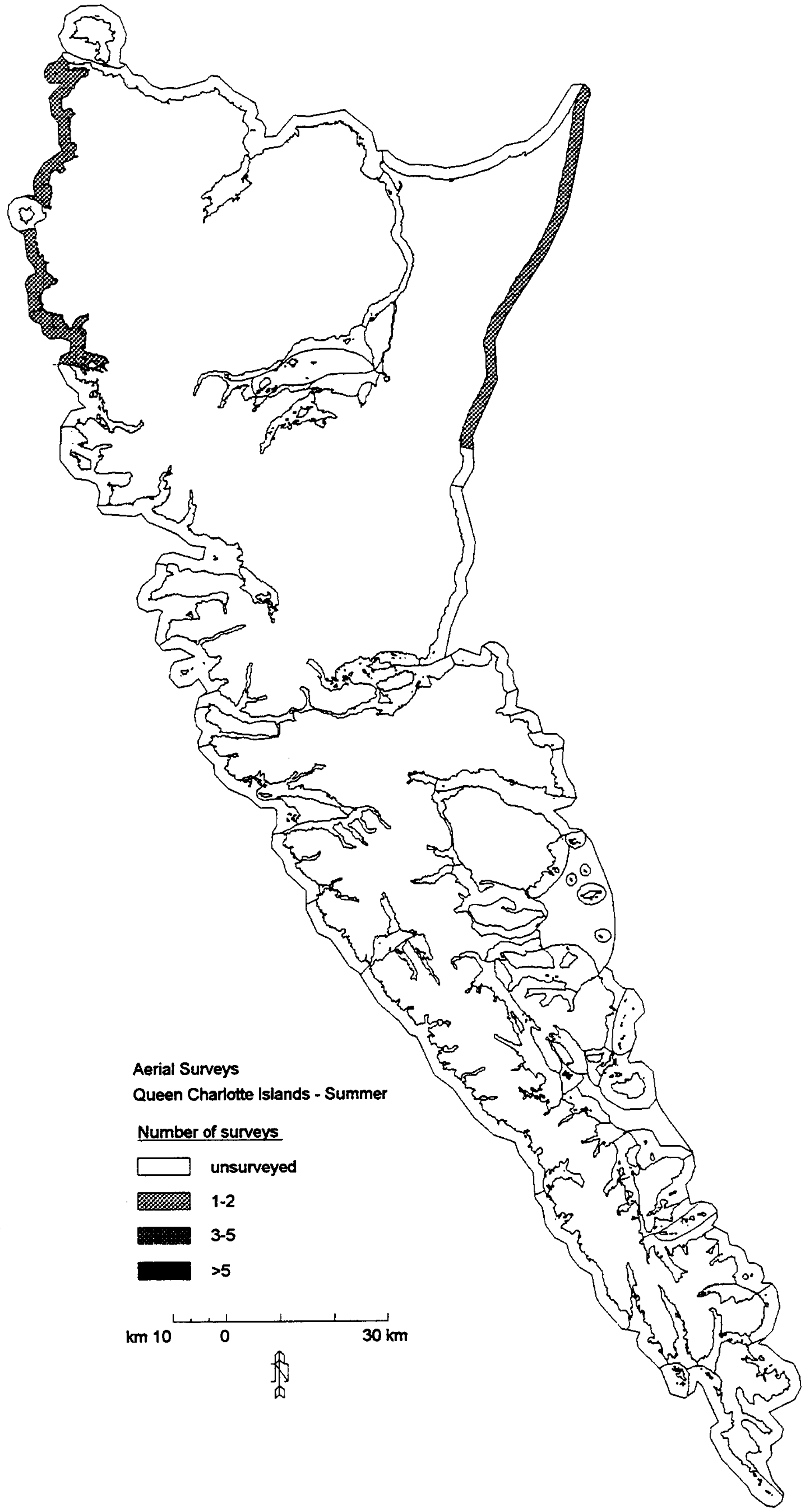


Figure 25. Total number of aerial surveys of the Queen Charlotte Islands during summer (1 June through 31 August).

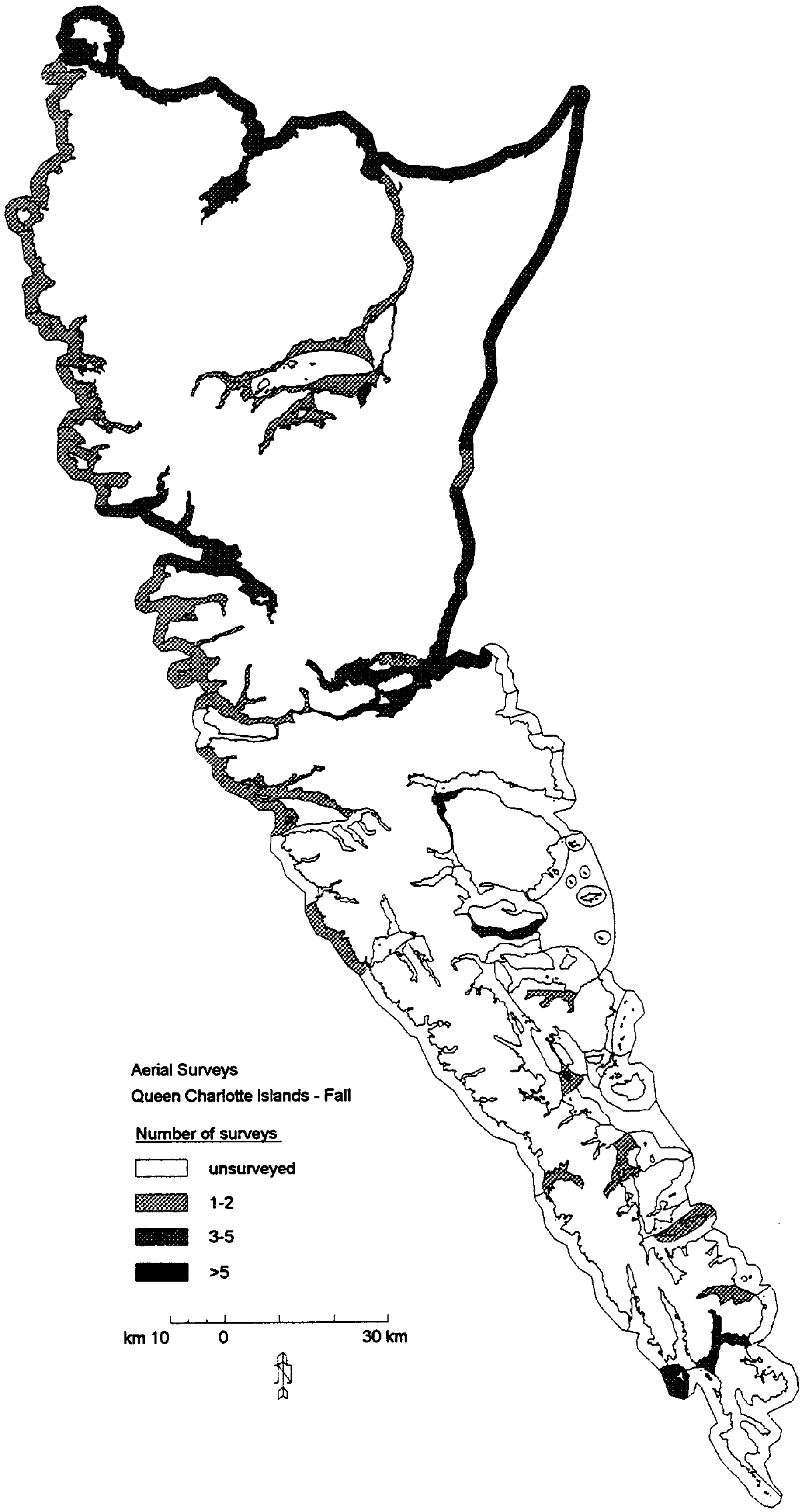


Figure 26. Total number of aerial surveys of the Queen Charlotte Islands during fall (1 September through 30 November).

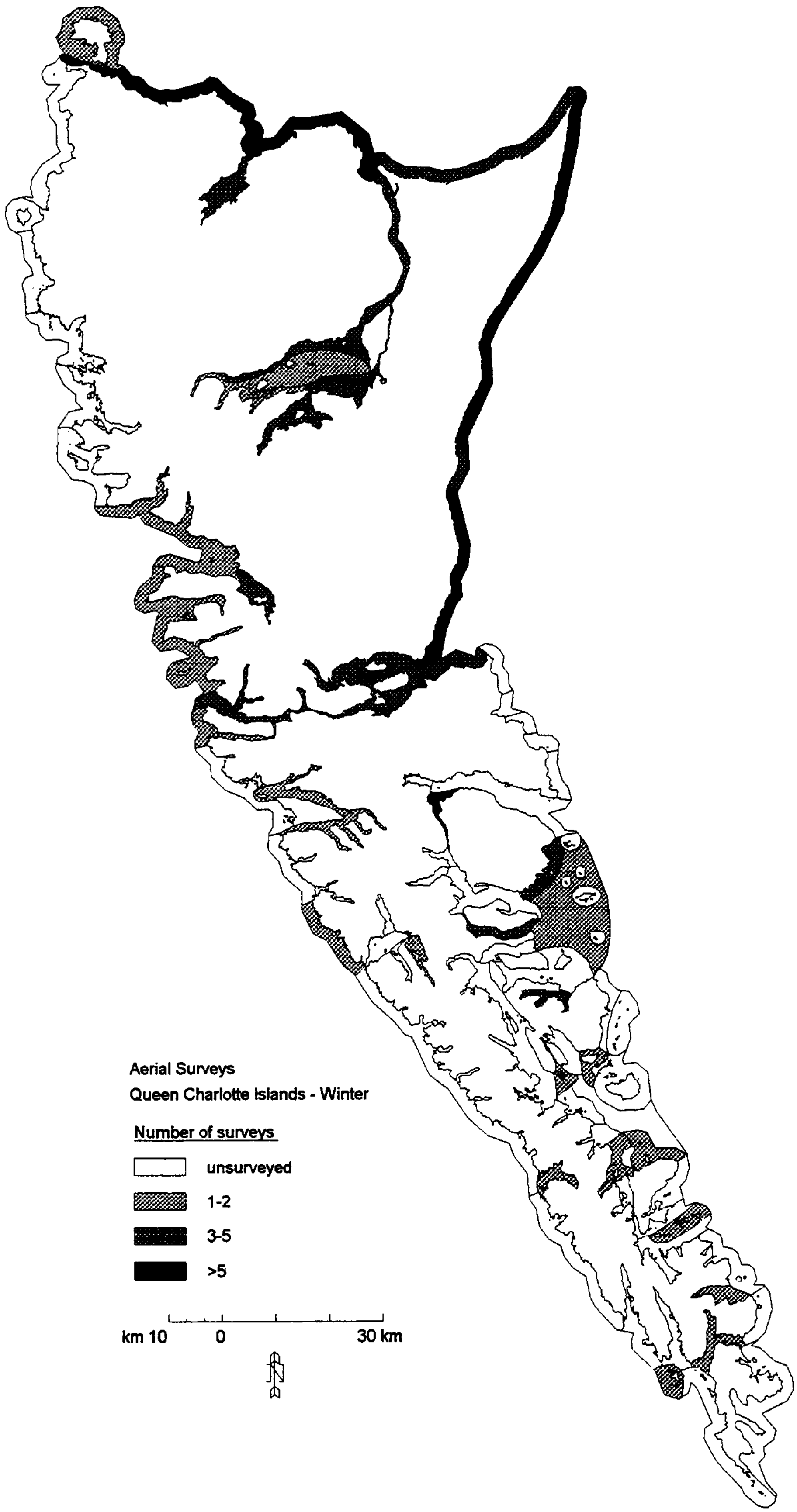


Figure 27. Total number of aerial surveys of the Queen Charlotte Islands during winter (1 December through 28 February).

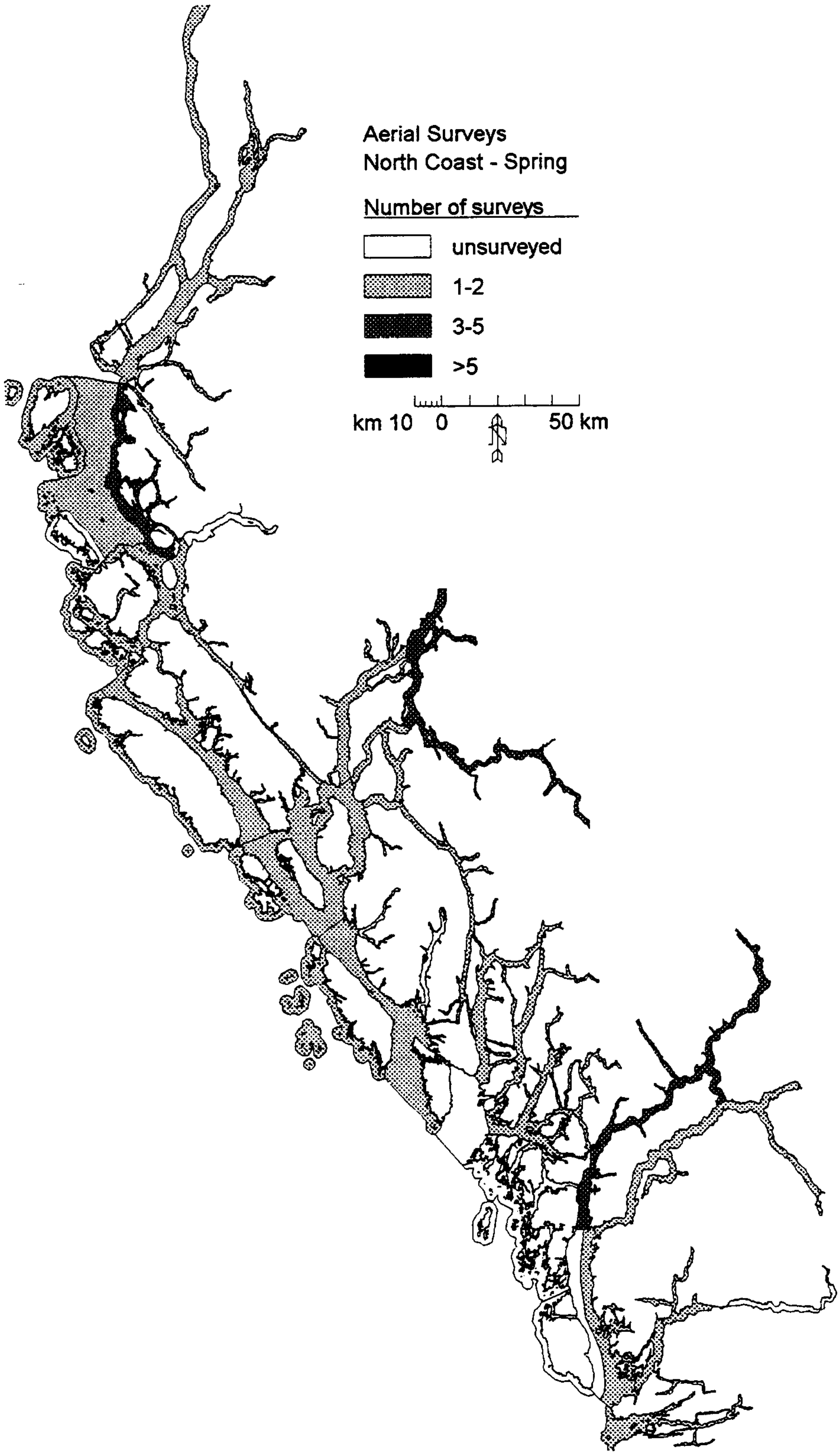


Figure 28. Total number of aerial surveys of the North coast during spring (1 March through 31 May).

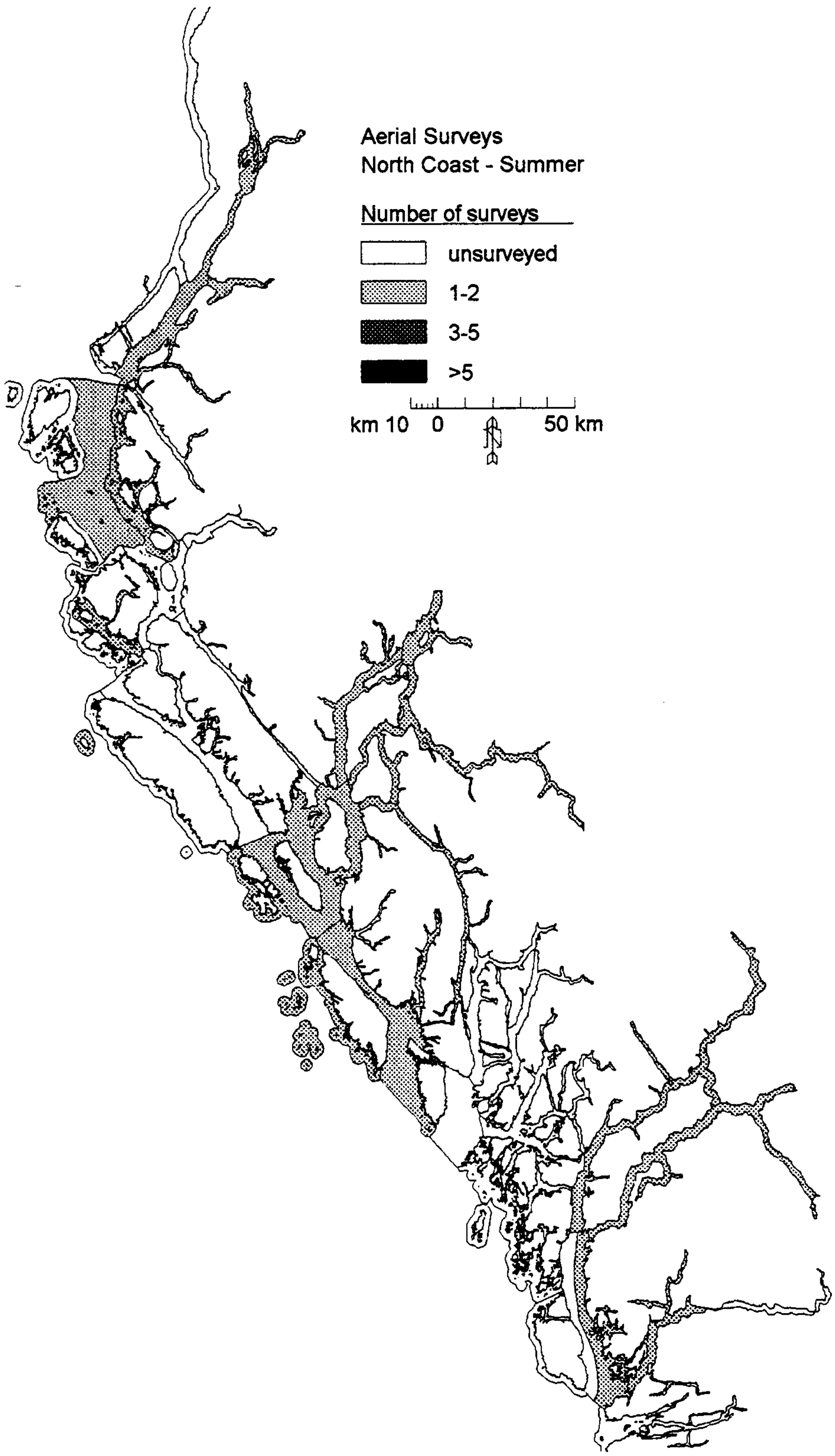


Figure 29. Total number of aerial surveys of the North coast during summer (1 June through 31 August).

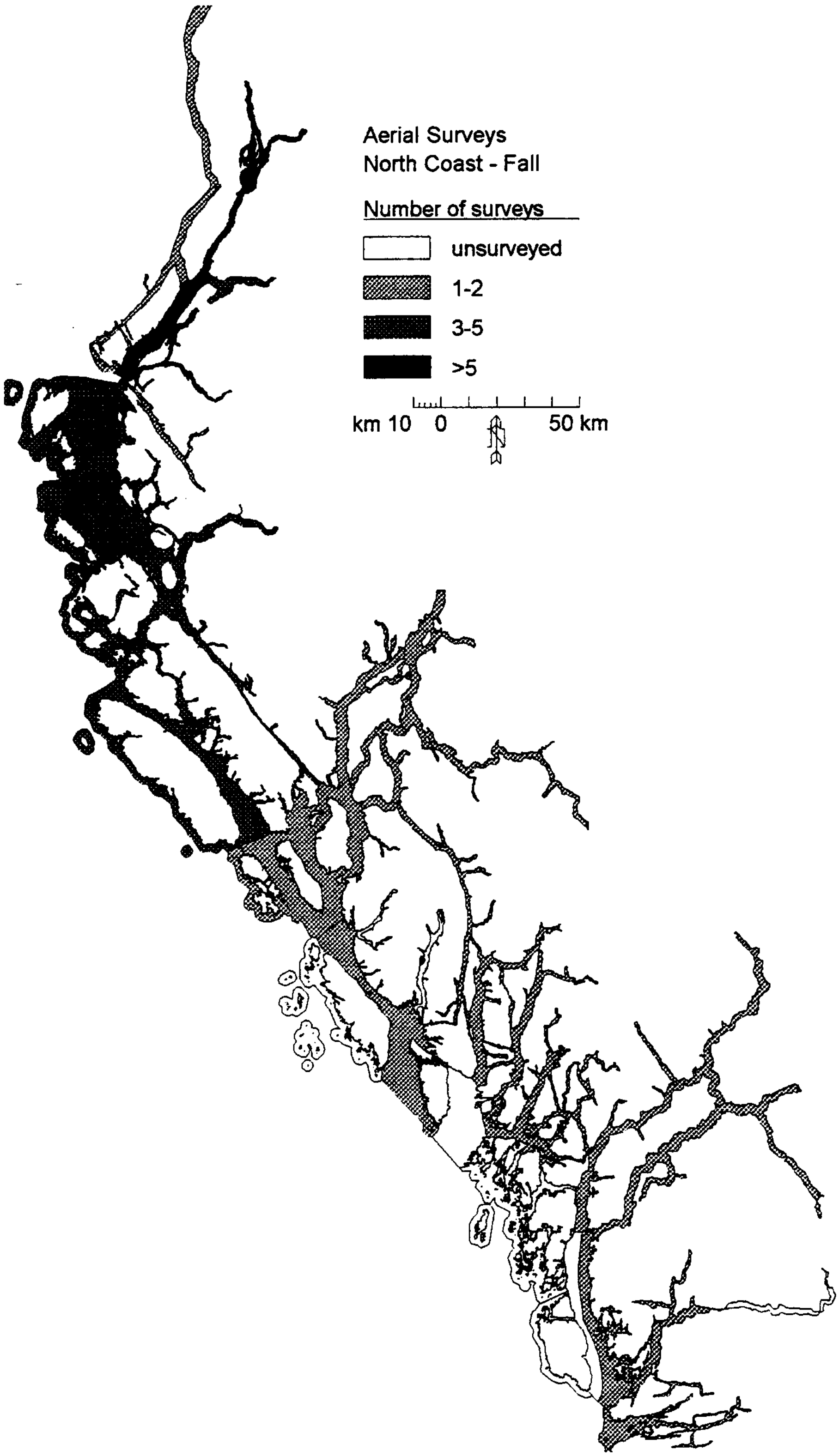


Figure 30. Total number of aerial surveys of the North coast during fall (1 September through 30 November).

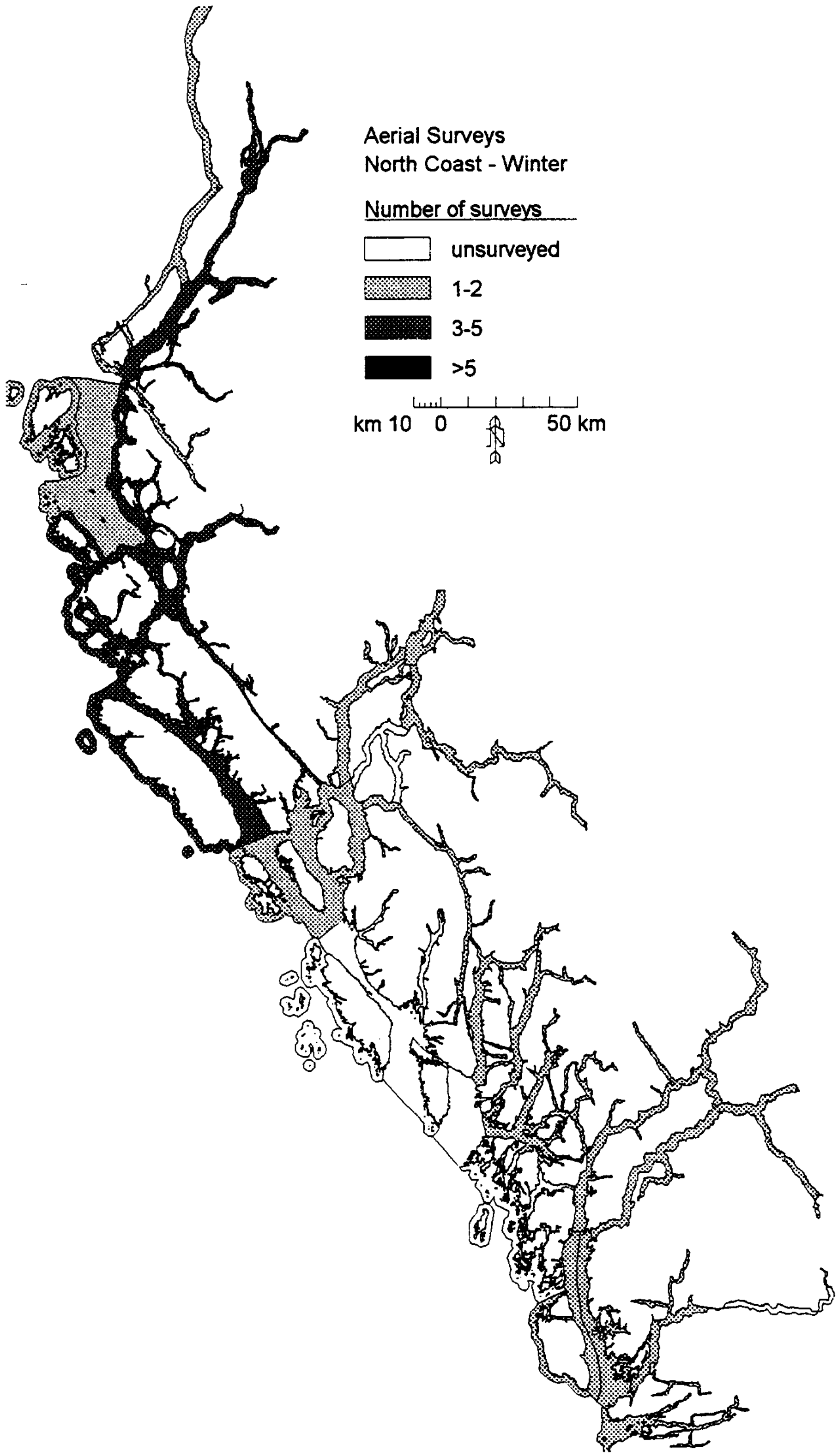


Figure 31. Total number of aerial surveys of the North coast during winter (1 December through 28 February).

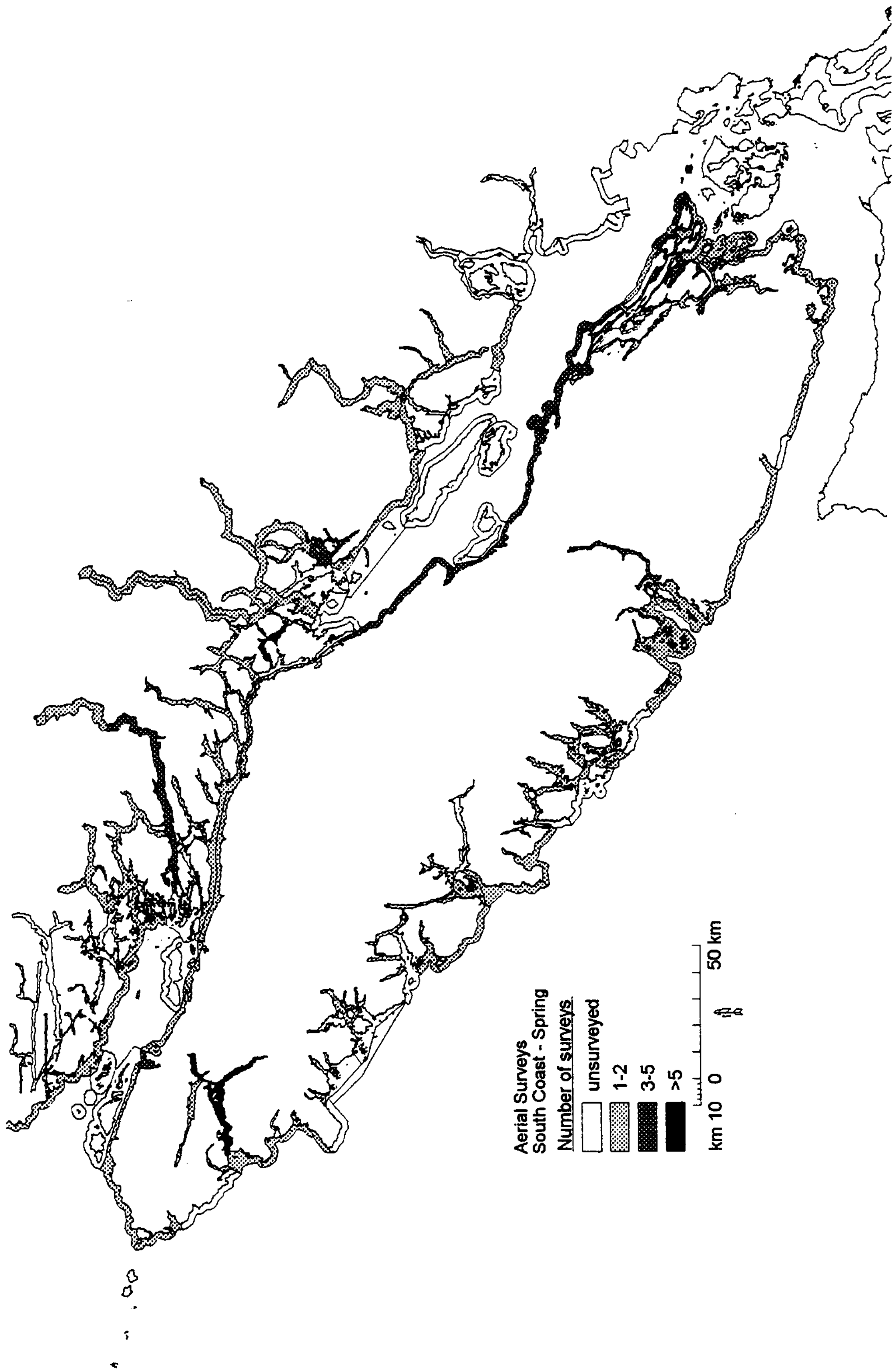


Figure 32. Total number of aerial surveys of the South coast during spring (1 March through 31 May).

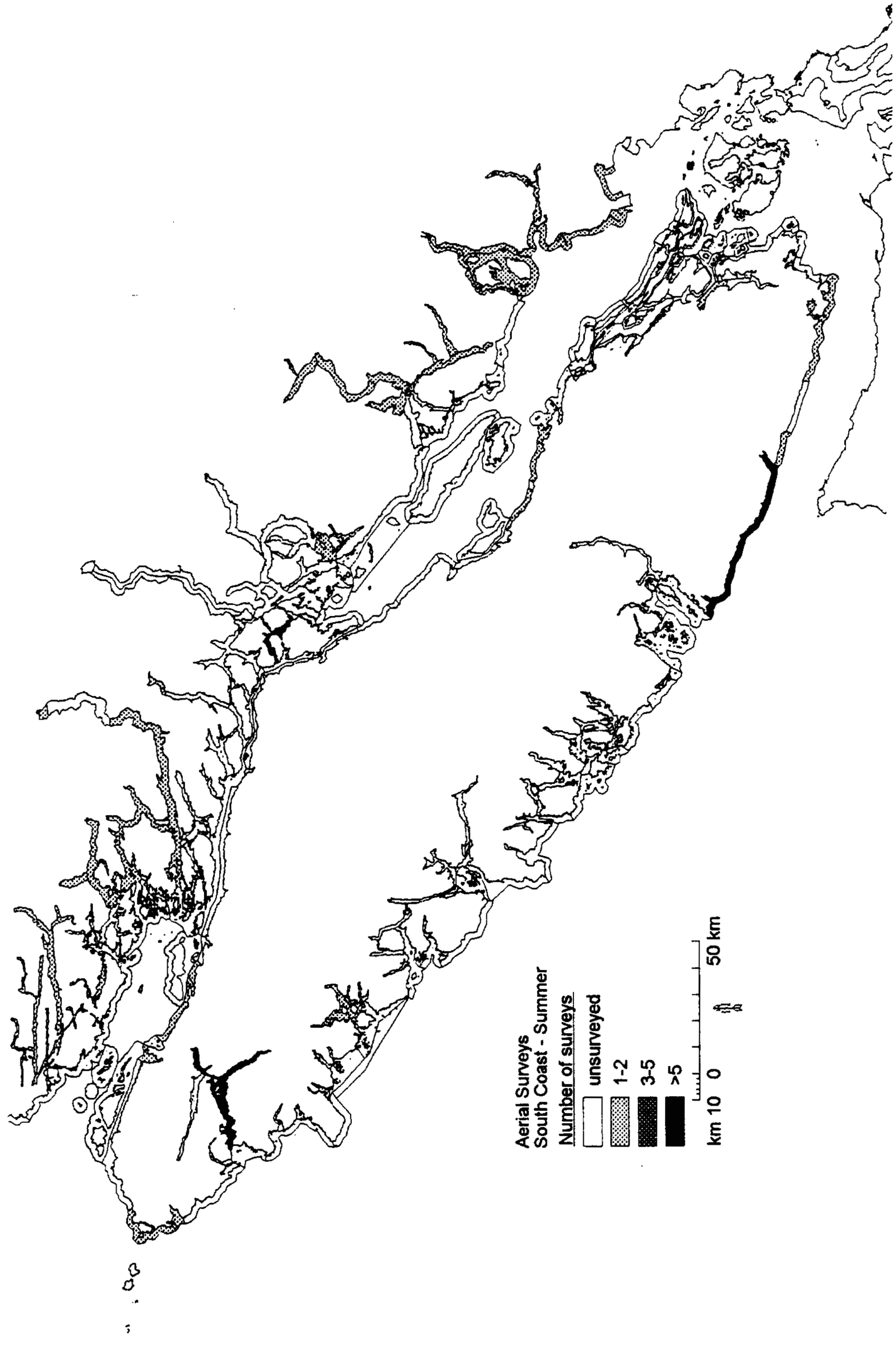


Figure 33. Total number of aerial surveys of the South coast during summer (1 June through 31 August).

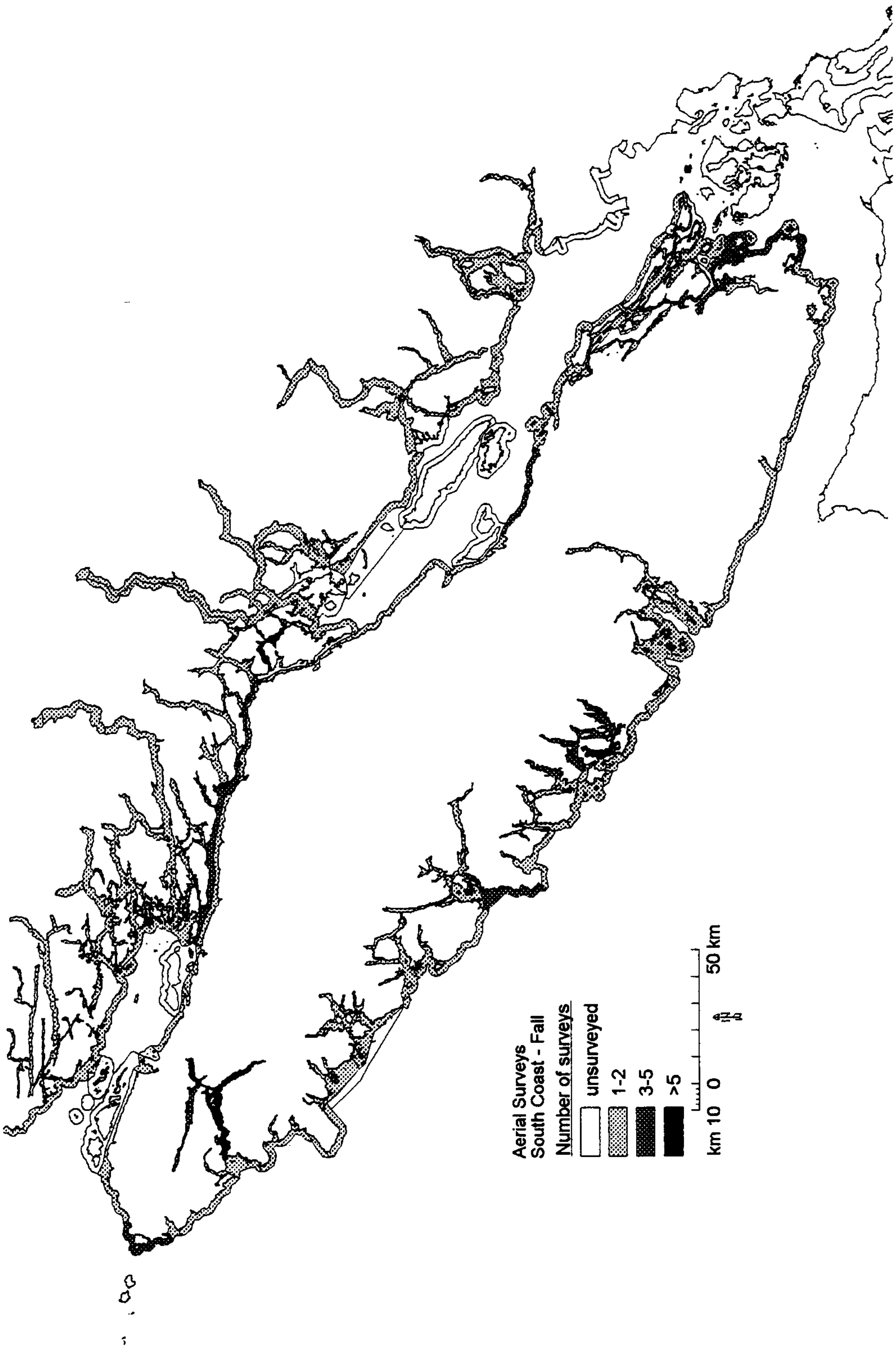


Figure 34. Total number of aerial surveys of the South coast during fall (1 September through 30 November).

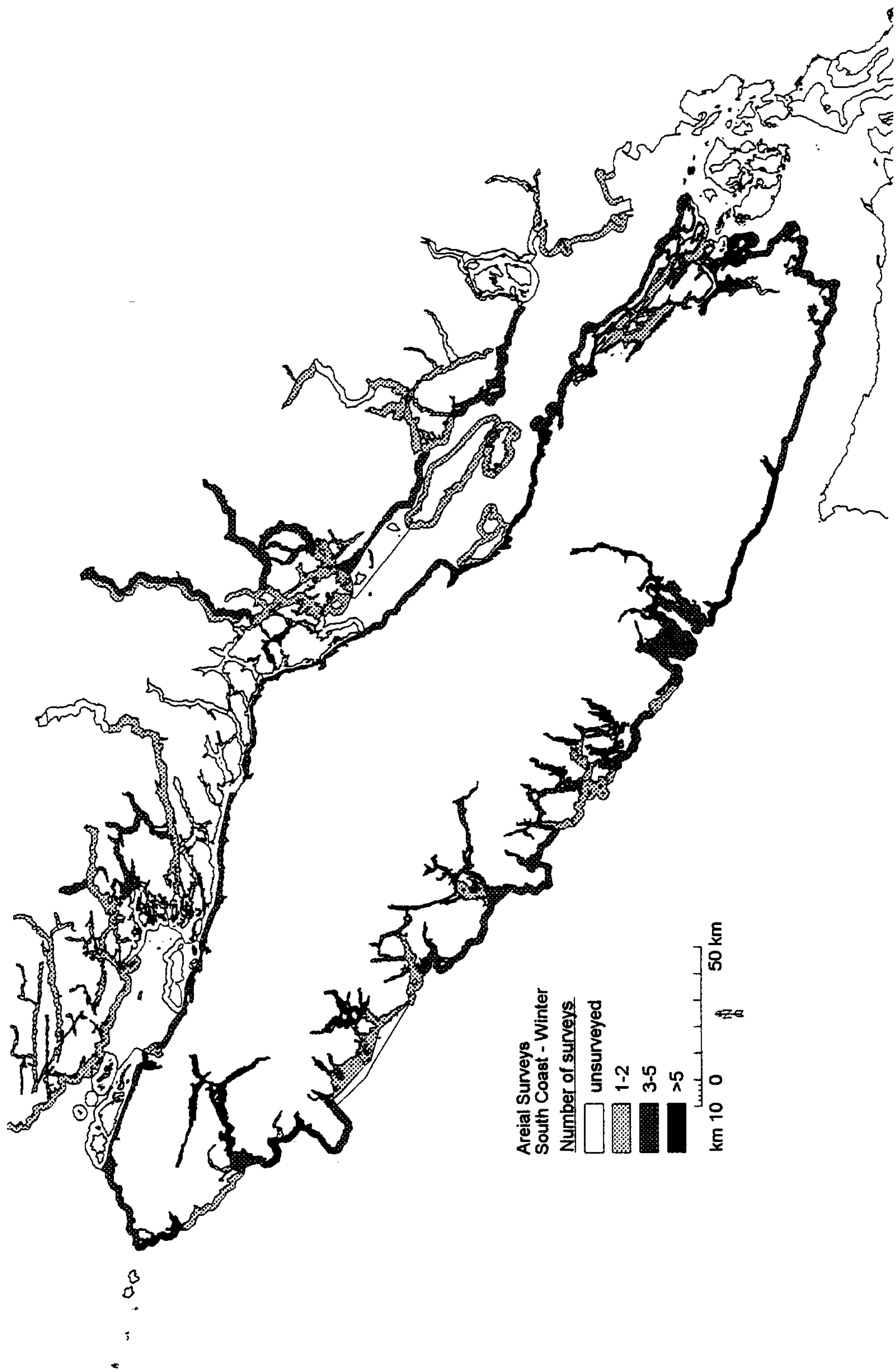


Figure 35. Total number of aerial surveys of the South coast during winter (1 December through 28 February).

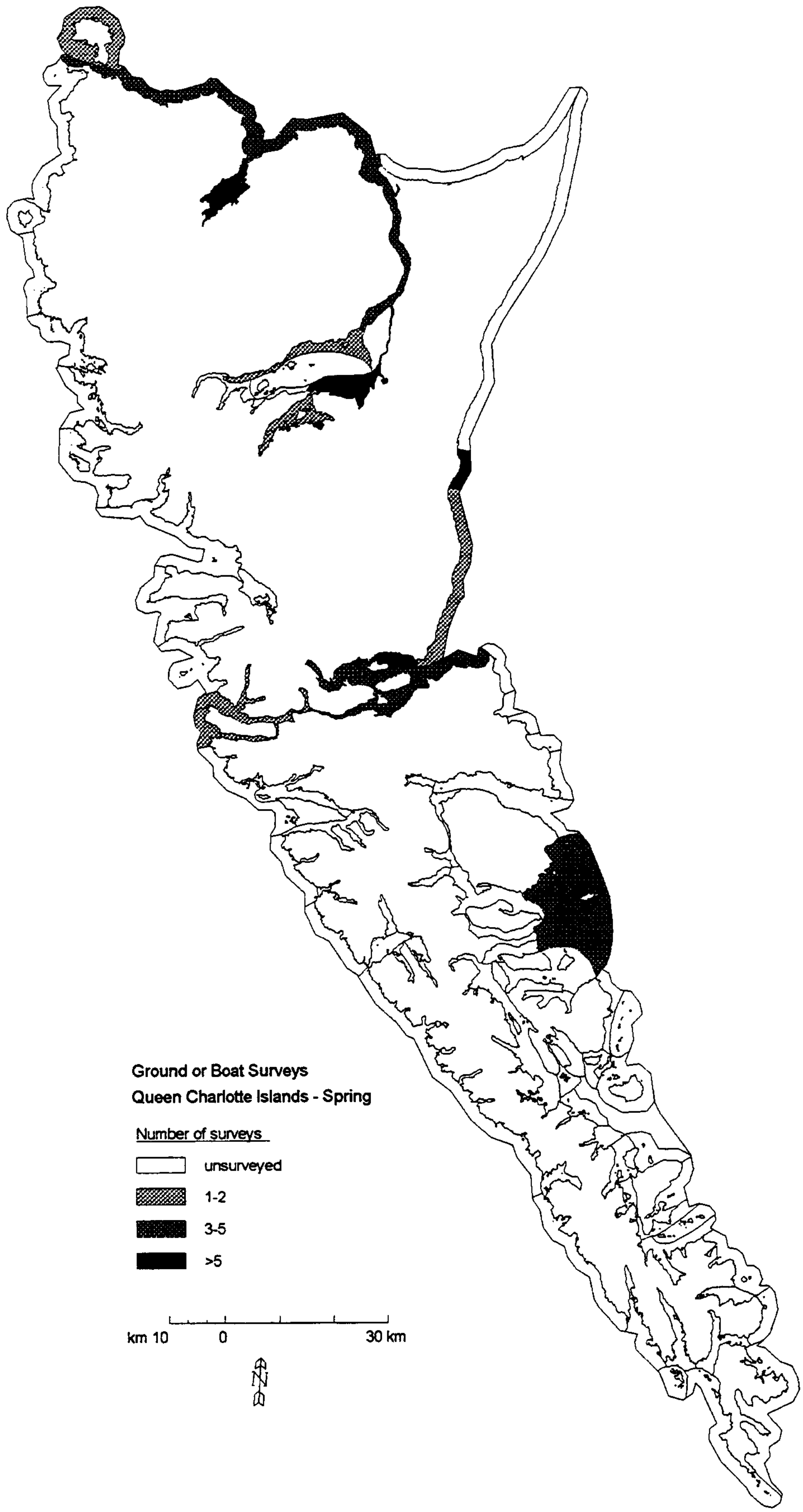


Figure 36. Total number of ground or boat surveys of the Queen Charlotte Islands during spring (1 March through 31 May).

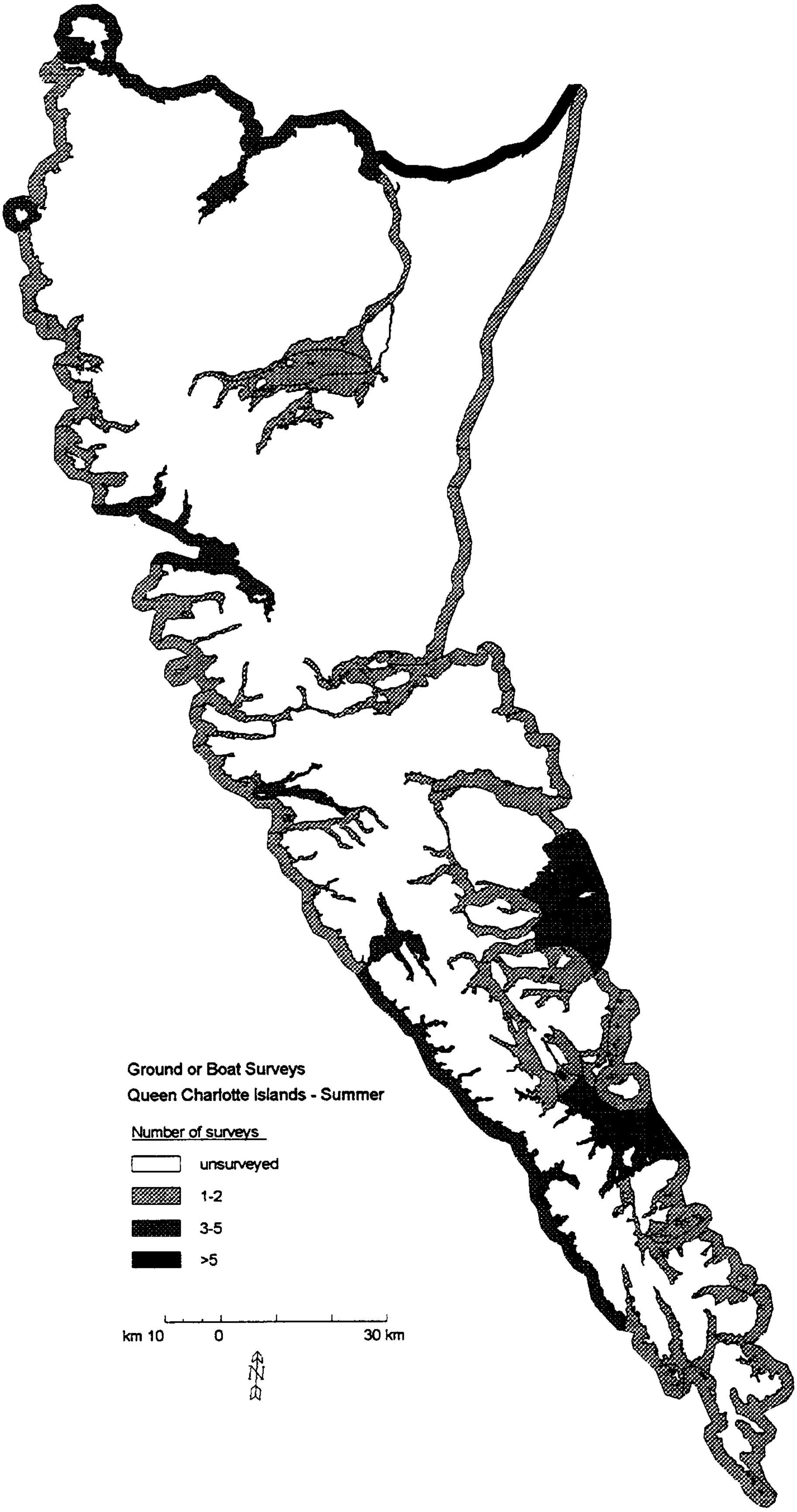


Figure 37. Total number of ground or boat surveys of the Queen Charlotte Islands during summer (1 June through 31 August).

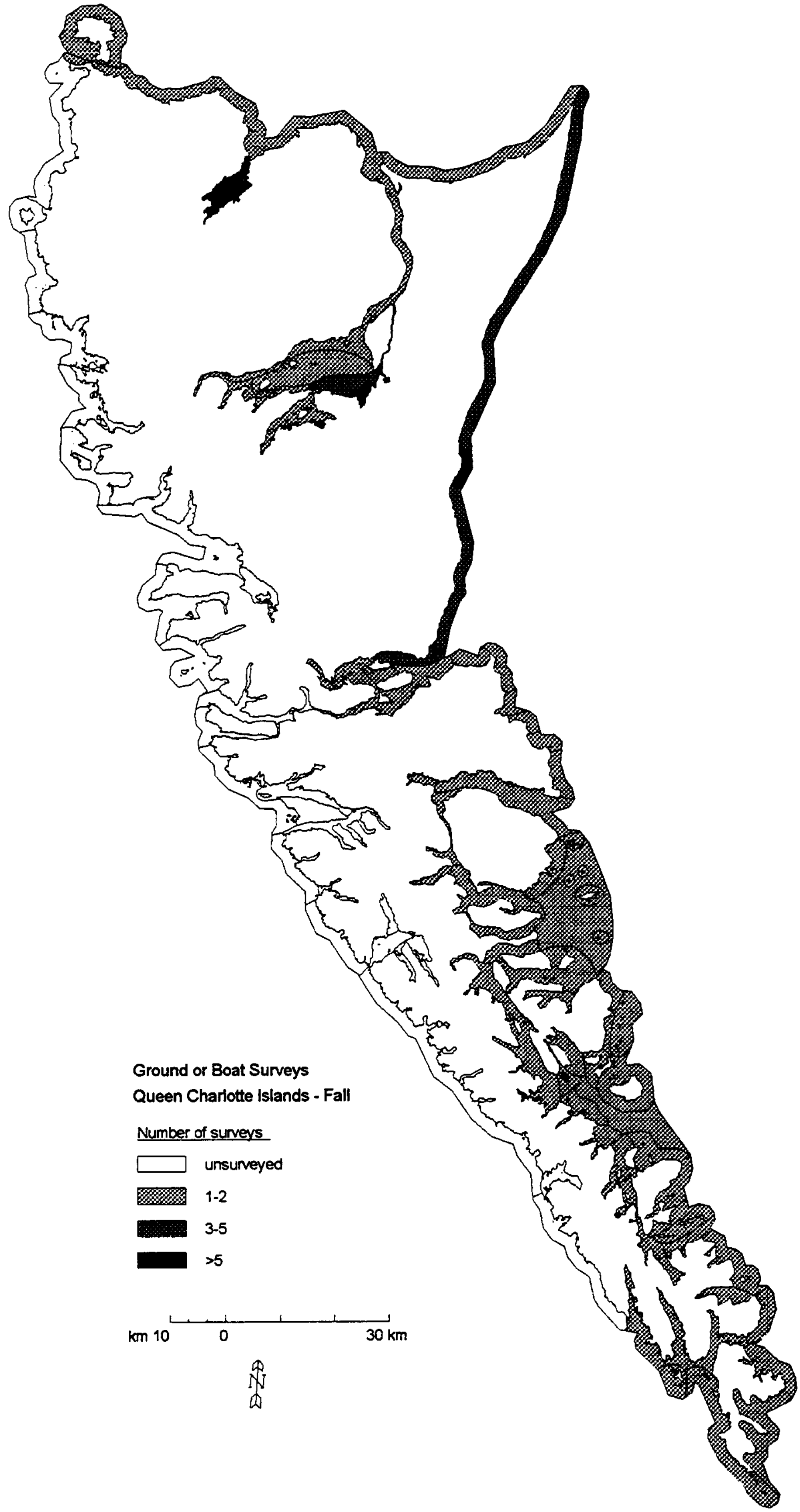
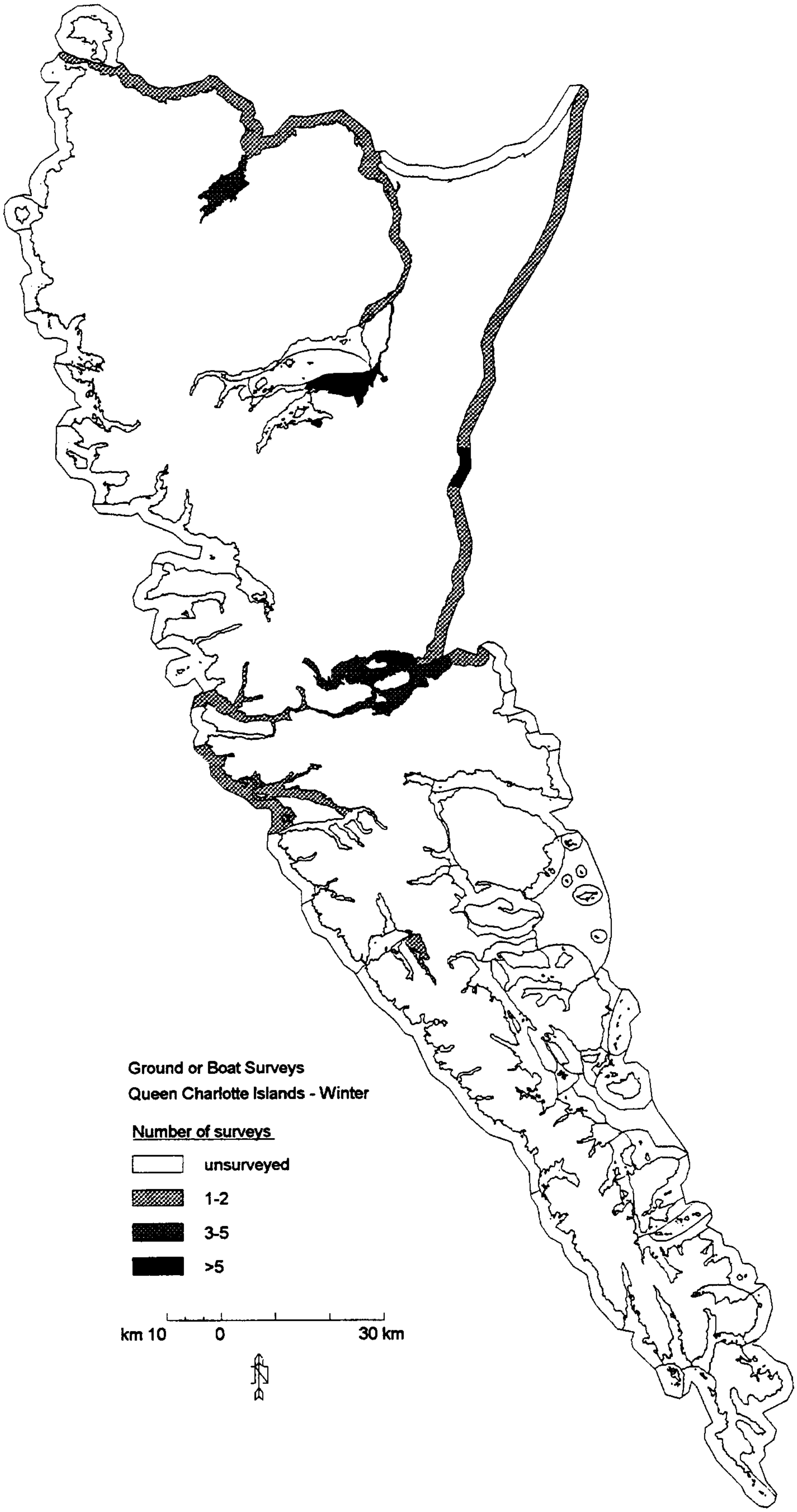


Figure 38. Total number of ground or boat surveys of the Queen Charlotte Islands during fall (1 September through 30 November).



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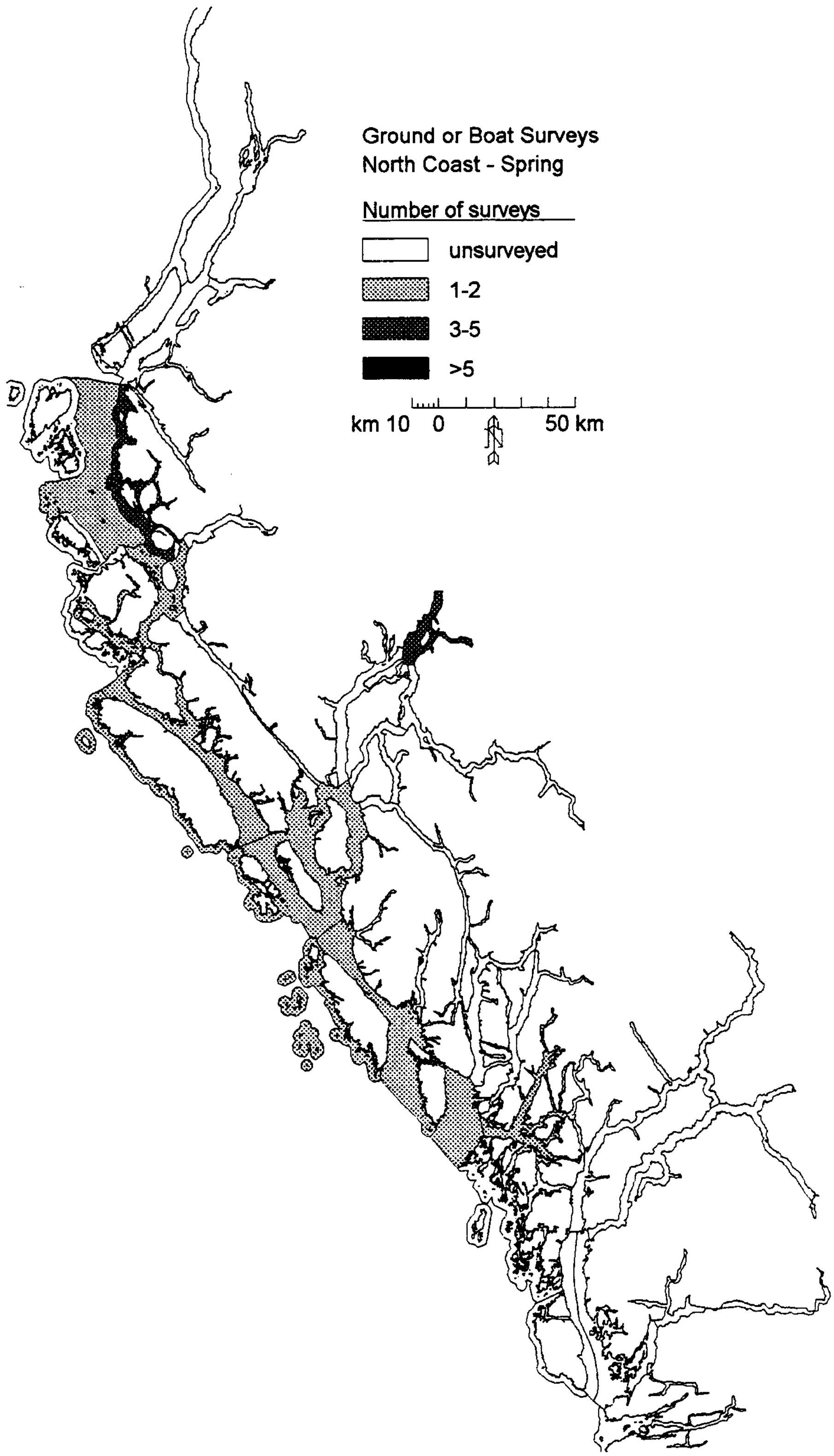

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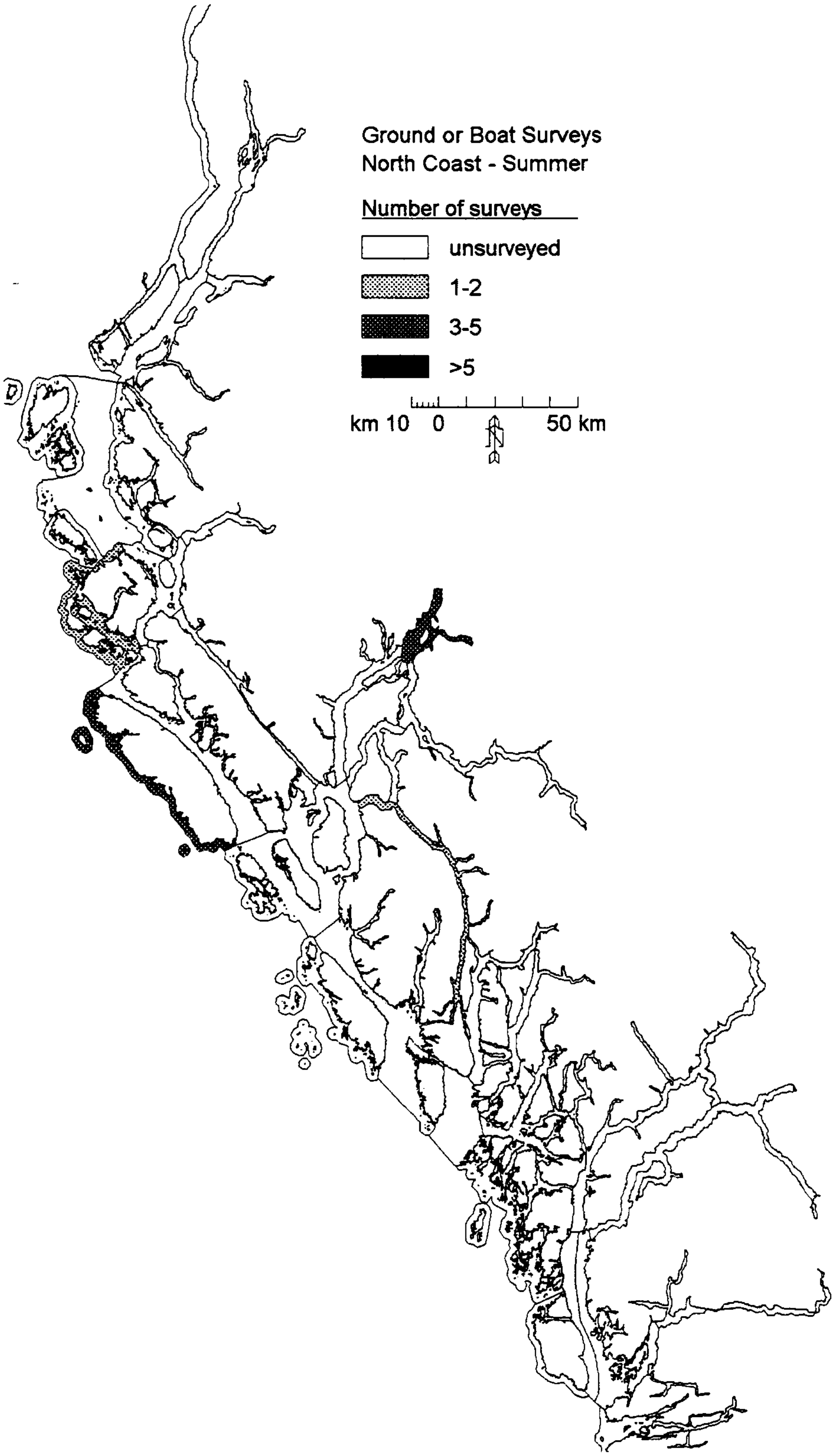
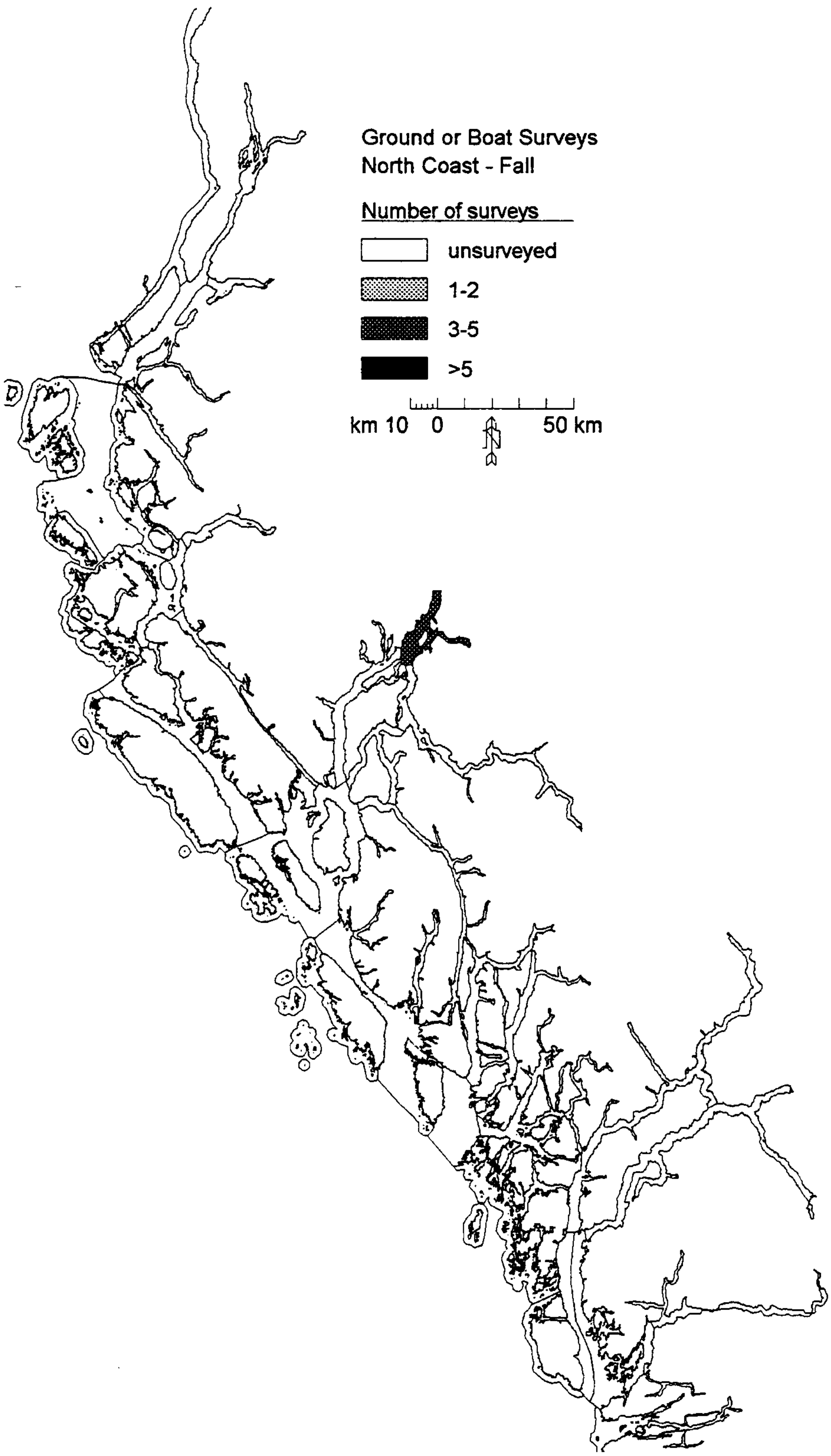


Figure 41. Total number of ground or boat surveys of the North coast during summer (1 June through 31 August).



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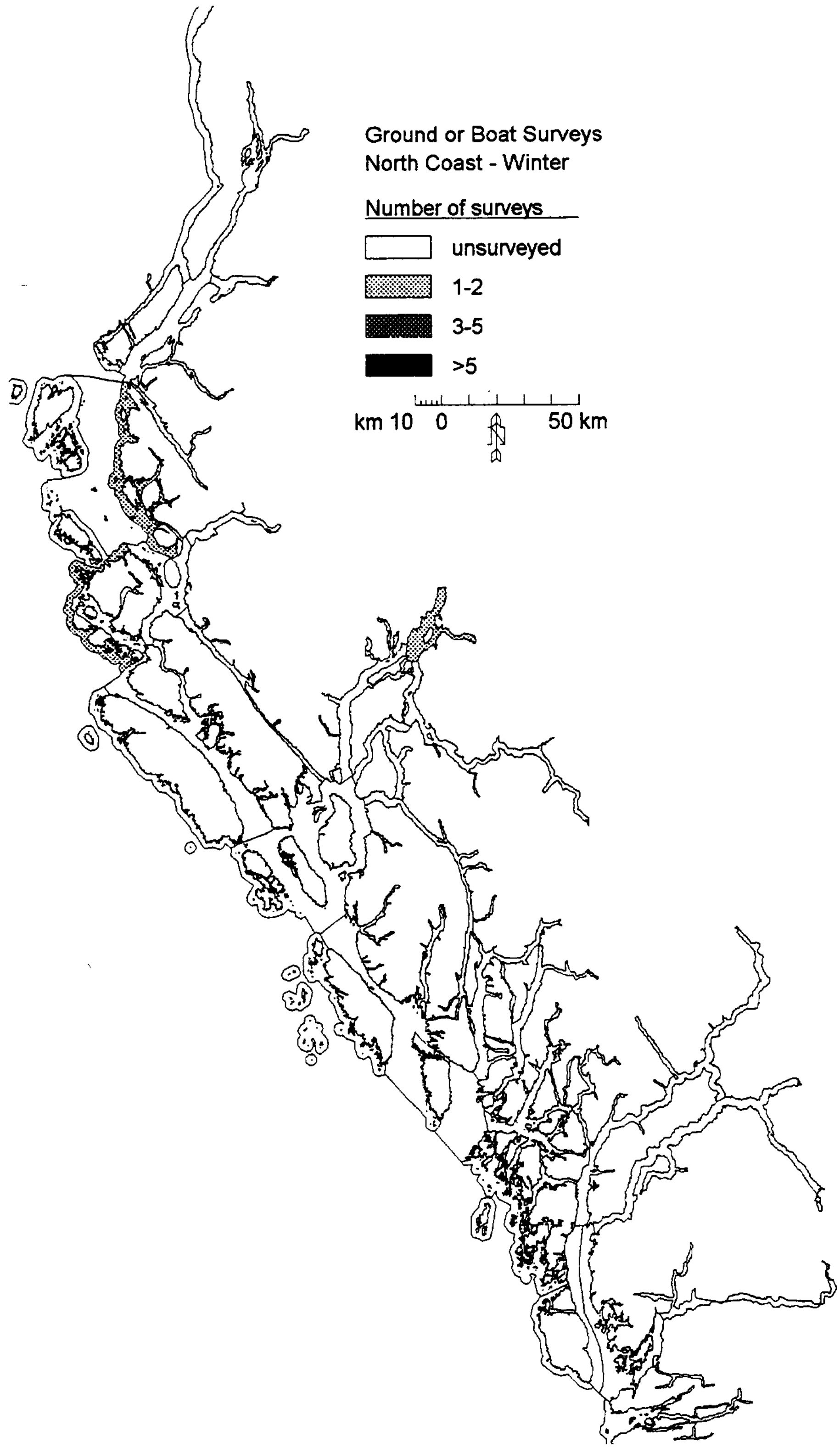


Figure 43. Total number of ground or boat surveys of the North coast during winter (1 December through 28 February).

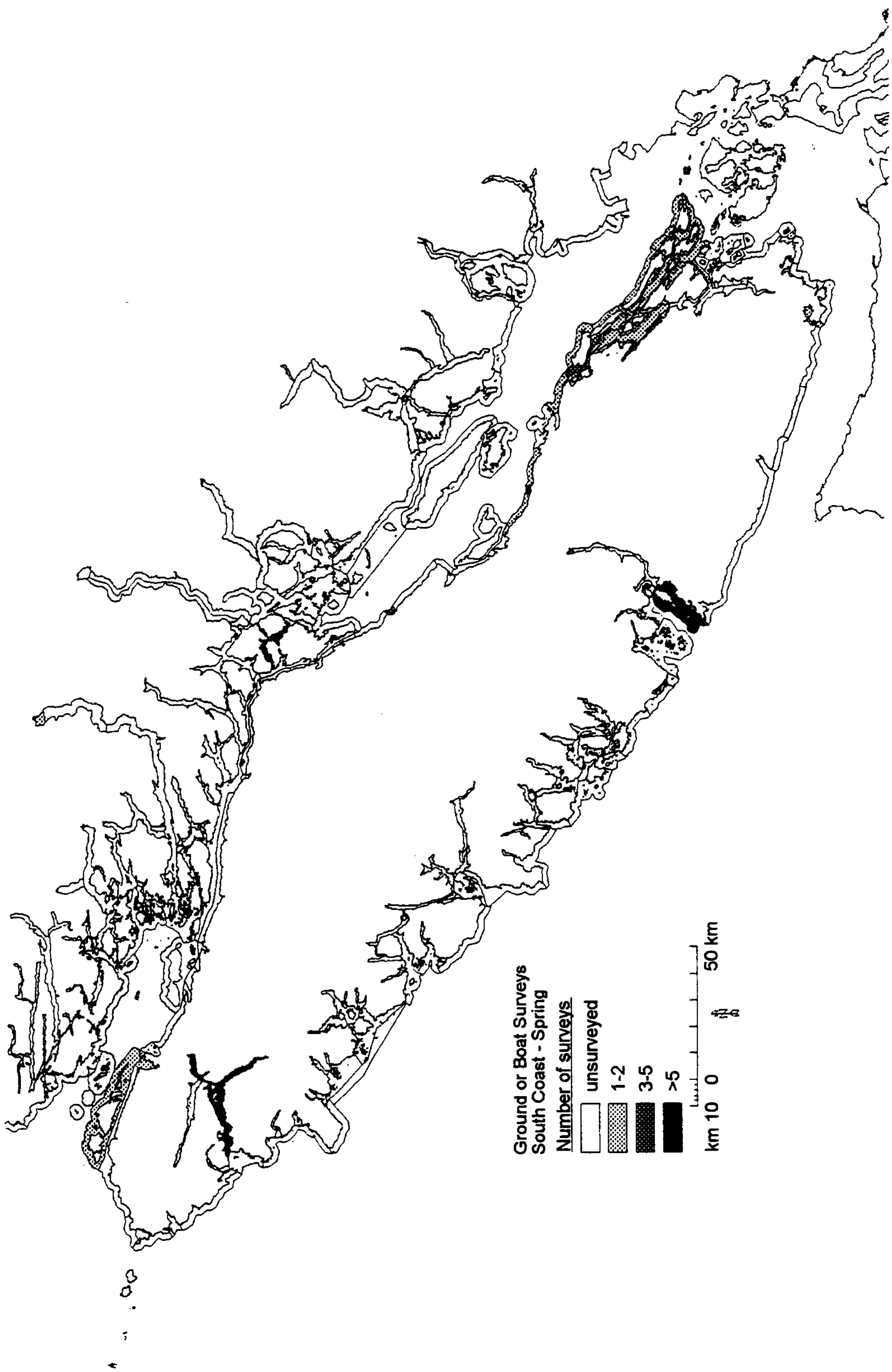
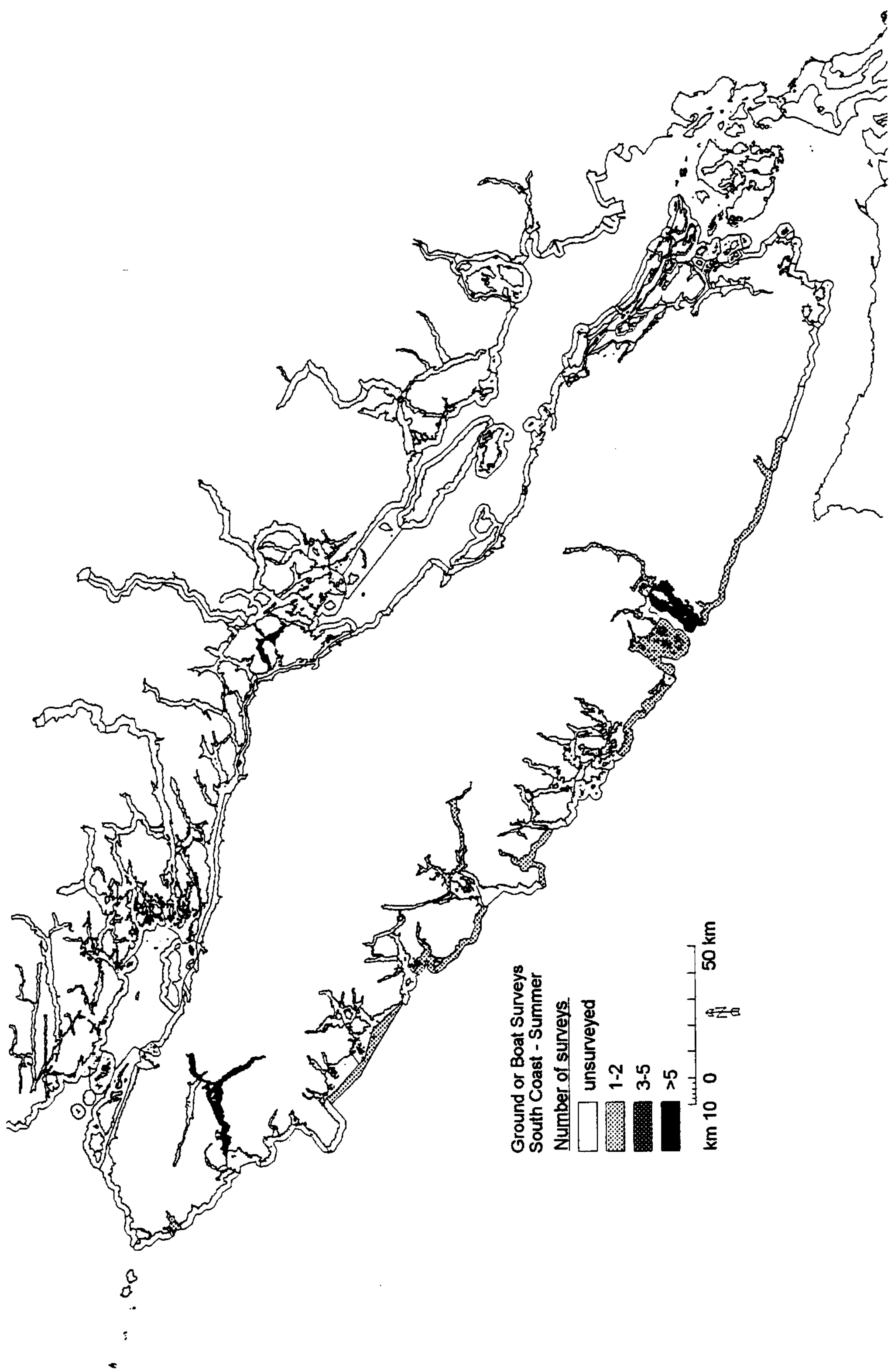


Figure 44. Total number of ground or boat surveys of the South coast during spring (1 March through 31 May).



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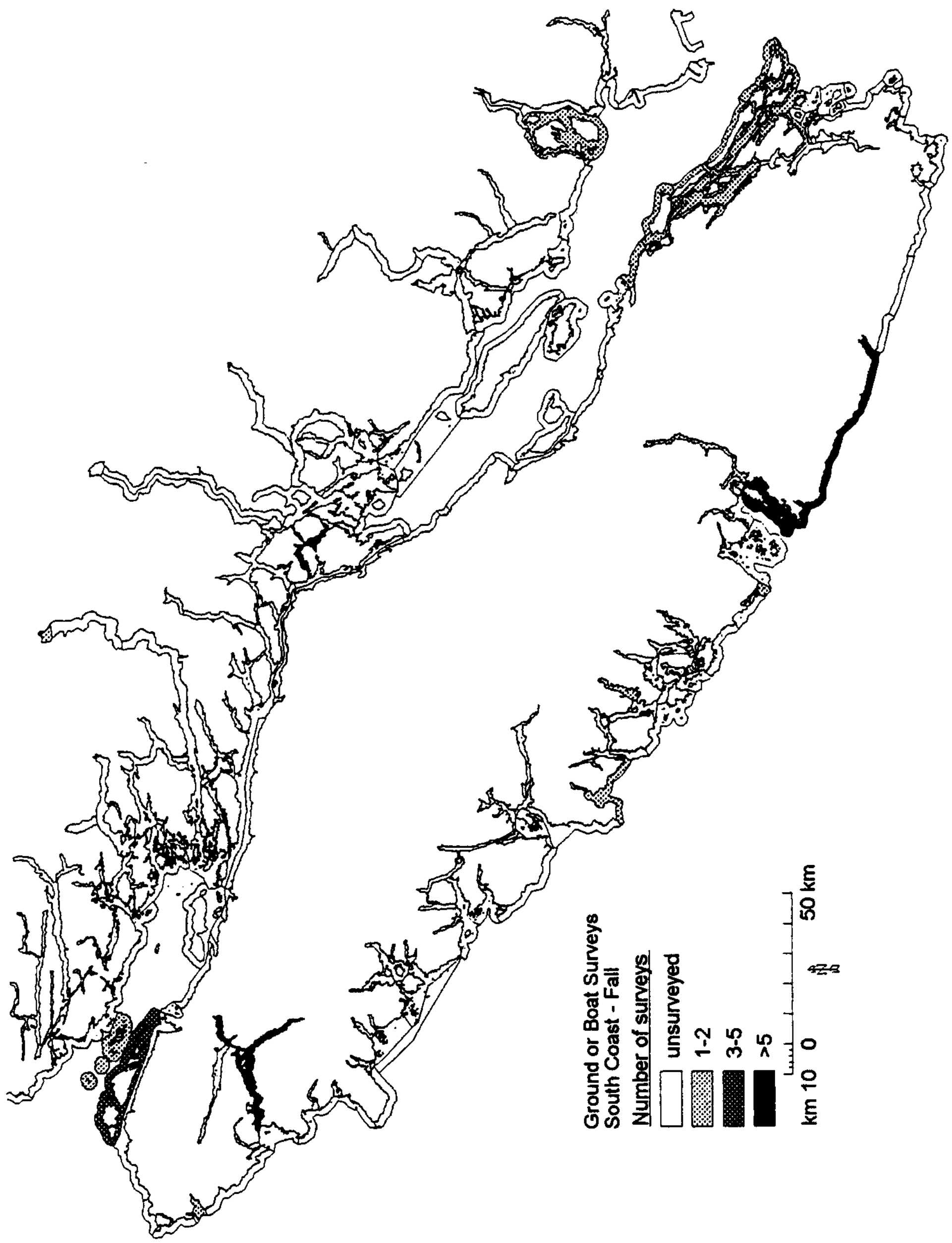

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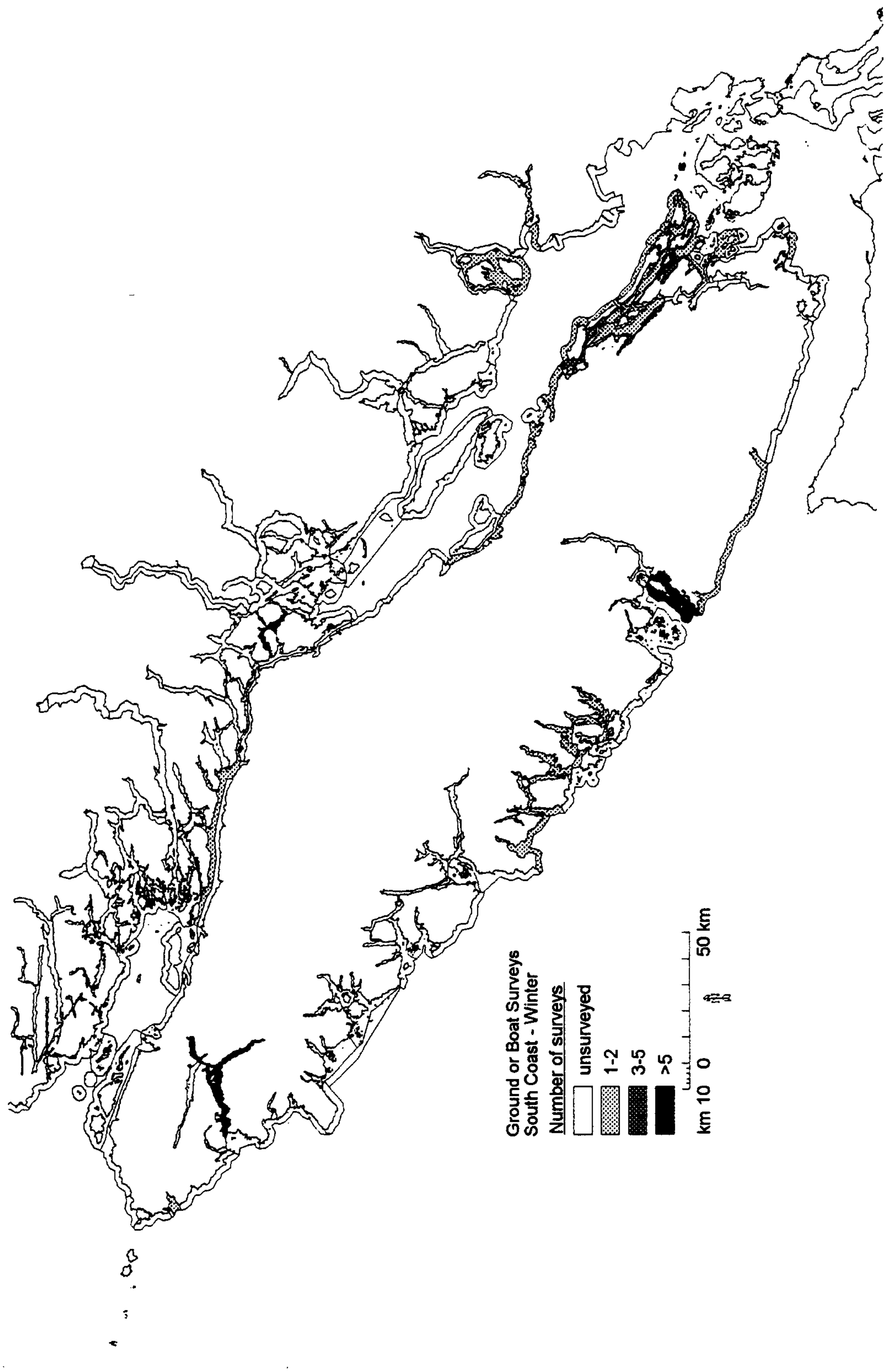

Figure 47. Total number of ground or boat surveys of the South coast during winter (1 December through 28 February).

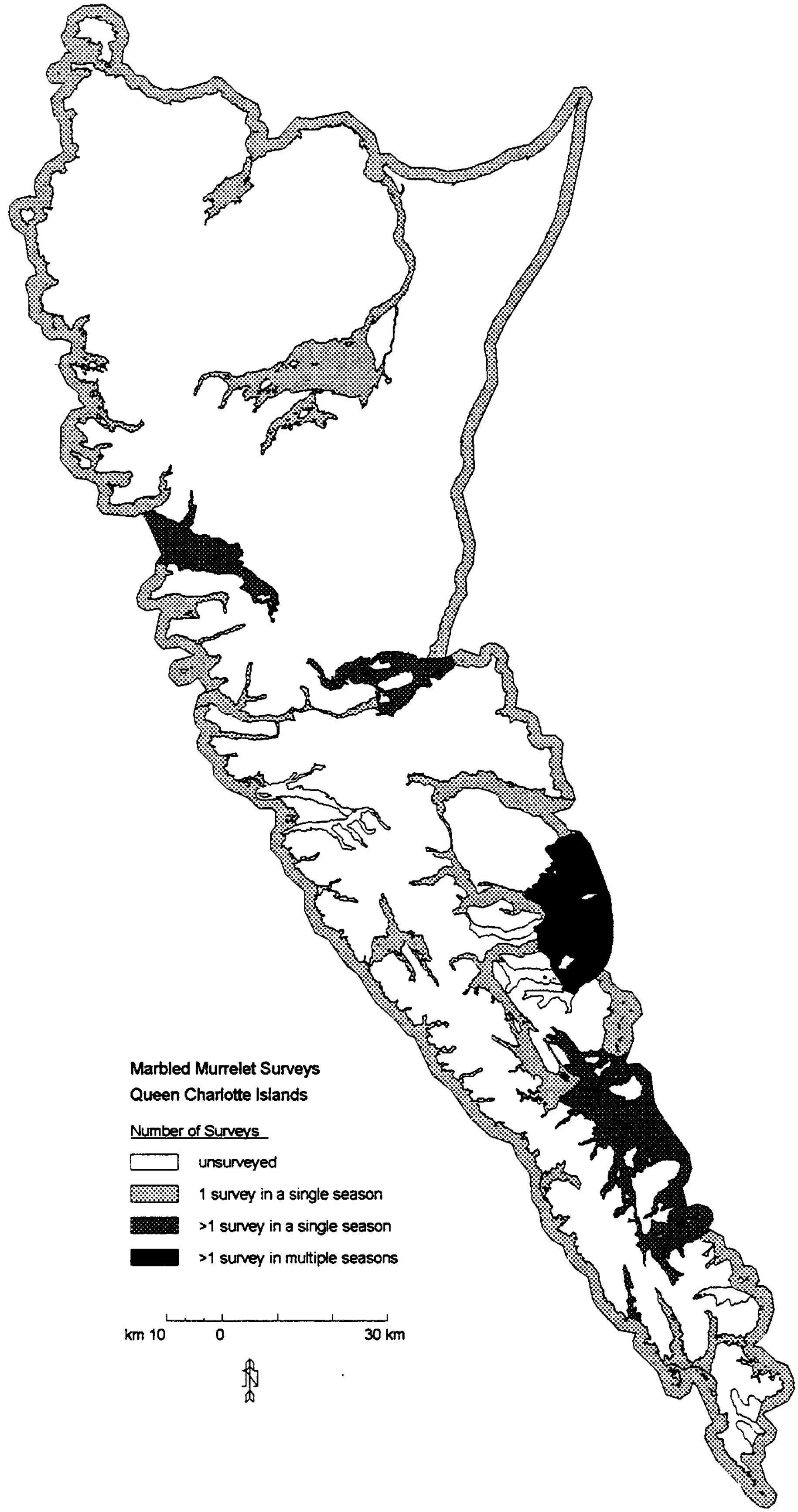

Figure 48. Total number of surveys of Marbled Murrelets in the Queen Charlotte Islands.

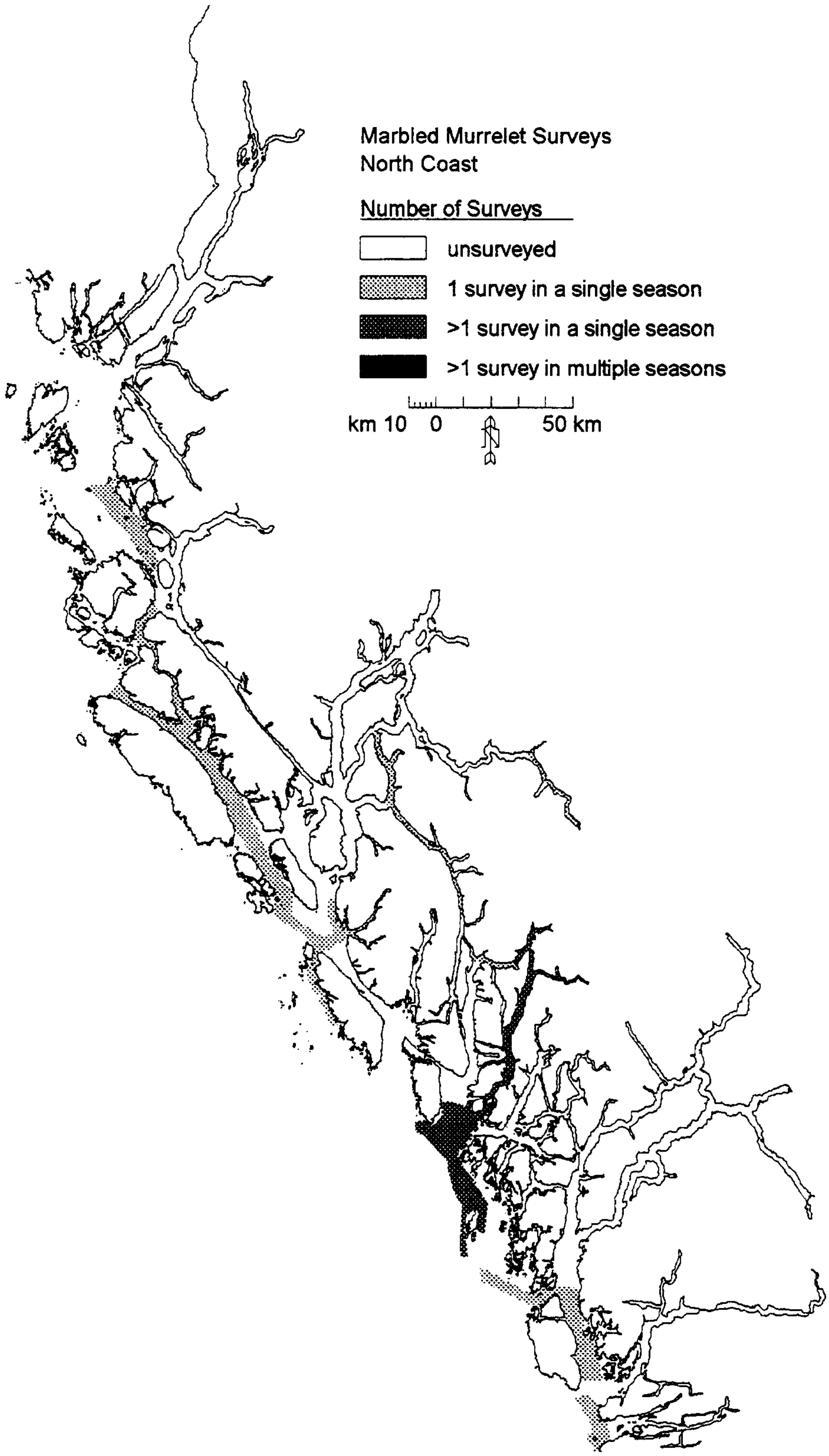

Figure 49. Total number of surveys of Marbled Murrelets along the North coast.

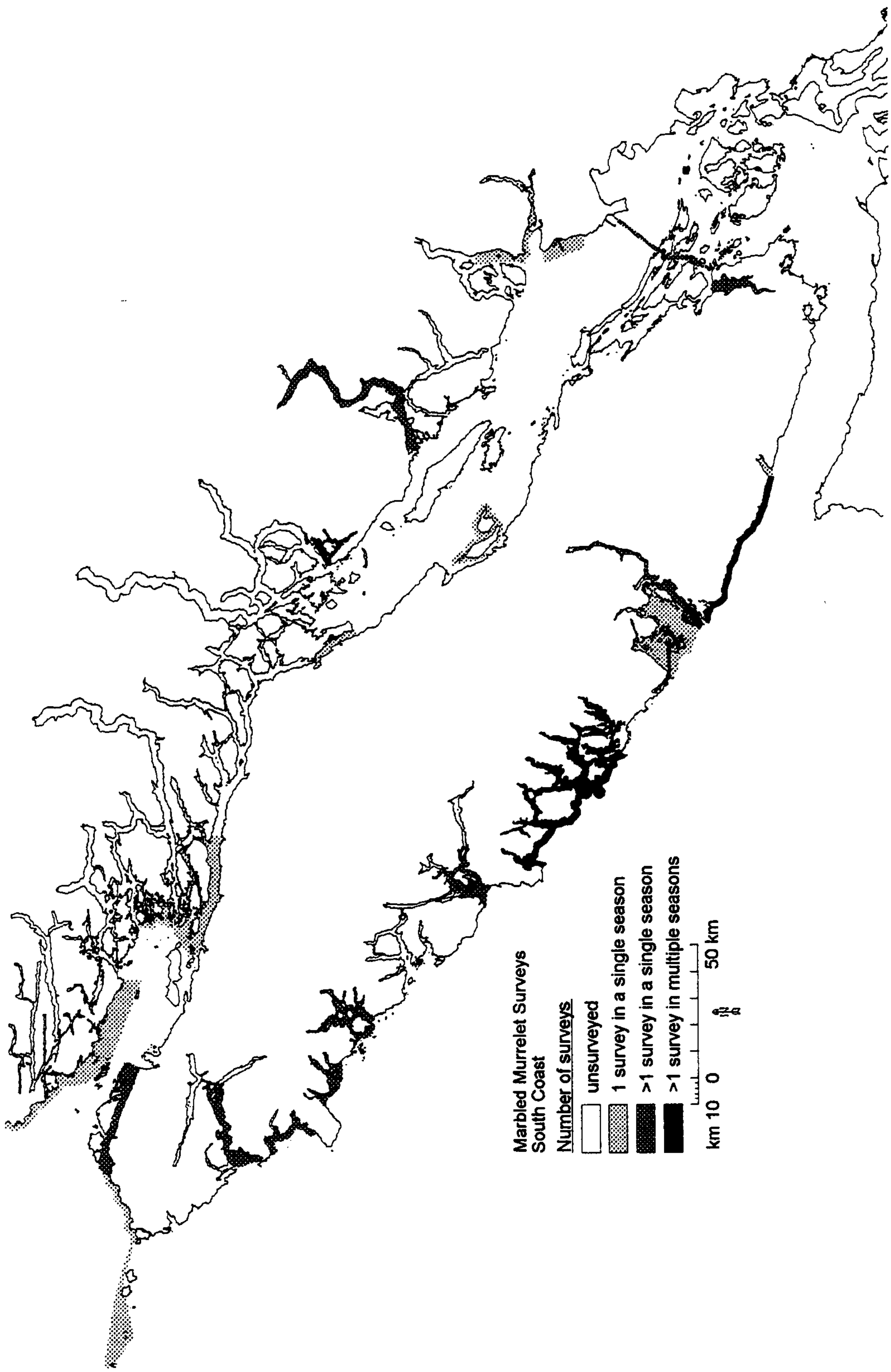

Figure 50. Total number of surveys of Marbled Murrelets along the South coast.

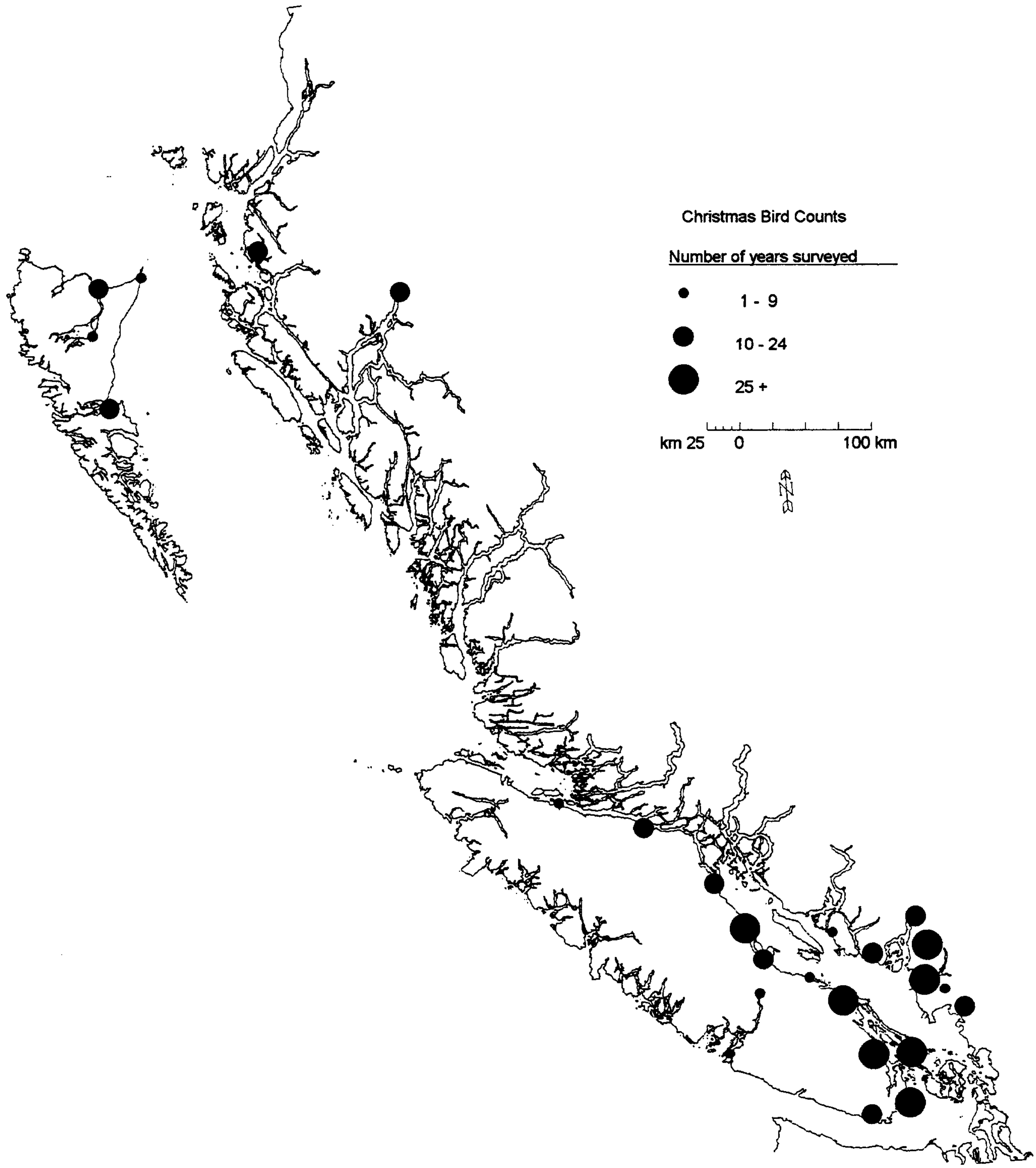

Figure 51. Locations of Christmas Bird counts with a marine area in the count circle.

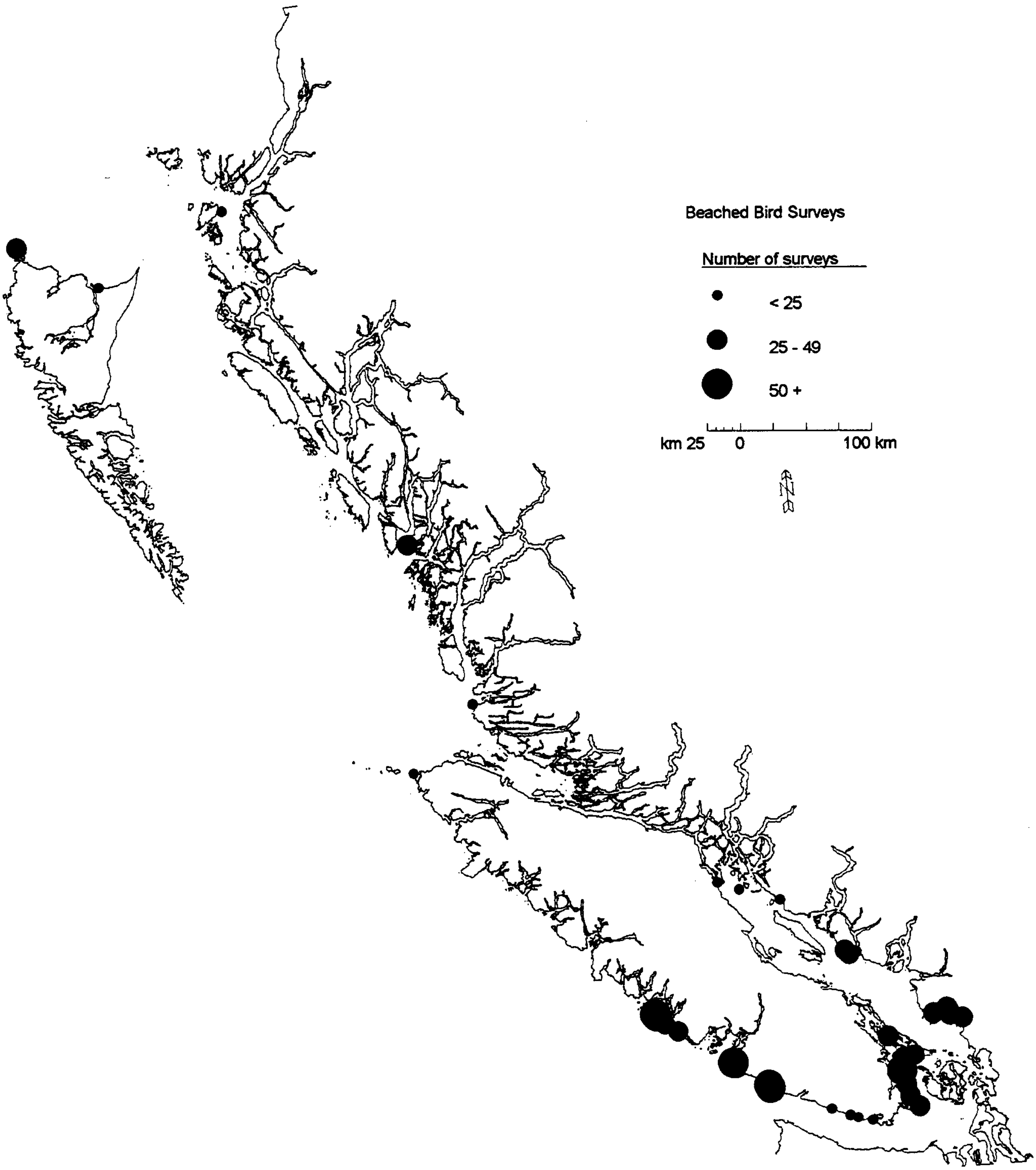

Figure 52. Locations of beached bird surveys in British Columbia.

Figure 53. Detailed locations of beached bird surveys along the South coast and southern Vancouver Island.