
Contents

Preface	v
About international polar year	vii
Contributors	xvii
1 Introduction to the limnology of high-latitude lake and river ecosystems	1
<i>Warwick F. Vincent, John E. Hobbie, and Johanna Laybourn-Parry</i>	
Outline	1
1.1 Introduction	1
1.2 History of polar limnology	4
1.3 Limnological diversity	5
1.4 Controlling variables for biological production	7
1.4.1 Water supply	7
1.4.2 Irradiance	8
1.4.3 Low temperature	8
1.4.4 Nutrient supply	9
1.4.5 Benthic communities	9
1.5 Food webs in polar lakes	10
1.6 Polar lakes and global change	12
1.6.1 Physical thresholds	12
1.6.2 Biogeochemical thresholds	13
1.6.3 Biological thresholds	13
1.7 Conclusions	14
Acknowledgements	14
References	14
Appendix 1.1	18
2 Origin and geomorphology of lakes in the polar regions	25
<i>Reinhard Pienitz, Peter T. Doran, and Scott F. Lamoureux</i>	
Outline	25
2.1 Introduction	25
2.2 Lake origins	26
2.2.1 Wetlands	26
2.2.2 Ice-dependent lakes	27
2.2.3 Postglacial lakes	28
2.2.4 Thermokarst lakes and ponds	30
2.2.5 Coastal uplift systems	31
2.2.6 Meteoritic impact crater lakes	32

2.2.7 Volcanic lakes	32
2.2.8 Karst systems	34
2.2.9 Tectonic lakes	34
2.2.10 Lakes of other origins	34
2.3 Geographical regions	35
2.3.1 The circumpolar Arctic	35
2.3.2 Coastal Antarctic lakes	35
2.3.3 Antarctic and Arctic subglacial lakes	36
2.4 Effects of landscape evolution and climate change on polar lakes	37
2.5 Conclusions	38
Acknowledgments	38
References	38
3 High-latitude paleolimnology	43
<i>Dominic A. Hodgson and John P. Smol</i>	
Outline	43
3.1 Introduction	43
3.1.1 Why study paleolimnology at high latitudes?	43
3.2 Lake geomorphology and ontogeny	45
3.2.1 Geomorphology	45
3.2.2 Lake ontogeny	47
3.2.3 Origin of the lake biota	48
3.3 Applied studies: tracking environmental change	49
3.3.1 Climate change	49
3.3.2 Regional vegetation change	51
3.3.3 Reconstructing sea-level change	51
3.3.4 Tracking past fish and wildlife populations	53
3.3.5 Changes in UV radiation	53
3.3.6 Atmospheric and terrestrial pollutants	55
3.4 Synthesis studies	55
3.5 Prospects	56
3.5.1 Paleolimnology of subglacial lakes	56
3.5.2 Paleolimnology of earlier interglacial periods	56
3.5.3 Paleolimnology of extreme environments	59
3.6 Conclusions	59
Acknowledgments	59
References	60
4 The physical limnology of high-latitude lakes	65
<i>Warwick F. Vincent, Sally MacIntyre, Robert H. Spigel, and Isabelle Laurion</i>	
Outline	65
4.1 Introduction	65
4.2 Snow and ice dynamics	66
4.3 Underwater radiation	67
4.4 Stratification regimes	70
4.5 Hydrological balance and flow pathways under the ice	72

4.6	Mixing and circulation beneath the ice	73
4.7	Mixing and flow paths during ice-off and open-water conditions: Alaskan lakes	74
4.8	Stratification and mixing beneath perennial ice: McMurdo Dry Valley lakes	77
4.9	Conclusions	79
	Acknowledgments	80
	References	80
5	High-latitude rivers and streams	83
	<i>Diane M. McKnight, Michael N. Gooseff, Warwick F. Vincent, and Bruce J. Peterson</i>	
	Outline	83
5.1	Introduction	83
5.2	Antarctic streams	84
5.3	Case study: effect of flow restoration on microbial mats and ecosystem processes	88
5.4	Arctic streams	89
5.5	Case study: long-term effect of nutrient enrichment	90
5.6	Large Arctic rivers	93
5.7	Arctic flood-plain lakes	95
5.8	Comparison of Arctic and Antarctic fluvial ecosystems	96
	5.8.1 Stream discharge	96
	5.8.2 Stream ecosystems	97
5.9	Conclusions	97
	Acknowledgments	98
	References	98
6	Ice-based freshwater ecosystems	103
	<i>Ian Hawes, Clive Howard-Williams, and Andrew G. Fountain</i>	
	Outline	103
6.1	Introduction	103
6.2	Ecosystems on and in glacial ice	104
	6.2.1 Types of glacier-based ecosystem	104
	6.2.2 Cryoconite holes	104
	6.2.2.1 Physical processes in cryoconite holes	105
	6.2.2.2 Ecosystem processes in cryoconite holes	105
	6.2.3 Supraglacial pools and streams	106
6.3	Ecosystems on floating ice shelves	107
	6.3.1 Types of ice-shelf ecosystem	107
	6.3.2 Physical processes in ice-shelf ponds	108
	6.3.3 Ecosystem processes in ice-shelf ponds	109
6.4	Lake-ice ecosystems	111
	6.4.1 Introduction	111
	6.4.2 Physical processes in lake ice	112
	6.4.3 Ecosystem processes in lake ice	112
6.5	The significance of ice-based systems	113
6.6	Conclusions	114
	Acknowledgments	115
	References	115

7 Antarctic subglacial water: origin, evolution, and ecology	119
<i>John C. Prisco, Slawek Tulaczyk, Michael Studinger, Mahlon C. Kennicutt II, Brent C. Christner, and Christine M. Foreman</i>	
Outline	119
7.1 Introduction	119
7.2 Antarctic subglacial lakes and rivers: distribution, origin, and hydrology	120
7.2.1 Distribution	120
7.2.2 Origin	121
7.2.3 Hydrology	123
7.3 Antarctic ice streams: regions of dynamic liquid water movement that influence ice-sheet dynamics	124
7.4 Subglacial environments as habitats for life and reservoirs of organic carbon	125
7.4.1 Lake Vostok	125
7.4.2 Microbial ecology of icy environments	128
7.4.3 Subglacial environments as reservoirs of organic carbon	130
Acknowledgments	132
References	132
8 Biogeochemical processes in high-latitude lakes and rivers	137
<i>W. Berry Lyons and Jacques C. Finlay</i>	
Outline	137
8.1 Introduction	137
8.2 Carbon cycle	139
8.2.1 Inorganic carbon dynamics	139
8.2.2 Dissolved organic carbon dynamics	140
8.3 Nutrient cycling	142
8.4 Geochemical linkages	147
8.5 Future responses to a warming climate	148
8.5.1 Hydrologic change	149
8.5.2 Direct effects of rising temperatures	149
8.5.3 Permafrost thaw	150
8.6 Conclusions	151
Acknowledgments	152
References	152
9 Phytoplankton and primary production	157
<i>Michael P. Lizotte</i>	
Outline	157
9.1 Introduction	157
9.2 Photosynthetic plankton	157
9.2.1 Photosynthetic bacteria	159
9.2.2 Eukaryotic phytoplankton	160
9.2.3 Ciliates	161
9.3 Biomass	162
9.4 Primary production	166
9.5 Environmental stressors	172

9.6 Conclusions	174
Acknowledgments	175
References	175
10 Benthic primary production in polar lakes and rivers	179
<i>Antonio Quesada, Eduardo Fernández-Valiente, Ian Hawes, and Clive Howard-Williams</i>	
Outline	179
10.1 Introduction	179
10.2 Types of benthic community	180
10.2.1 Microbial mats	180
10.2.1.1 Benthic communities in perennially ice-covered lakes	180
10.2.1.2 The benthic flora of McMurdo Dry Valley lakes	181
10.2.1.3 Mats in seasonally ice-covered freshwater ecosystems	184
10.2.2 Aquatic mosses	185
10.2.3 Benthic communities in running waters	187
10.3 Benthic primary production	188
10.4 Conclusions	192
Acknowledgments	193
References	193
11 Heterotrophic microbial processes in polar lakes	197
<i>John E. Hobbie and Johanna Laybourn-Parry</i>	
Outline	197
11.1 Introduction	197
11.2 Food webs	198
11.3 Bacteria	198
11.4 Photosynthetic plankton: autotrophs and mixotrophs	199
11.5 Heterotrophic microplankton: flagellates, ciliates, and rotifers	200
11.6 Viruses	201
11.7 Microbial heterotrophic processes and controls	202
11.8 Carbon and microbial heterotrophy	208
11.9 Conclusions	209
References	210
12 Microbial biodiversity and biogeography	213
<i>David A. Pearce and Pierre E. Galand</i>	
Outline	213
12.1 Microbial biodiversity	213
12.2 Bacteria	215
12.3 Cyanobacteria	218
12.4 Archaea	218
12.5 Eukaryotes	218
12.6 Viruses	221
12.7 Survival	221
12.8 Dispersal	222
12.9 Biogeography	223

12.10 Endemism	225
12.11 Conclusions	225
Acknowledgments	226
References	226
13 Zooplankton and zoobenthos in high-latitude water bodies	231
<i>Milla Rautio, Ian A.E. Bayly, John A.E. Gibson, and Marjut Nyman</i>	
Outline	231
13.1 Introduction	231
13.2 The origin of polar fauna	232
13.3 Species diversity between poles	234
13.4 Habitats and their key species	236
13.4.1 Lakes and ponds	236
13.4.2 Saline standing waters	238
13.4.3 Rivers and streams	239
13.5 Implications of climate change	242
13.5.1 Temperature	242
13.5.2 UV radiation	243
13.6 Conclusions	245
References	245
14 Fish in high-latitude Arctic lakes	249
<i>Michael Power, James D. Reist, and J. Brian Dempson</i>	
Outline	249
14.1 Introduction	249
14.2 Fish population structure in Arctic lakes	251
14.3 Adaptations for high-latitude life	252
14.4 Arctic char, <i>Salvelinus alpinus</i>	253
14.5 Lake char, <i>Salvelinus namaycush</i>	261
14.6 Atlantic salmon, <i>Salmo salar</i>	262
14.7 The coregonines	263
14.8 Other species	264
14.9 Conclusions	264
Acknowledgments	265
References	265
15 Food-web relationships and community structures in high-latitude lakes	269
<i>Kirsten S. Christoffersen, Erik Jeppesen, Daryl L. Moorhead, and Lars J. Tranvik</i>	
Outline	269
15.1 Introduction	269
15.1.1 Why study high-latitude lake food webs?	269
15.1.2 Commonalities and differences between Arctic and Antarctic lakes	270
15.2 Food webs	271
15.2.1 Structural features	271
15.2.2 Continental Antarctic lakes	272
15.2.3 Maritime Antarctic and Sub-Antarctic lakes	272
15.2.4 Arctic lakes	275

15.2.5 Benthic and pelagic production and the role in the food web	276
15.3 Climate as a stressor	279
15.4 Case studies	281
15.4.1 Energy flow in Ace Lake and Lake Fryxell, Antarctica	281
15.4.2 Reverse spatial subsidies model for Antarctic landscapes	282
15.4.3 Nine years' monitoring of two small lakes in northeast Greenland	283
15.5 Conclusions	285
Acknowledgments	285
References	285
16 Direct human impacts on high-latitude lakes and rivers	291
<i>Martin J. Riddle and Derek C.G. Muir</i>	
Outline	291
16.1 Introduction	291
16.2 Physical impacts	293
16.3 Chemical impacts	294
16.3.1 Chemical contamination in Antarctica	294
16.3.2 Acidifying substances and nutrients	295
16.3.3 Heavy metals	296
16.3.4 Radionuclides	298
16.3.5 Petroleum hydrocarbons	299
16.3.6 Combustion-related hydrocarbons and particles	299
16.3.7 Persistent organic pollutants	299
16.4 Conclusions	301
Acknowledgments	301
References	302
17 Future directions in polar limnology	307
<i>Johanna Laybourn-Parry and Warwick F. Vincent</i>	
Outline	307
17.1 Introduction	307
17.2 Wireless networks	308
17.3 Underwater sensors and imaging systems	309
17.4 Surface imagery	310
17.5 Environmental genomics	311
17.6 Extremophiles and bioprospecting	312
17.7 Model development	313
17.8 Conclusions	314
References	314
Glossary	317
Index	321