

Pros and cons of using seabirds as ecological indicators

J. M. Durant^{1,*}, D. Ø. Hjermmann¹, M. Frederiksen², J. B. Charrassin³, Y. Le Maho⁴, P. S. Sabarros¹,
R. J. M. Crawford^{5,6}, N. Chr. Stenseth^{1,7}

¹Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biology, University of Oslo, PO Box 1066 Blindern, 0316 Oslo, Norway

²National Environmental Research Institute, Department of Arctic Environment, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

³Laboratoire d'Océanographie et du Climat: Expérimentation et Approches Numériques, Département Milieux et Peuplements Aquatiques, Muséum National d'Histoire Naturelle, 43 rue Cuvier, 75231 Paris Cedex 05, France

⁴Institut Pluridisciplinaire Hubert Curien, Département Ecologie, Physiologie et Ethologie, UMR 7178 CNRS-ULP, 23 rue Becquerel, 67087 Strasbourg Cedex 2, France

⁵Marine and Coastal Management, Department of Environmental Affairs and Tourism, Private Bag X2, Rogge Bay 8012, South Africa

⁶Animal Demography Unit, Department of Zoology, University of Cape Town, Rondebosch 7701, South Africa

⁷Institute of Marine Research, Flødevigen Marine Research Station, 4817 His, Norway

Email: j.m.durant@bio.uio.no

Climate Research 39:115–129 (2009)

Table S1. Relationship between environmental and biological variables as found in the seabird literature (a selection of seabird literature, 127 articles). Environmental variables include: weather = weather packages (ENSO, NAO...); oceanography = fronts, eddies, currents, etc.; SST = sea surface temperature; prey = prey abundance, location, etc.; integrate index = index issue from statistical calculation (e.g. principal component). Biological variables include: behaviour = behaviour (outside foraging), phenology, etc.; breeding success = breeding success sensus largo that encompasses the fledging success (no. chicks that fledge per no. chicks in nest), survival through the first year, etc.; condition = body condition (mass, reserves, etc.); diet = diet, food deliveries etc; foraging = foraging activity, transit, exploration, diving, etc.; growth = chick growth (mass, linear, development, etc.); population = population parameters, etc.; survival = adult survival. Last two rows of the table: references from telemetry (GPS, satellite, loggers...) studies and reviews

Environmental variable	Biological variable	Source
Fishing	Breeding success	46
	Diet	116
	Survival	46, 112
Ice extent	Behaviour	54
	Breeding success	2, 54, 75
	Growth	53
	Population	34, 69, 76
	Survival	75
Integrate index	Population	38, 101
Oceanography	Behaviour	110, 123
	Breeding success	92
	Condition	12
	Diet	91, 123
	Distribution	70
	Foraging	5, 52, 92, 98, 110, 114, 123, 122, 121
	Population	3, 92
	Survival	7, 77
Prey	Behaviour	63, 82, 86, 94, 100, 109, 123
	Breeding success	9, 30, 33, 41, 43, 47, 48, 55, 57, 78, 80, 83, 84, 86, 87, 90, 94, 96, 108
	Condition	86, 96
	Diet	8, 20, 28, 37, 55, 58, 65, 84, 88, 123
	Distribution	10
	Foraging	25, 27, 58, 85, 86, 123
	Growth	82, 94, 96, 97
	Population	29, 31, 32, 33, 47, 82
	Survival	100

Table S1 (continued)

Environmental variable	Biological variable	Source
SST	Behaviour	22, 26, 45, 119
	Breeding success	2, 13, 39, 41, 42, 45, 46, 48, 56, 61, 72, 75, 79, 81, 90, 113
	Condition	61
	Diet	39, 89
	Foraging	59, 115
	Growth	56
	Population	73, 113, 120
	Survival	6, 46, 61, 64, 75, 81
Weather	Behaviour	45, 99
	Breeding success	1, 4, 40, 45, 61, 62, 66, 74, 81, 105, 106, 113
	Condition	61, 95
	Growth	11, 62, 66, 125
	Population	18, 21, 113
	Survival	49, 60, 61, 81, 95, 106
Telemetry	Behaviour	22, 26, 86, 109, 110, 119, 123, 126
	Breeding success	86
	Condition	86
	Diet	117, 123
	Foraging	5, 15, 23, 25, 36, 44, 59, 86, 102, 103, 110, 111, 114, 115, 117, 121, 122, 123, 124
	Other	16, 24, 104, 107, 127
Review		14, 16, 17, 19, 35, 50, 51, 67, 68, 71, 93, 118

LITERATURE CITED

- Aebischer NJ, Coulson JC, Colebrook JM (1990) Parallel long-term trends across 4 marine trophic levels and weather. *Nature* 347:753–755
- Ainley DG, Sydeman WJ, Norton J (1995) Upper trophic level predators indicate interannual negative and positive anomalies in the California Current food-web. *Mar Ecol Prog Ser* 118:69–79
- Ainley DG, Sydeman WJ, Norton J (1996) Apex predators indicate interannual negative and positive anomalies in the California Current food web. *Mar Ecol Prog Ser* 137: 1–10
- Ainley DG, Clarke ED, Arrigo K, Fraser WR, Kato A, Barton KJ, Wilson PR (2005) Decadal-scale changes in the climate and biota of the Pacific sector of the Southern Ocean, 1950s to the 1990s. *Antarct Sci* 17:171–182
- Ancel A, Kooyman GL, Ponganis PJ, Gendner JP and others (1992) Foraging behavior of emperor penguins as a resource detector in winter and summer. *Nature* 360: 336–339
- Barbraud C, Weimerskirch H (2003) Climate and density shape population dynamics of a marine top predator. *Proc R Soc Lond B Biol Sci* 270:2111–2116
- Barbraud C, Weimerskirch H (2005) Environmental conditions and breeding experience affect costs of reproduction in blue petrels. *Ecology* 86:682–692
- Barrett RT (2002) Atlantic puffin *Fratercula arctica* and common guillemot *Uria aalge* chick diet and growth as indicators of fish stocks in the Barents Sea. *Mar Ecol Prog Ser* 230:275–287
- Barrett RT (2007) Food web interactions in the southwestern Barents Sea: black-legged kittiwakes *Rissa tridactyla* respond negatively to an increase in herring *Clupea harengus*. *Mar Ecol Prog Ser* 349:269–276
- Barrett RT, Chapdelaine G, Anker-Nilssen T, Mosbech A, Montevecchi WA, Reid JB, Veit RR (2006) Seabird numbers and prey consumption in the North Atlantic. *ICES J Mar Sci* 63:1145–1158
- Bertram DF, Mackas DL, McKinnell SM (2001) The seasonal cycle revisited: interannual variation and ecosystem consequences. *Prog Oceanogr* 49:283–307
- Biuw M, Boehme L, Guinet C, Hindell M and others (2007) Variations in behavior and condition of a Southern Ocean top predator in relation to *in situ* oceanographic conditions. *Proc Natl Acad Sci USA* 104:13705–13710
- Boersma PD (1978) Breeding patterns of Galapagos penguins as an indicator of oceanographic conditions. *Science* 200:1481–1483
- Bost CA, Le Maho Y (1993) Seabirds as bio-indicators of changing marine ecosystems—new perspectives. *Acta Oecol Int J Ecol* 14:463–470
- Bost CA, Handrich Y, Butler PJ, Fahlman A, Halsey LG, Woakes AJ, Ropert-Coudert Y (2007) Changes in dive profiles as an indicator of feeding success in king and Adélie penguins. *Deep Sea Res II* 54:248–255
- Bost CA, Jaeger A, Huin W, Koubbi P, Halsey LG, Handrich Y (2008) Monitoring prey availability via data loggers deployed on seabirds: advances and present limitations. In: Tsukamoto K, Kawamura T, Takeuchi T, Beard TDJ, Kaiser MJ (eds) *Fisheries for global welfare and environment, The 5th World Fisheries Congress, Yokohama, Japan*, p 121–137
- Boyd IL, Wanless S, Camphuysen CJ (2006) Top predators in marine ecosystems: their role in monitoring and management, Vol 12. Cambridge University Press, Cambridge
- Bunce A, Norman FI, Brothers N, Gales R (2002) Long-term trends in the Australasian gannet (*Morus serrator*) population in Australia: the effect of climate change and commercial fisheries. *Mar Biol* 141:263–269
- Cairns DK (1987) Seabirds as indicators of marine food supplies. *Biol Oceanogr* 5:261–271
- Cairns DK (1992) Bridging the gap between ornithology and fisheries science: use of seabird data in stock assess-

- ment models. *Condor* 94:811–824
21. Causey D, Corbett DG, Lefevre C, West DL, Savinetsky AB, Kiseleva NK, Khassanov BF (2005) The palaeoenvironment of humans and marine birds of the Aleutian Islands: three millennia of change. *Fish Oceanogr* 14: 259–276
 22. Charrassin JB, Bost CA (2001) Utilisation of the oceanic habitat by king penguins over the annual cycle. *Mar Ecol Prog Ser* 221:285–297
 23. Charrassin JB, Kato A, Handrich Y, Sato K and others (2001) Feeding behaviour of free-ranging penguins determined by oesophageal temperature. *Proc R Soc Lond B Biol Sci* 268:151–157
 24. Charrassin JB, Le Maho Y, Bost CA (2002a) Seasonal changes in the diving parameters of king penguins (*Aptenodytes patagonicus*). *Mar Biol* 141:581–589
 25. Charrassin JB, Park YH, Le Maho Y, Bost CA (2002b) Penguins as oceanographers unravel hidden mechanisms of marine productivity. *Ecol Lett* 5:317–319
 26. Charrassin JB, Park YH, Le Maho Y, Bost CA (2004) Fine resolution 3D temperature fields off Kerguelen from instrumented penguins. *Deep-Sea Res I* 51:2091–2103
 27. Chérel Y, Weimerskirch H (1995) Seabirds as indicators of marine resources: black-browed albatrosses feeding on ommastrephid squids in Kerguelen waters. *Mar Ecol Prog Ser* 129:295–300
 28. Chérel Y, Phillips RA, Hobson KA, McGill R (2006) Stable isotope evidence of diverse species-specific and individual wintering strategies in seabirds. *Biol Lett* 2:301–303
 29. Crawford RJM (2007) Food, fishing and seabirds in the Benguela upwelling system. *J Ornithol* 148:253–260
 30. Crawford RJM, Barham PJ, Underhill LG, Shannon LJ and others (2006) The influence of food availability on breeding success of African penguins *Spheniscus demersus* at Robben Island, South Africa. *Biol Conserv* 132:119–125
 31. Crawford RJM, Cockcroft AC, Dyer BM, Upfold L (2008a) Divergent trends in bank cormorants *Phalacrocorax neglectus* breeding in South Africa's Western Cape consistent with a distributional shift of rock lobsters *Jasus lalandii*. *Afr J Mar Sci* 30:161–166
 32. Crawford RJM, Sabarros PS, Fairweather T, Underhill LG, Wolfaardt AC (2008b) Implications for seabirds off South Africa of a long-term change in the distribution of sardine. *Afr J Mar Sci* 30:177–184
 33. Crawford RJM, Underhill LG, Coetzee JC, Fairweather T, Shannon LJ, Wolfaardt AC (2008c) Influences of the abundance and distribution of prey on African penguins *Spheniscus demersus* off western South Africa. *Afr J Mar Sci* 30:167–175
 34. Croxall JP, Trathan PN, Murphy EJ (2002) Environmental change and Antarctic seabird populations. *Science* 297: 1510–1514
 35. Dale VH, Beyeler SC (2001) Challenges in the development and use of ecological indicators. *Ecol Indic* 1:3–10
 36. Daunt F, Benvenuti S, Harris MP, Dall'Antonia L, Elston DA, Wanless S (2002) Foraging strategies of the black-legged kittiwake *Rissa tridactyla* at a North Sea colony: evidence for a maximum foraging range. *Mar Ecol Prog Ser* 245:239–247
 37. Davoren GK, Montevecchi WA (2003) Signals from seabirds indicate changing biology of capelin stocks. *Mar Ecol Prog Ser* 258:253–261
 38. Dearborn DC, Anders AD, Flint EN (2001) Trends in reproductive success of Hawaiian seabirds: Is guild membership a good criterion for choosing indicator species? *Biol Conserv* 101:97–103
 39. Diamond AW, Devlin CM (2003) Seabirds as indicators of changes in marine ecosystems: ecological monitoring on Machias Seal Island. *Environ Monit Assess* 88:153–175
 40. Durant JM, Anker-Nilssen T, Stenseth NC (2003) Trophic interactions under climate fluctuations: the Atlantic puffin as an example. *Proc R Soc Lond B Biol Sci* 270:1461–1466
 41. Durant JM, Anker-Nilssen T, Hjermmann DØ, Stenseth NC (2004) Regime shifts in the breeding of an Atlantic puffin population. *Ecol Lett* 7:388–394
 42. Durant JM, Hjermmann DØ, Anker-Nilssen T, Beaugrand G, Mysterud A, Pettorelli N, Stenseth NC (2005) Timing and abundance as key mechanisms affecting trophic interactions in variable environments. *Ecol Lett* 8:952–958
 43. Durant JM, Anker-Nilssen T, Stenseth NC (2006) Ocean climate prior to breeding affects the duration of the nestling period in the Atlantic puffin. *Biol Lett* 2:628–631
 44. Fauchald P, Tveraa T (2003) Using first-passage time in the analysis of area-restricted search and habitat selection. *Ecology* 84:282–288
 45. Frederiksen M, Harris MP, Daunt F, Rothery P, Wanless S (2004a) Scale-dependent climate signals drive breeding phenology of three seabird species. *Glob Change Biol* 10:1214–1221
 46. Frederiksen M, Wanless S, Harris MP, Rothery P, Wilson LJ (2004b) The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. *J Appl Ecol* 41:1129–1139
 47. Frederiksen M, Wright PJ, Harris MP, Mavor RA, Heubeck M, Wanless S (2005) Regional patterns of kittiwake *Rissa tridactyla* breeding success are related to variability in sandeel recruitment. *Mar Ecol Prog Ser* 300: 201–211
 48. Frederiksen M, Edwards M, Mavor RA, Wanless S (2007) Regional and annual variation in black-legged kittiwake breeding productivity is related to sea surface temperature. *Mar Ecol Prog Ser* 350:137–143
 49. Frederiksen M, Daunt F, Harris MP, Wanless S (2008) The demographic impact of extreme events: stochastic weather drives survival and population dynamics in a long-lived seabird. *J Anim Ecol* 77:1020–1029
 50. Furness RW, Camphuysen K (1997) Seabirds as monitors of the marine environment. *ICES J Mar Sci* 54:726–737
 51. Furness RW, Greenwood JJD (1993) Birds as monitors of environmental change. Chapman & Hall, London
 52. Garthe S, Montevecchi WA, Chapdelaine G, Rail JF, Hedd A (2007) Contrasting foraging tactics by northern gannets (*Sula bassana*) breeding in different oceanographic domains with different prey fields. *Mar Biol* 151:687–694
 53. Gaston AJ, Gilchrist HG, Hipfner JM (2005a) Climate change, ice conditions and reproduction in an Arctic nesting marine bird: Brunnich's guillemot (*Uria lomvia* L.). *J Anim Ecol* 74:832–841
 54. Gaston AJ, Gilchrist HG, Mallory ML (2005b) Variation in ice conditions has strong effects on the breeding of marine birds at Prince Leopold Island, Nunavut. *Ecography* 28: 331–344
 55. Gill VA, Hatch SA, Lanctot RB (2002) Sensitivity of breeding parameters to food supply in black-legged kittiwakes *Rissa tridactyla*. *Ibis* 144:268–283
 56. Gjerdrum C, Vallee AMJ, St Clair CC, Bertram DF, Ryder JL, Blackburn GS (2003) Tufted puffin reproduction reveals ocean climate variability. *Proc Natl Acad Sci USA* 100:9377–9382
 57. Gray CM, Phillips RA, Hamer KC (2003) Non-random nestling mortality in northern fulmars: implications for monitoring marine environments. *J Zool (Lond)* 259: 109–113
 58. Grémillet D, Kuntz G, Delbart F, Mellet M and others

- (2004) Linking the foraging performance of a marine predator to local prey abundance. *Funct Ecol* 18:793–801
59. Grémillet D, Lewis S, Drapeau L, van Der Linden CD and others (2008) Spatial match-mismatch in the Benguela upwelling zone: Should we expect chlorophyll and sea-surface temperature to predict marine predator distributions? *J Appl Ecol* 45:610–621
 60. Grosbois V, Thompson PM (2005) North Atlantic climate variation influences survival in adult fulmars. *Oikos* 109: 273–290
 61. Guinet C, Chastel O, Koudil M, Durbec JP, Jouventin P (1998) Effects of warm sea-surface temperature anomalies on the blue petrel at the Kerguelen Islands. *Proc R Soc Lond B Biol Sci* 265:1001–1006
 62. Harding AMA, Piatt JF, Hamer KC (2003) Breeding ecology of horned puffins (*Fratercula comiculata*) in Alaska: annual variation and effects of El Niño. *Can J Zool* 81: 1004–1013
 63. Harding AMA, Piatt JF, Schmutz JA (2007) Seabird behavior as an indicator of food supplies: sensitivity across the breeding season. *Mar Ecol Prog Ser* 352:269–274
 64. Harris MP, Anker-Nilssen T, McCleery RH, Erikstad KE, Shaw DN, Grosbois V (2005) Effect of wintering area and climate on the survival of adult Atlantic puffins *Fratercula arctica* in the eastern Atlantic. *Mar Ecol Prog Ser* 297: 283–296
 65. Hatch SA, Sanger GA (1992) Puffins as samplers of juvenile pollock and other forage fish in the Gulf of Alaska. *Mar Ecol Prog Ser* 80:1–14
 66. Hedd A, Ryder JL, Cowen LL, Bertram DF (2002) Inter-annual variation in the diet, provisioning and growth of Cassin's auklet at Triangle Island, British Columbia: responses to variation in ocean climate. *Mar Ecol Prog Ser* 229:221–232
 67. Hilty J, Merenlender A (2000) Faunal indicator taxa selection for monitoring ecosystem health. *Biol Conserv* 92: 185–197
 68. Hollamby S, Afema-Azikuru J, Waigo S, Cameron K, Gandolf AR, Norris A, Sikarskie JG (2006) Suggested guidelines for use of avian species as biomonitors. *Environ Monit Assess* 118:13–20
 69. Hunt GL Jr, Stabeno P, Walters G, Sinclair E, Brodeur RD, Napp JM, Bond NA (2002) Climate change and control of the southeastern Bering Sea pelagic ecosystem. *Deep-Sea Res II* 49:5821–5853
 70. Hyrenbach KD, Veit RR, Weimerskirch H, Hunt GL Jr (2006) Seabird associations with mesoscale eddies: the subtropical Indian Ocean. *Mar Ecol Prog Ser* 324:271–279
 71. ICES (2003) Seabirds as monitors of the marine environment. In: Tasker ML, Furness RW (eds) ICES Cooperative Research Report No. 258
 72. Inchausti P, Guinet C, Koudil M, Durbec JP and others (2003) Inter-annual variability in the breeding performance of seabirds in relation to oceanographic anomalies that affect the Crozet and the Kerguelen sectors of the Southern Ocean. *J Avian Biol* 34:170–176
 73. Irons DB, Anker-Nilssen T, Gaston AJ, Byrd GV and others (2008) Fluctuations in circumpolar seabird populations linked to climate oscillations. *Glob Change Biol* 14: 1455–1463
 74. Jenouvrier S, Barbraud C, Weimerskirch H (2003) Effects of climate variability on the temporal population dynamics of southern fulmars. *J Anim Ecol* 72:576–587
 75. Jenouvrier S, Barbraud C, Cazelles B, Weimerskirch H (2005a) Modelling population dynamics of seabirds: importance of the effects of climate fluctuations on breeding proportions. *Oikos* 108:511–522
 76. Jenouvrier S, Weimerskirch H, Barbraud C, Park YH, Cazelles B (2005b) Evidence of a shift in the cyclicity of Antarctic seabird dynamics linked to climate. *Proc R Soc Lond B Biol Sci* 272:887–895
 77. Jones IL, Hunter FM, Robertson GJ (2002) Annual adult survival of Least Auklets (Aves, Alcidae) varies with large-scale climatic conditions of the North Pacific Ocean. *Oecologia* 133:38–44
 78. Kitaysky A, Golubova E (2000) Climate change causes contrasting trends in reproductive performance of planktivorous and piscivorous alcids. *J Anim Ecol* 69:248–262
 79. Kitaysky AS, Hunt GL Jr, Flint EN, Rubega MA, Decker MB (2000) Resource allocation in breeding seabirds: responses to fluctuations in their food supply. *Mar Ecol Prog Ser* 206:283–296
 80. Lanctot RB, Hatch SA, Gill VA, Eens M (2003) Are corticosterone levels a good indicator of food availability and reproductive performance in a kittiwake colony? *Horm Behav* 43:489–502
 81. Le Bohec C, Durant JM, Gauthier-Clerc M, Stenseth NC and others (2008) King penguin population threatened by Southern Ocean warming. *Proc Natl Acad Sci USA* 105: 2493–2497
 82. Le Corre M, Jaquemet S (2005) Assessment of the seabird community of the Mozambique Channel and its potential use as an indicator of tuna abundance. *Estuar Coast Shelf Sci* 63:421–428
 83. Le Maho Y, Gendner JP, Challet E, Bost CA and others (1993) Undisturbed breeding penguins as indicators of changes in marine resources. *Mar Ecol Prog Ser* 95:1–6
 84. Lewis S, Wanless S, Wright PJ, Harris MP, Bull J, Elston DA (2001) Diet and breeding performance of black-legged kittiwakes *Rissa tridactyla* at a North Sea colony. *Mar Ecol Prog Ser* 221:277–284
 85. Miller GD, Davis LS (1993) Foraging flexibility of Adelie penguins *Pygoscelis adeliae*—consequences for an indicator species. *Biol Conserv* 63:223–230
 86. Monaghan P (1996) Relevance of the behaviour of seabirds to the conservation of marine environments. *Oikos* 77:227–237
 87. Monaghan P, Uttley JD, Burns MD, Thaine C, Blackwood J (1989) The relationship between food supply, reproductive effort and breeding success in Arctic terns *Sterna paradisaea*. *J Anim Ecol* 58:261–274
 88. Montevecchi WA (2007) Binary dietary responses of northern gannets *Sula bassana* indicate changing food web and oceanographic conditions. *Mar Ecol Prog Ser* 352:213–220
 89. Montevecchi WA, Myers RA (1995) Prey harvests of seabirds reflect pelagic fish and squid abundance on multiple spatial and temporal scales. *Mar Ecol Prog Ser* 117:1–9
 90. Montevecchi WA, Myers RA (1996) Dietary changes of seabirds indicate shifts in pelagic food webs. *Sarsia* 80: 313–322
 91. Nel DC, Lutjeharms JRE, Pakhomov EA, Anson IJ, Ryan PG, Klages NTW (2001) Exploitation of mesoscale oceanographic features by grey-headed albatross *Thalassarche chrysostoma* in the southern Indian Ocean. *Mar Ecol Prog Ser* 217:15–26
 92. Parrish JK, Zador SG (2003) Seabirds as indicators: an exploratory analysis of physical forcing in the Pacific Northwest coastal environment. *Estuaries* 26:1044–1057
 93. Parsons M, Mitchell I, Butler A, Ratcliffe N, Frederiksen M, Foster S, Reid JB (2008) Seabirds as indicators of the marine environment. *ICES J Mar Sci* 65:1520–1526
 94. Phillips RA, Caldow RWG, Furness RW (1996) The influence of food availability on the breeding effort and repro-

- ductive success of Arctic *Skuas Stercorarius* parasiticus. *Ibis* 138:410–419
95. Piatt J, van Pelt T (1997) Mass-mortality of guillemots (*Uria aalge*) in the Gulf of Alaska in 1993. *Mar Pollut Bull* 34:656–662
 96. Piatt JF, Harding AMA, Shultz M, Speckman SG, van Pelt TI, Drew GS, Kettle AB (2007) Introduction: seabirds as indicators of marine food supplies: Cairns revisited. *Mar Ecol Prog Ser* 352:221–234
 97. Pinaud D, Weimerskirch H (2002) Ultimate and proximate factors affecting the breeding performance of a marine top-predator. *Oikos* 99:141–150
 98. Pinaud D, Weimerskirch H (2005) Scale-dependent habitat use in a long-ranging central place predator. *J Anim Ecol* 74:852–863
 99. Reed TE, Wanless S, Harris MP, Frederiksen M, Kruuk LEB, Cunningham EJA (2006) Responding to environmental change: plastic responses vary little in a synchronous breeder. *Proc R Soc Lond B Biol Sci* 273:2713–2719
 100. Regehr HM, Montevecchi WA (1997) Interactive effects of food shortage and predation on breeding failure of black-legged kittiwakes: indirect effects of fisheries activities and implications for indicator species. *Mar Ecol Prog Ser* 155:249–260
 101. Reid K, Croxall JP, Briggs DR, Murphy EJ (2005) Antarctic ecosystem monitoring: quantifying the response of ecosystem indicators to variability in Antarctic krill. *ICES J Mar Sci* 62:366–373
 102. Robinson PW, Tremblay Y, Crocker DE, Kappes MA and others (2007) A comparison of indirect measures of feeding behaviour based on ARGOS tracking data. *Deep-Sea Res II* 54:356–368
 103. Ropert-Coudert Y, Kato A, Wilson RP, Cannell B (2006) Foraging strategies and prey encounter rate of free-ranging Little Penguins. *Mar Biol* 149:139–148
 104. Ropert-Coudert Y, Wilson RP, Yoda K, Kato A (2007) Assessing performance constraints in penguins with externally-attached devices. *Mar Ecol Prog Ser* 333:281–289
 105. Sandvik S, Erikstad KE (2008) Seabird life histories and climatic fluctuations: a phylogenetic-comparative time series analysis of North Atlantic seabirds. *Ecography* 31: 73–83
 106. Sandvik H, Coulson T, Saether BE (2008) A latitudinal gradient in climate effects on seabird demography: results from interspecific analyses. *Glob Change Biol* 14: 703–713
 107. Schreer JF, Kovacs KM, Hines RJO (2001) Comparative diving patterns of pinnipeds and seabirds. *Ecol Monogr* 71:137–162
 108. Scott BE, Sharples J, Wanless S, Ross ON, Frederiksen M, Daunt F (2006) The use of biologically meaningful oceanographic indices to separate the effects of climate and fisheries on seabird breeding success. In: Boyd IL, Wanless S, Camphuysen CJ (eds) *Top predators in marine ecosystems: their role in monitoring and management*. Cambridge University Press, Cambridge, p 46–62
 109. Shaffer SA, Tremblay Y, Weimerskirch H, Scott D and others (2006) Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. *Proc Natl Acad Sci USA* 103:12799–12802
 110. Sokolov S, Rintoul SR, Wienecke B (2006) Tracking the Polar Front south of New Zealand using penguin dive data. *Deep-Sea Res I* 53:591–607
 111. Takahashi A, Dunn MJ, Trathan PN, Croxall JP, Wilson RP, Sato K, Naito Y (2004) Krill-feeding behaviour in a chinstrap penguin *Pygoscelis antarctica* compared with fish-eating in Magellanic penguins *Spheniscus magellanicus*: a pilot study. *Mar Ornithol* 32:47–54
 112. Tasker ML, Camphuysen CJ, Cooper J, Garthe S, Montevecchi WA, Blaber SJM (2000) The impacts of fishing on marine birds. *ICES J Mar Sci* 57:531–547
 113. Thompson PM, Ollason JC (2001) Lagged effects of ocean climate change on fulmar population dynamics. *Nature* 413:417–420
 114. Trathan PN, Green C, Tanton J, Peat H, Poncet J, Morton A (2006) Foraging dynamics of macaroni penguins *Eudyptes chrysolophus* at South Georgia during brood-guard. *Mar Ecol Prog Ser* 323:239–251
 115. Trathan PN, Bishop C, Maclean G, Brown P, Fleming A, Collins MA (2008) Linear tracks and restricted temperature ranges characterise penguin foraging pathways. *Mar Ecol Prog Ser* 370:285–294
 116. Velarde E, Tordesillas M, Vieyra L, Esquivel R (1994) Seabirds as indicators of important fish populations in the Gulf of California. *CCOFI Rep* 35:137–143
 117. Watanuki Y, Daunt F, Takahashi A, Newell M, Wanless S, Sato K, Miyazaki N (2008) Microhabitat use and prey capture of a bottom-feeding top predator, the European shag, shown by camera loggers. *Mar Ecol Prog Ser* 356: 283–293
 118. Weimerskirch H (2002) Seabird demography and its relationship with the marine environment. In: Schreiber EA, Burger J (eds) *Biology of marine birds*. CRC Press, Boca Raton, FL, p 115–135
 119. Weimerskirch H, Wilson RP, Guinet C, Koudil M (1995) Use of seabirds to monitor sea-surface temperatures and to validate satellite remote-sensing measurements in the Southern Ocean. *Mar Ecol Prog Ser* 126:299–303
 120. Weimerskirch H, Inchausti P, Guinet C, Barbraud C (2003) Trends in bird and seal populations as indicators of a system shift in the Southern Ocean. *Antarct Sci* 15: 249–256
 121. Weimerskirch H, Le Corre M, Jaquemet S, Potier M, Marsac F (2004) Foraging strategy of a top predator in tropical waters: great frigate birds in the Mozambique Channel. *Mar Ecol Prog Ser* 275:297–308
 122. Weimerskirch H, Le Corre M, Jaquemet S, Marsac F (2005) Foraging strategy of a tropical seabird, the red-footed booby, in a dynamic marine environment. *Mar Ecol Prog Ser* 288:251–261
 123. Weimerskirch H, Le Corre M, Bost CA (2008) Foraging strategy of masked boobies from the largest colony in the world: relationship to environmental conditions and fisheries. *Mar Ecol Prog Ser* 362:291–302
 124. Wilson UW (2005) The effect of the 1997–1998 El Niño on rhinoceros auklets on Protection Island, Washington. *Condor* 107:462–468
 125. Wilson RP, Grémillet D, Syder J, Kierspel MAM and others (2002a) Remote-sensing systems and seabirds: their use, abuse and potential for measuring marine environmental variables. *Mar Ecol Prog Ser* 228:241–261
 126. Wilson RP, Steinfurth A, Ropert-Coudert Y, Kato A, Kurita M (2002b) Lip-reading in remote subjects: an attempt to quantify and separate ingestion, breathing and vocalisation in free-living animals using penguins as a model. *Mar Biol* 140:17–27
 127. Wilson RP, Liebsch N, Davies IM, Quintana F and others (2007) All at sea with animal tracks: methodological and analytical solutions for the resolution of movement. *Deep-Sea Res II* 54:193–210