

## Index

- Adélie penguin
  - dive behavior, 18
- aerobic dive limit
  - ADL, 172
    - variability, 179
  - ADL calculation, 175
    - assumptions and limitations, 175
    - diving metabolic rate, 175
    - oxygen stores, 175
  - behavioral ADL, 175
  - calculated ADL, 175
  - definition, 172
  - diving lactate threshold, 176
  - measured ADL, 172
    - Baikal seals, 173
    - beluga whales, 173
    - bottlenose dolphins, 173
    - California sea lions, 173
    - emperor penguins, 172
    - Weddell seals, 172
  - physiological basis
    - muscle oxygen depletion – emperor penguin, 177
- African darter
  - dive behavior, 17
- African penguin
  - dive behavior, 18
- air exhalation
  - Antarctic fur seals, 189
- air sacs, 40
- ama
  - dive performance, 22
  - nitrogen levels, 27
  - oxygen and carbon dioxide levels, 23
- American coot
  - dive behavior, 20
- Antarctic fur seal
  - dive behavior, 7
- Antarctic prion
  - dive behavior, 13
- Antarctic shag
  - dive behavior, 16
- aorta
  - aortic bulb
    - anatomy, 122
    - windkessel, 123
  - aortic windkessel
    - coronary perfusion, 123
  - ascending aorta and arch
    - windkessel in whales, 123
  - ascending aortic compliance
    - ventricular impedance, 123
  - descending aorta
    - noncompliant structure, 124
- Arnoux's beaked whale
  - dive behavior, 9
- arterialization
  - effect on blood O<sub>2</sub> store calculation, 53
  - elephant seals – free dives, 92, 184
  - emperor penguins – free dives, 107
- arterio-venous (A-V) anastomoses
  - brood patch, 128, 157
  - duck, 100
  - feet and eyelids
    - birds, 128
  - skin, 76, 121
  - sympathetic innervation – bowhead whales, 77
- arterio-venous (A-V) shunts
  - arterio-venous anastomoses, 76
  - emperor penguins
    - free dives, 194
  - emperor penguins – free dives, 107
  - forced submersion – duck, 100
  - forced submersions, 76, 150
  - in foreflipper of seals, 76
  - free dives – elephant seals, 76
- Atlantic puffin
  - dive behavior, 15
- Atlantic white-sided dolphin
  - dive behavior, 9
- atmospheres absolute
  - definition, 27
- Audubon's shearwater
  - dive behavior, 13

- Australasian grebe
  - dive behavior, 19
- Australian fur seal
  - dive behavior, 7
- Australian sea lion
  - dive behavior, 7
- avian hemodynamics – forced submersion
  - central venous pressure, 131
  - left ventricle distention, 131
  - pulmonary vascular resistance, 131
  - right atrium and ventricle distention, 131
  - ventricular contractility, 131
- Baikal seal
  - dive behavior, 3
- Baird’s beaked whale
  - dive behavior, 9
- Balearic shearwater
  - dive behavior, 13
- bar-headed goose
  - hemoglobin, 46
- Barolo shearwater
  - dive behavior, 13
- barotrauma, 205
  - air-filled cavities, 207
  - cranial sinuses, 207
  - middle ear cavities, 207
- bearded seal
  - dive behavior, 3
- beaver
  - dive behavior, 12
- Beluga whale
  - dive behavior, 9
- black-browed albatross
  - dive behavior, 13
- black-vented shearwater
  - dive behavior, 13
- Blainville’s beaked whale
  - controlled exposure study, 217
  - dive behavior, 9
- blood lactate concentrations
  - forced submersions, 199
  - free dives – emperor penguins, 199
  - free dives – seals, 199
  - sleep apnea, 181
- blood pH
  - forced submersion – ducks, 197
  - forced submersion – seals, 196
  - free dives – emperor penguins, 198
  - free dives – seals, 197
  - post-dive in seals, 200
  - stationary submersions – cetaceans, 197
- blood pressure
  - forced submersion, 75
  - forced submersion – duck, 98
  - formula, 77
- blood volumes
  - avian divers, 53
  - marine mammals, 53
- blue petrel
  - dive behavior, 13
- blue whale
  - controlled exposure study, 218
  - dive behavior, 10
- blue-eyed shag
  - dive behavior, 16
- blue-footed booby
  - dive behavior, 17
- body mass
  - advantage of increased size
    - basal metabolic rate, 70
    - cost of locomotion, 70
- bottlenose dolphin
  - dive behavior, 9
- bowhead whale
  - dive behavior, 10
- Boyle’s Law, 25
- bradycardia, 71
  - duck – forced submersion, 98
  - spontaneous dives – Baikal seals, 83
- break point
  - physiology, 23
- bronchiolar sphincters, 35
- Bryde’s whale
  - dive behavior, 10
- Bulwer’s petrel
  - dive behavior, 13
- California sea lion
  - dive behavior, 7
- canvasback duck
  - dive behavior, 19
- cape cormorant
  - dive behavior, 16
- cape gannet
  - dive behavior, 17
- capybara
  - dive behavior, 12
- carbon dioxide
  - end tidal, 198
  - forced submersion – ducks, 197
  - forced submersion – seals, 196
  - free dives – emperor penguins, 198
  - free dives – Weddell seal, 197
  - sleep apnea, 197
  - storage in humans, 24
  - trained submersion – cetaceans, 197
- carbon monoxide
  - dissociation curve shift, 46
  - hemoglobin affinity, 45
  - in seals, 53
  - mitochondrial biogenesis, 47
  - reperfusion injury, 46

- cardiac output
  - tissue distribution at rest – humans, 73
- Caspian seal
  - dive behavior, 3
- Cassin's auklet
  - dive behavior, 15
- chinstrap penguin
  - dive behavior, 18
- chromium 51 label
  - red cell volume technique, 52
- common diving petrel
  - dive behavior, 13
- common dolphin
  - dive behavior, 9
- common eider, 19
- common goldeneye
  - dive behavior, 19
- common loon
  - dive behavior, 19
- common murre
  - dive behavior, 15
- common pochard
  - dive behavior, 19
- common scoter
  - dive behavior, 19
- compression hyperoxia
  - emperor penguins, 192–3
- countercurrent exchange
  - flukes, flippers, and dorsal fins, 121
  - manatee fluke, 149
  - reproductive organs, 122, 150
  - tongues of mysticetes, 122, 151
  - vascular anatomy, 121
  - wings and feet in birds, 127
- crabeater seal
  - dive behavior, 3
- Crozet shag
  - dive behavior, 16
- Cuvier's beaked whale
  - controlled exposure study, 218
  - dive behavior, 9
- cytoglobin
  - function, 44
- Dall's porpoise
  - dive behavior, 9
- decompression sickness, 205
  - arterial gas emboli, 213
  - asymptomatic bubbles, 205
  - autochthonous bubble formation, 206
  - bubble formation, 206
  - bubble formation thresholds, 205
  - disseminated intravascular coagulation, 206
  - fat, 206
  - humans, 26
  - marine mammals
    - bubble gas content, 214
    - dysbaric osteonecrosis – sperm whales, 213
    - fat emboli – necropsy, 213
    - intravascular bubbles – necropsy, 213–14
    - tissue bubbles – stranded dolphins, 214
  - pathological mechanisms, 206
  - periarticular tissues, 206
  - rectified diffusion, 206
  - spinal cord white matter, 206
  - supersaturation, 206
  - tissue N<sub>2</sub> solubility, 214
  - tribonucleation, 206
- digestion
  - delay in gray seals, 6, 147
- dive reflex, 71, 79
- dive response, 71
  - forced submersion – birds, 97
  - forced submersion – seals, 71
  - forced submersion vs. exercise, 74
  - free dives – birds, 101
  - free dives – marine mammals, 85
  - simulated dives – penguins, 100
  - simulated dives – seals, 79
  - sleep apnea, 83
  - surface swimming
    - cardiac response – birds, 100
    - cardiac response – marine mammals, 83
  - trained submersion – seals, 80
- diving metabolism
  - basal metabolic rate
    - allometric equations, 165
    - definition, 165
  - diving metabolic rate
    - emperor penguins, 170
    - gray seals, 169
    - Humboldt penguins, 170
    - sea otters, 169
    - Steller sea lions, 169
    - tufted ducks and lesser scaups, 170
    - Weddell seals, 168–9
- diving metabolic rate determinants, 162
- field metabolic rate
  - elephant seals, 168
- forced submersion
  - duck muscle metabolic rate, 163
  - O<sub>2</sub> debt of seals, 162
  - seal muscle metabolic rate, 163
- metabolic rate at rest
  - marine mammals, 166
- oxygen consumption measurements
  - doubly labeled water, 167
  - Fick method, 166
  - heart rate, 168
  - respirometry, 166
- possible mechanisms of metabolic suppression
  - acidosis, 203
  - carbon monoxide, 204

- diving metabolism (cont.)  
 hydrogen sulfide, 164  
 hypoxia-linked, 163  
   arrest of protein synthesis, 163  
   ion channel arrest, 163  
   reverse Pasteur effect, 163  
   nitric oxide, 164  
 standard metabolic rate, 165
- drift dives, 6
- ducks  
   divers vs. dabblers, 21
- dugong  
   dive behavior, 11
- dusky dolphin  
   dive behavior, 9
- ear  
   ear squeeze, 31  
   mechanisms of hearing, 31  
   venous plexuses, 31
- emperor penguin  
   dive behavior, 18
- Eurasian otter  
   dive behavior, 12
- European shag  
   dive behavior, 16
- Evan's blue dye  
   plasma volume technique, 52
- exercise response  
   mechanisms, 74  
   muscle blood flow  
     local mechanisms, 74  
   neuroregulation  
     baroreceptor reflex, 115  
     cardiac sympathetic nerve, 115  
     central command, 114  
     exercise pressor reflex, 115  
     renal sympathetic nerve, 115
- extradural vein  
   anatomy, 120  
   direction and magnitude of flow, 120  
   negative inspiratory pressures, 121
- eye  
   cornea, 29  
   lens and pupil, 29  
   photoreceptors, 30  
   tapetum lucidum, 30
- false killer whale  
   dive behavior, 9
- fin whale  
   dive behavior, 10
- finless porpoise  
   dive behavior, 9
- flesh-footed shearwater  
   dive behavior, 13
- flightless cormorant  
   dive behavior, 16
- forced submersion  
   adrenal blood flow, 76  
   adrenal gland – duck, 99  
   angiography and Doppler flow probes, 75  
   arterio-venous shunts, 76  
   arterio-venous shunts – duck, 100  
   blood pressure, 75  
   brain blood flow, 76  
   brain blood flow – duck, 99  
   brain temperature, 150  
   catecholamine levels, 76  
   catecholamine levels – duck, 99  
   cortisol levels, 76  
   dive reflex  
     bradycardia and vasoconstriction, 74  
   duck, 97  
   duck – muscle blood flow, 98  
   heat loss – A-V shunts, 76  
   lactate wash out, 75  
   mesenteric blood flow, 75  
   muscle blood flow – Baikal seal, 78  
   myocardial blood flow, 78  
   myocardial blood flow – duck, 99  
   penguin, 97  
   renal blood flow, 75  
   tissue perfusion – microspheres, 76  
   various diving birds, 99
- free dives – birds  
   eiders – heart rate, 102
- emperor penguins  
   heart rate and stroke rate, 110  
   heart rate at isolated dive hole, 106  
   heart rates at sea, 109  
   muscle temperature, 107  
   myoglobin saturation, 107  
   venous Hb saturation, 107  
   heart rate, 103–4
- Humboldt penguins – heart rate, 104
- king penguins  
   heart rate, 104  
   muscle temperature, 107
- macaroni penguins – heart rate, 104
- redhead ducks – heart rate, 101
- rhinoceros auklets – heart rate, 103
- South Georgian shags – heart rate, 103
- tufted ducks  
   chest muscle blood flow, 102  
   heart rate, 101  
   leg blood flow, 102  
   organ blood flow, 102
- free dives – marine mammals, 85  
   California sea lions  
     heart rate, 93  
     venous O<sub>2</sub> profiles, 94

- dolphins
  - heart rate, 95
  - heart rate and stroke rate, 88
- elephant seals
  - heart rate, 89
  - venous O<sub>2</sub> saturation, 92
- gray seals – heart rate, 89
- heart rate, 85
- manatees – heart rate, 89
- multiple pinnipeds – heart rate, 89
- other mammals – heart rate, 96
- Steller sea lions – heart rate and ODBA, 92
- Weddell seals
  - fetal heart rate, 86
  - heart rate and stroke rate, 88
  - heart rates, 85–6
  - hepatic blood flow, 85–6
  - Mb saturation profiles, 87
  - muscle temperature, 88
  - renal blood flow, 85–6
- Galapagos fur seal
  - dive behavior, 7
- Galapagos penguin
  - dive behavior, 18
- Galapagos sea lion
  - dive behavior, 7
- Gentoo penguin
  - dive behavior, 18
- gray whale
  - dive behavior, 10
- great cormorant
  - dive behavior, 16
- great crested grebe
  - dive behavior, 19
- gray seal
  - dive behavior, 3
- gray-headed albatross
  - dive behavior, 13
- Guadalupe fur seal
  - dive behavior, 7
- harbor porpoise
  - dive behavior, 9
- harbor seal
  - dive behavior, 3
- harp seal
  - dive behavior, 3
- heart
  - anatomy and size
    - marine mammals, 118
  - ductus arteriosus, 118
  - foramen ovale, 118
  - right ventricle
    - birds, 127
    - mammals, 118
  - size and anatomy
    - birds, 127
- hematocrit, 52
- fluctuations in phocid seals, 119
- seals – effect of anesthesia, 52
- splenic contraction, 52
- hemoglobin
  - Bohr effect – marine mammals, 47
  - Bohr effect – penguins, 48
  - carboxyhemoglobin, 45
  - concentrations in diving birds, 47
  - concentrations in marine mammals, 47
  - dissociation curve, 45
    - 2,3 diphosphoglycerate, 45
  - Bohr effect, 45
  - carboxyhemoglobin, 46
  - myoinositol 1,3,4,5,6-pentophosphate, 46
  - pH, 45
  - temperature, 45
  - fetal hemoglobin – not in Weddell seal, 47
  - Hill coefficient – marine mammals, 47
  - Hill coefficient – penguins, 48
  - methemoglobin, 45
  - oxygen binding capacity, 45
  - P<sub>50</sub>, 45
  - P<sub>50</sub> – diving birds, 47
  - P<sub>50</sub> – marine mammals, 47
  - structure, 45
- hemoglobin concentrations
  - avian divers, 53
  - marine mammals, 53
- Henry's Law, 23, 25
- hepatic blood flow
  - free dives, 85–6
- hepatic sinus
  - venous capacitance, 119
- high-pressure nervous syndrome
  - human threshold, 27
  - symptoms, 205
  - threshold, 206
- hoary-headed grebe
  - dive behavior, 19
- hooded seal
  - dive behavior, 3
- horned grebe
  - dive behavior, 19
- human breath-hold divers
  - “black out” threshold, 23
  - barotrauma, 25
  - bradycardia, 24
  - break point, 22
  - decompression sickness, 26
  - diuresis, 28
  - dive behavior, 22
  - dive response and metabolic rate, 24
  - ear squeeze, 25
  - heart rate, arrhythmias and pressure, 26

- human breath-hold divers (cont.)  
 heat loss, 28  
 high-pressure nervous syndrome, 27  
 intrathoracic blood volume, 25  
 lung packing, 26  
 lung residual volume and chest squeeze, 25  
 meditation, 25  
 muscle sympathetic nerve activity, 77  
 nitrogen narcosis, 27  
 oxygen stores, 23  
 skin sympathetic nerve activity, 77  
 splenic contraction, 24  
 taravana, 27
- Humboldt penguin  
 dive behavior, 18
- humpback whale  
 dive behavior, 10
- hyperventilation  
 risk in human divers, 23
- hypoxemic limits  
 bar-headed goose at altitude  
 inspiratory oxygen, 192
- dog  
 arterial oxygen, 181
- human  
 shallow water black-out thresholds, 192
- human patients  
 arterial oxygen, 182
- humans – ambient air-Mt Everest  
 arterial oxygen, 184
- seal  
 arterial blood oxygen, 181  
 venous blood oxygen, 181
- hypoxemic tolerance  
 anaerobic metabolism – seal neuron, 201  
 avian tissue capillary densities, 201  
 avoidance of reperfusion injury  
 carbon monoxide, 204  
 glutathione, 204  
 nitrite reductase of myoglobin, 204  
 peroxidase activity, 204  
 blood buffering capacity in marine mammals and penguins, 202  
 brain capillary densities, 200  
 glycogen concentrations – brain and heart, 202  
 human comparisons, 200  
 ischemic pre-conditioning, 204  
 mitochondrial distribution, 200  
 mitochondrial volume densities, 201  
 muscle buffering capacity in seals and penguins, 202  
 neuroglobin, 201  
 cetacean neurons, 202  
 seal glial cells, 201  
 oxygen diffusion distances, 200  
 pekin ducks – “imminent cardiovascular collapse”  
 blood oxygen, 44, 48, 191
- possible hypoxia-linked protective mechanisms, 203  
 hypoxia inducible factor, 203
- regional hypothermia  
 Q<sub>10</sub> effect., 203
- seal kidney – ischemic tolerance, 200
- seal neurons – intrinsic hypoxic tolerance, 204
- shift in penguin dissociation curve, 201
- hypoxic pulmonary vasoconstriction, 231  
 acidosis, 232  
 human pathology, 231  
 hypercarbia, 232  
 mechanisms, 231
- sea lions  
 hypoxic pulmonary vasodilation, 232  
 hydrogen sulfide, 232
- vascular dilation  
 blood nitrite – dolphins, 232  
 carbon monoxide, 233  
 exhaled nitric oxide – dolphins, 233  
 nitric oxide, 232
- intra-aortic balloon pump  
 analogue to aortic bulb, 130
- ischemic preconditioning  
 ATP depletion rate, 228  
 calcium homeostasis, 228  
 mitochondrial aldehyde dehydrogenase-2, 229  
 mitochondrial K<sup>+</sup>-dependent ATPase, 228  
 mitochondrial permeability transition pore, 229
- isolated dive hole  
 emperor penguins, 106, 170, 191  
 Weddell seals, 86, 169, 172
- Japanese cormorant  
 dive behavior, 16
- Juan Fernandez fur seal  
 dive behavior, 7
- killer whale  
 dive behavior, 9
- king cormorant  
 dive behavior, 16
- king penguin  
 dive behavior, 18
- least grebe  
 dive behavior, 19
- leopard seal  
 dive behavior, 3
- lesser scaup  
 dive behavior, 19
- light  
 absorption by water, 28

- light-mantled albatross
  - dive behavior, 14
- little auk
  - dive behavior, 15
- little penguin
  - dive behavior, 18
- locomotion
  - buoyancy – oxygen costs, 143
  - cormorants – webbed feet, 142
  - cost of transport
    - marine mammals, 144
    - seabirds, 144
    - semi-aquatic mammals, 144
  - drag
    - drag equation, 141
    - oxygen consumption, 141
    - surface drag, 141
  - engulfment drag – rorqual whales, 142
  - hydrodynamics, 140
    - appendages, 140
    - boundary layer, 140
    - drag, 141
    - feathers and microbubbles, 141
    - fineness ratio, 140
    - laminar flow, 140
    - maximum body width, 140
    - Reynolds number, 140
    - skin and fur, 141
  - locomotory appendages and thrust, 141
  - prolonged glides, 143
  - sea lion foreflipper
    - hydrofoil and paddle, 142
  - seal hind flippers
    - hydrofoils, 142
  - stroke and glide patterns, 142
    - buoyancy, 142
  - stroke rate patterns, 143
    - pregnant elephant seals, 143
  - tail fluke
    - hydrofoil, 142
    - subdermal connective tissue sheath, 142
  - water density and viscosity, 139
- long-tailed duck
  - dive behavior, 19
- lung anatomy
  - airway reinforcement, 34
  - airway vascular plexuses, 34
  - avian air sacs, 40
  - avian airways and lung, 40
  - bird vs mammals, 32
  - bronchiolar myoelastic sphincters, 35
  - “lung collapse”, 33, 207, 209, 220
  - tracheobronchial biomechanics, 35
- lung volumes
  - avian lung and air-sac volumes, 41
  - diving air volume
    - ducks, 41
    - penguins at sea, 42
    - marine flighted birds, 41
    - penguins, 41
  - diving lung volumes – marine mammals, 39
  - lungs and air sacs – penguins-CT scan, 43
  - tidal volumes
    - birds, 43
    - marine mammals, 39
  - total lung capacity-marine mammals, 37
- macaroni penguin
  - dive behavior, 18
- Magellanic penguin
  - dive behavior, 18
- mallard (pekin) duck
  - dive behavior, 20
- manatee
  - dive behavior, 11
- marbled murrelet
  - dive behavior, 15
- Mediterranean monk seal
  - dive behavior, 3
- minke whale
  - dive behavior, 10
- Monteiro’s storm petrel
  - dive behavior, 13
- muscle
  - buffering capacity, 137
    - histidine dipeptides, 137
  - capillary density, 138
  - fatty acid oxidation, 138
  - fiber types, 133
    - Antarctic fur seal, 135
    - auklet, 135
    - beaked whales, 134
    - California sea lion, 135
    - dolphins, 135
    - elephant seal, 135
    - emperor penguin, 135
    - fin whale, 135
    - gray seal, 135
    - narwhal, 135
    - pilot whales, 134
    - pygmy sperm whale, 135
    - sea otter, 135
    - tufted duck, 135
    - Weddell seal, 135
  - glycogen, 137
  - glycolytic enzyme activities, 137
  - lipid droplets, 138
  - locomotory muscle, 133
  - metabolic suppression, 139
  - mitochondrial volume densities, 138
  - myoglobin content, 139
    - marine mammals, 61
    - seabirds, 63

- muscle (cont.)
  - oxidative enzyme activities, 138
  - oxygen consumption during ischemia, 139
  - phosphocreatine, 137
  - temperature, 139
- muscle blood flow
  - forced submersion, 75
    - Baikal seal, 78
    - duck, 98
    - fluctuations, 80
  - sleep apnea, 83
  - surface swimming – ducks, 100
  - trained submersion, 80
- muskrat
  - dive behavior, 12
- myocardial oxygen supply/demand
  - afterload, 130
    - aortic bulb, 130
    - aortic bulb as intra-aortic balloon pump, 130
    - Law of LaPlace, 130
  - cardiac preload, 129
    - Law of LaPlace, 129
    - vena caval sphincter, 129
  - heart rate, 128
  - myocardial contractility, 129
    - effect of vagal input, 129
- myoglobin
  - dissociation curve, 49
    - pH, 49
    - temperature, 49
  - facilitation of O<sub>2</sub> diffusion, 50
  - nitric oxide, 50
  - nitrite reductase activity, 204
  - oxygen binding capacity, 49
  - P<sub>50</sub>, 49
  - peroxidase activity, 204
  - reactive O<sub>2</sub> species, 50
  - structure, 48
- myoglobin – facilitated diffusion of oxygen, 237
  - equipoise P<sub>O<sub>2</sub></sub>, 238
  - myoglobin diffusion coefficient, 237
  - oxygen flux equation, 237
  - rat myocardium, 238
  - seal muscle, 238
  - seal muscle myoglobin diffusion coefficient, 238
  - translational diffusion
    - net surface charge, 239
- myoglobin concentrations
  - avian divers, 63
  - marine mammals, 61
- myoglobin production
  - chicks – non-shivering thermogenesis, 235
  - emperor penguins – myoglobin mRNA, 236
  - hypoxia + exercise, 234
  - messenger RNA
    - calcineurin-NFAT, 233
    - regulation of transcription, 233
- muscle activity, 233
- muscle maturation, 233
- myoglobin concentration
  - marine mammal neonates, 234
  - penguin chick, 235
- myoglobin genes, 233
- Weddell seals
  - hypoxia + lipid, 234
- narwhal
  - dive behavior, 9
- neuroglobin
  - amino acid sequence, 44
  - assay, 201
  - in cetacean neurons, 202
  - in seal glial cells, 201
- neuroregulation, 111
  - anterior ethmoidal nerve, 111
  - baroreceptor, 112
    - ducks, 113
  - carotid chemoreceptor
    - dabbling ducks, 112
    - diving ducks, 113
    - seals, 112
  - cortical input, 112
  - diving rat model, 112
  - glossopharyngeal nerve, 111
  - lung inflation, 112
  - nucleus ambiguus, 111
  - parasympathetic nervous system
    - acetylcholine, 113
    - vagus nerve, 111
  - pontine neurotoxic center, 111
  - respiratory center, 111
  - spinal trigeminal nucleus, 111
  - stimuli, 111
  - sympathetic nervous system, 111
    - neurotransmitters, 113
  - sympathetic nervous system
    - adrenoreceptors, 113
  - sympathetic nervous system
    - cardiac sympathetic fibers, 113
  - trigeminal nerve, 111
- New Zealand dabchick
  - dive behavior, 19
- New Zealand fur seal
  - dive behavior, 7
- New Zealand sea lion
  - dive behavior, 7
- nitrogen narcosis, 205
  - threshold, 27, 206
- northern bottlenosed whale
  - dive behavior, 9
- northern elephant seal
  - dive behavior, 3
- northern fulmar
  - dive behavior, 13



- northern fur seal
  - dive behavior, 7
- northern gannet
  - dive behavior, 17
- northern rockhopper penguin
  - dive behavior, 18
- olfactory adaptations, 29
- oxygen store calculations
  - assumptions and potential sources of error, 50
  - blood O<sub>2</sub> store
    - assumptions, 51
    - blood volume – effects of large spleens, 52
    - determination of blood volume, 52
    - initial and final Hb saturations, 53
  - muscle O<sub>2</sub> store
    - assumptions, 58
    - distribution of Mb, 59
    - Mb determinations, 59
    - muscle mass, 59
  - respiratory O<sub>2</sub> store
    - diving air volumes, 50
    - net extraction of O<sub>2</sub>, 51
- oxygen store depletion
  - end tidal oxygen, 198
  - flume swim
    - emperor penguin – maximum muscle O<sub>2</sub> consumption, 195
- forced submersion
  - pekin duck
    - blood oxygen, 191
  - pekin ducks
    - blood oxygen depletion rate, 191
  - penguins
    - air-sac oxygen, 191
    - arterial oxygen, 190
    - blood O<sub>2</sub> depletion rate, 191
    - muscle oxygen, 191
  - seals
    - blood, 180
    - blood oxygen depletion rate, 181
    - lungs, 180
    - muscle, 180
    - muscle O<sub>2</sub> depletion rate, 180
- free dives
  - ama
    - blood oxygen depletion rate, 187
  - Antarctic fur seals
    - air exhalation, 189
  - California sea lion
    - arterial oxygen, 189
  - California sea lions
    - blood O<sub>2</sub> depletion rate, 190
    - venous oxygen, 190
  - elephant seals
    - arterial P<sub>O<sub>2</sub></sub>, 184
    - ascent – muscle blood flow, 186
    - blood oxygen profiles, 184
    - hepatic sinus Hb saturation, 184
    - venous P<sub>O<sub>2</sub></sub>, 184
  - emperor penguins
    - air-sac oxygen, 192
    - air-sac oxygen depletion rate, 193
    - arterial oxygen, 193
    - muscle O<sub>2</sub> consumption, 195
    - muscle oxygen, 194
    - venous oxygen, 193
  - Weddell seal
    - arterial oxygen, 187
    - lung, 187
    - muscle oxygen, 187
  - Weddell seals
    - blood oxygen depletion rate, 187
    - muscle O<sub>2</sub> depletion rates, 188
- simulated dives
  - penguins
    - air-sac oxygen, 191
    - arterial oxygen, 191
  - sleep apnea
    - blood oxygen, 181, 187
    - blood oxygen depletion rate, 182
    - metabolic rate, 183
    - muscle blood flow, 181
    - muscle O<sub>2</sub> depletion rate, 183
    - muscle oxygen, 182
  - stationary breath holds
    - dolphins
      - fluke blood oxygen, 190
  - trained dives
    - dolphins
      - lung, 190
- Pacific white-sided dolphin
  - dive behavior, 9
- pericardial venous plexus
  - anatomy, 125
  - blood flow, 126
  - brown fat, 126
- Peruvian booby
  - dive behavior, 17
- Peruvian diving petrel
  - dive behavior, 13
- Peruvian pelican
  - dive behavior, 17
- pie-billed grebe
  - dive behavior, 19
- pigeon guillemot
  - dive behavior, 15
- pilot whale
  - dive behavior, 9
- platypus
  - dive behavior, 12
- polar bear
  - swim behavior, 12

- portal vein sphincters  
 cetaceans, 125
- pressure tolerance  
 barotrauma, 205  
 central pooling of blood, 207  
 chest compliance, 207  
 cranial sinuses, 207  
 engorgement of avian pulmonary blood capillary – hypothesis, 222  
 lungs – relative thoracic volumes, 209  
 middle ear cavities, 207  
 relative retial chest volumes, 209  
 retia mirabilia, 207  
 terminal air space engorgement, 207  
 thorax contents, 209  
 tracheal compliance, 207  
 tracheal venous sinuses, 207
- blood nitrogen levels  
 dolphins, post-dive, 215  
 penguins, free dive, 224  
 penguins, pressure chamber, 224  
 seals, free dive, 215  
 seals, pressure chamber, 215
- cellular adaptations  
 cardiac function, 26  
 enzyme kinetics, 216  
 glycolytic flux, 216  
 membrane composition, 216  
 platelet function, 58, 216
- decompression sickness, 205  
 lack of intravascular bubbles – live animals, 214  
 models – nitrogen kinetics, 219  
 N<sub>2</sub> solubilities, 214  
 thoraco-spinal retia model, 213  
 tissue bubbles – live stranded dolphins, 214
- depth of lung collapse  
 dolphins, 210  
 seals, 209  
 sea lions, 212
- gas exchange  
 heart rate at depth – penguins, 224  
 intrapulmonary shunting, 223
- high-pressure nervous syndrome, 205
- lung  
 penguin lung morphometrics, 223
- lung collapse  
 arterial nitrogen levels – seals, 209  
 arterial P<sub>O2</sub> profiles – sea lions, 211  
 arterial P<sub>O2</sub> profiles – seals, 209  
 graded pulmonary shunt, 211–12  
 hyperbaric CT scans, 211  
 muscle N<sub>2</sub> levels – dolphins, 210  
 surfactant, 212, *see* surfactant  
 tracheal anatomy and compliance, 211
- nitrogen narcosis, 205
- penguin air-sac and lung volumes, 223
- pressure tolerance – birds  
 barotrauma  
 bone pneumaticity, 221  
 middle ear venous sinuses, 221
- barotrauma  
 rigid lung, 221
- blood nitrogen levels  
 Adélie and gentoo penguins, 224  
 emperor penguins, 224  
 king penguins, 224
- lung  
 air capillaries, 222  
 blood capillary engorgement, 222  
 penguin lung morphometrics, 222  
 pulmonary blood capillary rigidity, 222  
 lung–air-sac volume ratio, 222
- pulmonary vascular resistance  
 hypoxia, hypercarbia and acidosis, 130  
 hypoxia-induced pulmonary vasodilation, 131  
 nitric oxide precursors, 131
- razorbill  
 dive behavior, 15
- red-footed booby  
 dive behavior, 17
- red-headed duck  
 dive behavior, 19
- red-necked grebe  
 dive behavior, 19
- red-tailed tropic bird  
 dive behavior, 17
- renal blood flow  
 forced submersion, 75  
 free dives, 85–6
- reperfusion injury, 226  
 reactive oxygen species (ROS), 226  
 thiobarbituric acid reactive substances (TBARS), 227  
 xanthine oxidase pathway, 226
- reperfusion injury – protection  
 antioxidant enzymes  
 penguins, 228  
 seals, 228
- blood antioxidant capacity – penguins, 228
- carbon monoxide, 46
- catalase, 226
- glutathione, 227  
 seals, 228
- glutathione peroxidase, 226
- glutathione-S-transferase, 227
- hypoxanthine concentrations – seals, 227
- ischemic preconditioning, 228
- myoglobin nitrite reductase, 165
- myoglobin peroxidase, 228
- seal brain cell hypoxic tolerance, 227
- seal kidney ischemic tolerance, 227

- superoxide dismutase, 226
- seal hearts, 227
- thiobarbituric acid reactive substances – seals, 227
- respiratory drive
  - hypercapnic, 198
  - hypoxic, 198
- respiratory mechanics, 36
  - expiratory flow rates – marine mammals, 36
  - flow volume curves – cetacean vs human, 37
  - relaxation volumes – marine mammals, 36
- retia mirabilia
  - anatomy, 124
  - narwhal and beluga whale, 124
  - baroprotection, 207
  - penguins
    - ophthalmic, 127
    - possible functions, 124
    - relative thoracic volumes, 209
  - sperm whales, 124
  - thoracic retia
    - kogiid whales, 124
  - thoracic retia and spinal meningeal artery, 124
- rheology
  - blood viscosity, 57
  - blood viscosity – red cell characteristics, 58
  - blood viscosity – shear rate, 57
  - blood viscosity and systemic vascular resistance, 57
  - risk of thrombosis, 58
    - absence of Factor XII in cetaceans, 58
    - clot lysis in seals, 58
    - clotting factors and platelets in seals, 58
    - platelet function, 58
- rhinoceros auklet
  - dive behavior, 15
- ribbon seal
  - dive behavior, 3
- right whale
  - dive behavior, 10
- ringed seal
  - dive behavior, 3
- Risso's dolphin
  - dive behavior, 9
- Ross seal
  - dive behavior, 3
- royal penguin
  - dive behavior, 18
- sea otter
  - dive behavior, 12
- shallow water black out
  - physiology, 23
- short-tailed shearwater
  - dive behavior, 13
- shy albatross
  - dive behavior, 14
- simulated dives, 79
  - heart rate, 79
  - penguins – heart rate, 100
- sinus arrhythmias, 82
- sleep apnea, 82
  - cardiac output, 83
  - heart rate, 83
  - muscle blood flow, 83
  - muscle oxygenation, 83
- slender-billed petrel
  - dive behavior, 13
- sonar-associated strandings, 216
  - controlled exposure studies, 217
  - models – N<sub>2</sub> absorption and distribution, 219
  - necropsy findings, 216
  - rectified diffusion, 217
  - sound resonance, 217
- sooty shearwater
  - dive behavior, 13
- sound production
  - mechanisms, 30
- South African fur seal
  - dive behavior, 7
- South American fur seal
  - dive behavior, 7
- South Georgian diving petrel
  - dive behavior, 13
- southern elephant seal
  - dive behavior, 3
- southern rockhopper penguin
  - dive behavior, 18
- southern sea lion
  - dive behavior, 7
- specific heat
  - definition, 28
  - of water, 28
- sperm whale
  - dive behavior, 10
- spinner dolphin
  - dive behavior, 9
- splanchnic blood flow
  - forced submersion, 75
- spleen
  - contraction/relaxation times, 120
  - hematocrit fluctuations, 119
  - human divers – contraction, 24
  - red cell storage, 119
  - size pinnipeds, 119
  - sympathetic innervation, 119
- spotted dolphin
  - dive behavior, 9
- spotted seal
  - dive behavior, 3
- star-nosed mole
  - dive behavior, 12
- Steller sea lion
  - dive behavior, 7

- streaked shearwater
  - dive behavior, 13
- sub-Antarctic fur seal
  - dive behavior, 7
- supraventricular tachycardia
  - facial immersion treatment, 226
- surface swimming
  - cardiac output
    - sea lions, 84
    - seals, 83
  - heart rate
    - dolphins, 84
    - sea lions, 84
    - seals, 83
  - wave-riding dolphins, 85
- O<sub>2</sub> consumption
  - dolphins, 84
  - pinnipeds, 84
- stroke volume – seals, 83
- surface swimming – birds
  - Adelie penguins – heart rate, 101
  - ducks
    - cardiac output, 100
    - heart rate, 100
    - hepatic blood flow, 100
    - muscle blood flow, 100
    - myocardial blood flow, 100
    - renal blood flow, 100
    - splanchnic blood flow, 100
  - emperor penguin
    - heart rate, 100
    - O<sub>2</sub> consumption, 100
  - gentoo penguins – heart rate, 101
- surfacers vs. diver, 4
- surfactant
  - antiadhesive function, 229
  - birds, 230
  - cholesterol, 229
  - composition, 229
  - human pathologies, 230
  - phospholipid, 229
    - phosphatidyl choline, 229
  - production
    - leptin – seals, 230
    - sea lions, 230
  - properties – seals and sea lions, 230
  - surface tension, 229
  - surfactant proteins, 229
- temperature – diving birds
  - emperor penguins
    - aortic, vena caval, peripheral venous, muscle, stomach, subcutaneous, and sub-feather temperatures, 159
  - gentoo penguins
    - abdominal temperature, 158
  - king penguins
    - muscle temperature, 161
    - upper abdomen, 158
    - upper/lower abdominal, and stomach temperatures, 158
- macaroni penguins
  - abdominal temperature, 158
- regional heterothermy
  - emperor penguins, 161
  - guillemot, 161
  - king penguins, 158
- South Georgian shags
  - abdominal temperatures, 158
- guillemot, 161
- tufted ducks
  - abdominal temperature, 158
- temperature – marine mammals
  - Antarctic fur seals
    - intraabdominal temperature, 155
  - California sea lions
    - vena caval temperature, 155
  - dolphins
    - stomach and abdominal temperatures, 152
  - elephant seal
    - aortic, hepatic sinus and extradural vein temperatures, 153
  - elephant seals
    - stomach temperature, 152
  - gray seals
    - stomach temperature, 153
  - manatee
    - stomach temperature, 152
  - muskrat
    - abdominal temperature, 152
  - regional heterothermy
    - dolphin, 151
    - elephant seal, 151, 153
    - humans, 151
  - sea otter
    - rectal temperature, 152
  - Weddell seals
    - arterial temperature, 152
    - muscle temperature, 152
  - whales
    - post-mortem temperatures, 151
- thermal conductance, 157
- thermal conductivity
  - definition, 28
  - of water, 28
- thermoregulation
  - baleen whales
    - corpus cavernosum maxillaris, 122
  - body mass and metabolic rate, 147
  - body mass and stroke rate, 147
  - brown fat, 145
  - cold prey ingestion, 151, 157
  - convection and conduction, 145
  - dive response – forced submersion, 150

- feathers
  - air layer, 156
  - cormorant feather structure, 156
  - critical water penetration pressure, 156
  - structure and density, 156
  - water repellency, 156
- forced submersion
  - A-V shunt – cooling, 150
  - brain temperature, 150
  - temperature decline, 146
- heat dissipation
  - skin hot spots, 149
- heat flux
  - brood patch, 157
  - dorsal fin, 150
- heat increment of feeding, 145, 147
- heat loss, 145
  - appendages, 149
  - appendages – birds, 157
- hypothermia
  - neuroprotection, 146
  - Q<sub>10</sub> effect, 146
- insulation, 145
  - blubber, 148
    - blood flow, 148
    - heat conductivity and thickness, 148
    - lipid content, 149
    - temperature difference, 148
  - feathers, 156
  - fur – thermal resistance, 148
  - hair density and morphology, 148
- metabolic efficiency, 145
- muscle
  - mitochondrial leak, 147
  - secondary heat production, 146
- respiratory heat loss, 150
- shivering, 145
- specific dynamic action, 145
- vasoconstriction, 145
- water
  - heat capacity, 145
  - heat conductance, 145
- thick-billed murre
  - dive behavior, 15
- total body O<sub>2</sub> stores
  - distribution of O<sub>2</sub> stores, 63
  - marine mammals and seabirds, 63
- trained submersions
  - cardiac output, 80
  - cerebral blood flow, 80
  - contraction/relaxation of the spleen, 80
  - heart rates, 79
  - muscle blood flow and oxygenation, 80
  - stroke volume, 79
- translocation model
  - elephant seals, 184
- tufted duck
  - dive behavior, 19
- vasoconstriction
  - coronary artery innervation, 78
  - extramuscular proximal arteries – seals, 77
  - forced submersion, 71
  - vascular nerve fiber distribution, 119
    - duck, 100
    - seals, 77
- vena caval sphincter
  - anatomy and function, 125
- ventilation
  - air-sac pressure oscillations – diving, 40
  - avian air flow pattern, 40
  - max. oxygen consumption
    - marine mammals, 39
    - penguins, 43
  - respiratory rate
    - penguins, 43
    - marine mammals, 39
  - tidal volumes
    - birds, 43
    - marine mammals, 39
- vibrissae
  - sensory function, 30
- walrus
  - dive behavior, 8
- wandering albatross
  - dive behavior, 14
- Weddell seal
  - dive behavior, 3
- wedge-tailed shearwater
  - dive behavior, 13
- western grebe
  - dive behavior, 19
- Westland petrel
  - dive behavior, 13
- white-chinned petrel
  - dive behavior, 13
- Xantu's murrelet
  - dive behavior, 15
- yellow-eyed penguin
  - dive behavior, 18