Edited by John S. Lucas & Paul C. Southgate

# Aquacutic animals and plants

SECOND EDITION

**WILEY-BLACKWELL** 

abalone (Haliotis species) biology, 569-70 commercial species, 569 culture, 570-6, 580 diets, 574-5 diseases, 575 life-cycle figure, 571 nacre, 570 production statistics, 568, 569-70 acclimation (rapid adaptation), 496 rates during stocking, 496-7 to salinity changes, 325, 328, 496, 518-19 to temperature changes, 64, 387, 496 acid stress, 65 actual costs, 254 adaptive immune response, 447 adjuvants, 456-7 aeration in larval rearing, 390, 549 of raceways and cages, 75-6 of ponds, 30, 71-5, 373-4, 499-500 of tanks/raceways, 326, 341 standard aeration efficiency (SAE), 74 aerators, 74 paddle wheel, 74, 114, 358, 359, 374, 500 propeller-aspirator-pump, 74 vertical púmp, 74 aerobic decomposition of organic matter, 61-2, 69, 72, 73 reactor, 103 sediment, 61-2, 74

aesthetics, 97-8 agriculture origins, 2 airlift pump, 75 Akoya pearl oysters, 563 algal culture, see seaweed and microalgae alkalinity (total), 58-9, 68-9, 76-9 allegory, 11-12 alum turbidity control, 76 alum-based adjuvants, 456 amino acids essential for carp, 299 essential for fish (general) (EAAs), 169 - 70essential for juvenile fish, 171 non-essential for fish (general), 169, 299 ammonia and ammonium NH<sub>3</sub>/NH<sub>4</sub><sup>+</sup> equilibrium, 67 pH and temperature effects, 67 excretion, 67 total ammonia nitrogen (TAN), 67 toxicity, 67, 391 ammonium hydroxide, 548 amnesic shellfish poisoning, 557 amoxycillin, 361 anaerobic organic matter decomposition, 61 sediment, 62, 89, 485, 558 anaesthetics, 415 anadromous fish, 315, 384, 424, 443 androgenesis, 149-50 anaerobic metabolism, 543 animal welfare, 99, 236 annual production statistics, see global production anoxic conditions, 21, 112, 308

antibiotics, 96, 210, 220, 224, 361, 416, 460 declining antibiotic usage, 445 impacts, 96 see also pharmaceuticals antibodies, 220, 446-7, 449, 461 antifoulants, 96 tributyl tin oxide (TBT), 96 antifungal agents, 210, 270 antigens, 219, 446-9, 452, 456 antigen-presenting cells (APCs), 447-8 antioxidants, 209-10, 411, 504 aquaculture challenges, 607-8 constraints to development, 11 definition, 1 distinguished from agriculture, 2 distinguished from fisheries, 1 diversity, 12 future, 16, 105, 123-4, 161-2, 182, 283-4, 289-90, 511, 607-9, 615 growth rate, 4-11 open ocean, 613 origins, 2 recent trends, 606 aquaculture and fisheries products, 231 - 2aquarium hobby, 583, 585, 603 Arabian Gulf, 117 Arava Valley, 108 Artemia (brine shrimp) commercial production, 123 culture, 197, 404 cysts, 196-7 fatty acid composition, 198 fatty acid (HUFA) enrichment, 197-8,402

Aquaculture: Farming Aquatic Animals and Plants, Second Edition. Edited by John S. Lucas, Paul C. Southgate. © 2012 Blackwell Publishing Ltd. Published 2012 by Blackwell Publishing Ltd.

Artemia (brine shrimp) (cont'd) marketing, 611 production in field, 120-1 Artemia (brine shrimp) used in culturing Chinese mitten crab larvae, 519 fish larvae and juveniles, 404, 420-43 Macrobrachium larvae, 525 mud crab larvae, 535-6 ornamental fish, 602 shrimp larvae, 489 spiny lobster larvae, 538 artificial hatchery feeds, see larval and juvenile feeds artificial propagation, 296 Asian seaperches (Lateolabracidae) culture Japanese seaperch, 423 astaxanthin, 210, 332, 410 Atlantic salmon (Salmo salar) biology and habitats, 315 global production, 314 grow-out farming, 327-33 harvest and processing, 336 hatchery and nursery culture, 318-25 reproduction and life cycle, 316 smolt, 324-5 see also salmonids Australia (statistics), 285, 314, 570 autosomes (general chromosomes), 344 average cost of production curve, 259 B lymphocytes, 446-8 Babylonia spirata, 568 bacteria (non-pathogenic) denitrifying, 59-60, 61, 62 in anaerobic sediment, 62 in global N cvcle, 59 in product spoilage, 241, 243 nitrifying, 36, 59, 60, 61, 73 Bangladesh, 6, 477-8, 524 barramundi (Lates calcarifer) cage farms, 608 diseases, 226, 227, 423 feeds, 422 growth rate, 422-3 hatchery culture, 422

vaccination, 454

basa, see pangasid catfish

#### Index

bass (Moronidae) culture European sea bass, 424 striped bass, 424 sunshine bass, 424-5 benefit-cost, 255 benefit-cost ratio, 254-5, 260 see also cost-benefit ratio benthic community impacts of bivalve culture, 92-3, 558-9 impacts of cage culture, 91-2 best management practices (BMPs), 81, 101, 511-2 Codes of Practice, 511 β-carotene production, 122-3, 265 bighead carp (Aristichthys nobilis), 295, 296, 297, 304 biofouling, 330, 555-6 biological filtration, 36, 111-12 see also filters biological oxygen demand (BOD), 86-8, 497 bioremediation, 279-81, 283 bio-security, 217, 507-8 biotoxins, 556-8 bivalve molluscs aerobic metabolism, 543 attributes for culture, 541 biotoxins, 556-9 breeding programs, 553-4 Condition Index (CI), 544 culch, 547-8 diseases, 555 environmental impacts, 92-3 filter feeding, 542-3 global production, 545 grow-out farming, 552-3 growth, 543 hatchery culture, 549-52 morphology, 541-2 predators, 554, 555 reproduction, 543-4 spatfall culture, 547-8 species in culture, 545-7 see also clams, mussels, oysters, pearl oysters, scallops black carp, 31, 295, 296, 297, 301-2, 308-9 black tiger prawn, see giant tiger prawn blue-green algae (cyanobacteria), 59, 60, 230, 355, 361, 375 producing off-flavours, 78, 238, 375

'Blue Revolution', 6 boring polychaetes, 222, 575 boron fertiliser supplement, 71 natural levels, 54 brackish water estuarine, 34 groundwater, 32, 107 Brazil (statistics), 339, 478 brine shrimp, see Artemia broodstock fish, 397 induced ovulation, 398-400 natural ovulation, 397-8 brown water, 407 business risk and uncertainty, 261-3 bycatch (from fisheries), 4, 5 cages (general structure), 23-5, 329-30 submersible cage, 7 cage culture, 76, 91-2, 357, 608 biofouling and net changing, 330 environmental impacts, 91-2 oxygen levels, 76, 77 predator problems, 330-1 Canada (statistics), 314, 419, 584 cannibalism, 199, 230, 408, 536 grading against, 427, 428, 430 canning products, 249-50 capital depreciation costs, 115 capture fisheries, see fisheries carbohydrates content of microalgae, 192 digestion, 166, 409-10 metabolism, 68, 172, 177 poor feed for carnivores, 168-9, 409 - 10carbon dioxide (CO<sub>2</sub>) dissolved, 58, 391 in rainwater, 58 toxicity, 66 carbon dioxide solubility temperature and salinity effects, 56 carbon dioxide toxicity, 66 carbon dioxide/carbonate/bicarbonate system, 58 carotenoids, 99, 210, 284, 602-3 carps (family Cyprinidae) biology and habitats, 294-6, 576 breeding programs, 308 broodstock spawning, 296-9 diseases, 307 foods and feeding, 304-6 global production, 295

growout (farming), 102, 103, 112, 295, 301-4 harvesting, 306-7 hatchery and nursery phases, 300-1 natural food availability 304-5 nutritional requirements, 299-300 pond production yields, 304, 309 species, 296 see also integrated agriaquaculture, polyculture and species catla (Catla catla), 295, 296, 304 CD4<sup>+</sup>helper T Cells, 447, 448 cellular response, 447 channel catfish (Ictalurus punctatus) attributes for culture, 365, 366-7 biology and habitats, 365-6 diseases, 376-80 grow-out farming, 367-8, 371-3 harvesting and processing, 380-1 industry future, 381-2 nursery culture, 370-1 nutrition and feeds, 375-6 production statistics, 366 reproduction and breeding, 368-71 water quality management; 373-4 char (charr), see salmonids chemical additives, 95-6 Chile (statistics), 8, 182, 268, 314, 419, 570 chilling (post-harvest), 236, 361 China (statistics), 8, 27, 182, 269, 271, 285, 461, 464, 477-8, 517, 524, 568, 570 growth of aquaculture, 8-9, 258 Chinese bream, 296 Chinese mitten crab (Eriocheir sinensis) annual production, 517 biology and habitats, 517-8 grow-out farming, 521-2, 523 hatchery culture, 518-20 marketing, 522-3 nursery culture, 520-1 Chinese mystery snail, 531, 567-8 chinook salmon (Oncorhynchus tshawytscha), 314, 317 see also salmonids Chloramines-T, 361 chloride in fertiliser, 71, 79 natural levels, 53-4 treating nitrite toxicity, 67

chlorine sterilising, 46, 218 toxicity, 392 cladocerans as larval feeds, 386-7, 402-3, 405-6 clams and cockles, 545, 546-7, 562 see also bivalve molluscs clay turbidity control limestone and fertiliser, 78 alum, 78 gypsum, 78 limestone and fertiliser, 78 cloning, 149-50, 452 clownfish culture, 586-7 coastline degradation, 89-90 cobalt, 54 cobia (Rachycentron canadum) feed, 429 global production, 429 growth rate, 429 larval development, 428-9 pathogens, 429 cockle culture, 562 see also bivalve molluscs cod (Gadidae) culture Atlantic, 421 Haddock, 421 Pacific, 421 colE1, 452 cold blooded, see poikilothermy commercial vaccine project, 458 development phase, 458 common carp (Cyprinus carpis), 2-4, 31, 102-3, 113, 115, 140-8, 150, 151, 155, 158-9, 166, 169-71, 174, 183, 294-5, 299, 302, 307, 308, 304, 368, 396, 464 communication, 614 compactor, 119 compensation depth, 57 conch (Strombus gigas) biology and habitat, 576 commercial importance, 576 culture, 576-7 life-cycle stages, 575-7 concrete tanks, 358, 396, 464 condition index (CI), 136-7 constricted tagelus (razor clam), 545 consumption and price, 356-7 contaminants from culture facilities, 392 contamination of product, 98-9 co-operative marketing, 259

copepods, 198-9, 404-5 as larval and juvenile fish feed, 198, 404, 409, 588 calanoid, 198, 404 culture, 199, 405 cyclopoids, 198, 404 harpacticoid, 198, 404 coping with uncertainty, 262 copper fertiliser supplement, 71 natural levels, 54 plant nutrient, 59 copper sulphate, 361 copper sulphate added to ponds concentration and time, 77 controlling blue green algae, 78 controlling phytoplankton, 77 corals and anemone culture disc anemones, 591 sea anemones, 590 soft corals, 590 stony corals, 588-90 zooanthid anemones, 590-1 coral reef fish culture techniques, 587-8 larval feeds, 588 major species, 586-7 production centres, 587 corporate social responsibility, 611 cost-benefit, 254 costs per unit of production, 259 crab predators, 554 crossbreeding heterosis (hybrid vigour), 140, 145 - 8interspecific crossing, 147-9 intraspecific crossing, 145-7 crucian carp (Carassius carassius), 295, 304 crude fibre in feeds, 410 culchless oysters, 548 culchless spat, 551 culture-based fisheries, 308-9 culture intensity comparisons, 26-32, 304, 341, 481 culture structures, choice, 394-7 cytokines signalling, 448 cytotoxic T cells, 447, 453 cytotoxic CD8+T cell, 448 debt-equity ratio, 263

decapod crustaceans global production, 516 growth, 134–5

decapod crustaceans (cont'd) morphology, 514-15 moulting, 135 reproduction and life cycles, 128-9, 515-16 size measurements, 137 see also species definition of aquaculture, 1-2 demand and supply, 257 demand curve, 256 denitrification, 36, 60, 73, 394 depuration, 231, 558 derris powder, 96, 300 desert aquaculture defined, 107 'desert sweet tomatoes', 110 'designer feeds', 615 'designer fish', 615 diadromous, 384 fish, 419 diatoms, 88-9, 91-3, 191-2, 487-8 digestible energy, 166-8 digestion and absorption, 116 digestive system of fish, 165-6 dinoflagellate toxicity, 556-7 discount rate, 260 discounted benefits, 253, 254 discounted costs, 253, 254 discounted value of future profits, 253 disease and culture density, 215-16 costs to industry, 214 philosophy of control, 216-17 Sneizko ring, 215 transgenic resistance, 157-8 disease management, 217, 359 batch culture, 217-18 intake water treatment, 218 lower stocking density, 218 single spawning stockings, 218-19 specific pathogen-free broodstock, 219 stress reduction, 219-20 vaccination, 219, 220, 445-58 see also pathogens disease transfer, 45-6, 93-4, 331 disinfection equipment, 392, 415 feed, 416 pond substrate, 385-6 dissolved gaseous nitrogen (N<sub>2</sub>), 60-1, 318 dissolved nutrients, 2, 89 dissolved organic carbon/compounds/ matter, 36, 54

# Index

dissolved oxygen (DO), 55, 65, 391 diurnal cycle, 61 effect of barometric pressure, 55 effect of temperature and salinity, 55 tolerated levels, 65 diversification and expansion, 261-3, 613 diversity of cultured species, 12 DNA cDNA libraries, 159 markers, 160, 249 vaccines, 450-3, 457 vaccine plasmid, 453 dolphinfish (Coryphaenidae) culture common dolphinfish, 431 domestic sewage fed aquaculture, 101-3 domestication and cross-breeding, 146 and strain evaluation, 140-1 carp, 307 shrimp, 490, 510 drip-irrigation, 110 drums (Sciaenidae) culture croakers, 436 meagre, 436 red drum, 435 spotted seatrout, 436 white seabass, 436 Dunaliella salina, 121-2, 192, 285 - 7economic cost. 254 economic failure, 50, 252 economic terminology, 253 economic uncertainty, 261 economic viability, 307 economics of reservoir vs. pond culture, 115 economies of scope (or diversification), 261-3 scale, 259-61 specialisation, 261 ecosystems, see natural ecosystems ectothermy, see poikilothermy eels (Anguilla species) elvers, 418 feeds, 419 growout, 420 European eel, 418 Japanese eel, 418 shortfinned eel, 418 snake eel culture, 420

effluent and wastewater treatment, see bioremediation effluent from aquaculture, 30, 80, 81, 85-9, 509-10 cf. domestic and industrial effluent, 88 from ponds, 80 impacts, 85, 88 re-cycling, 103, 111-12, 279-81 sources and composition, 88 use in irrigation, 112, 115, 509 eggs general fertilisation, 131 yolk, 131-2 see also fish eggs egg yolk paste, 301 Egypt (statistics), 339, 419 elvers, 418 emperors and sweetlips (Lethrinidae) culture spangled emperor, 434 trumpet emperor, 434 enclosures, 25, 33, 537, 562, 598 energy partitioning, 167 enrichment of larval feeds, 197-8, 402, 404, 406 environmental impact assessment (EIA), 99 environmental impact statement (EIS) 99-100 environmental impacts of aquaculture aesthetic impacts, 97-8 bivalve and cage culture, 91-3 coastal degradation, see topic development, 612, 613 disease transfer, 93-4 effluent, see topic exotics, 94-5 'genetic pollution', 95 mangroves see mangroves miscellaneous, 99 pollutants, 85-8 poor image, 84-5 positive, 103-4 social aspects, 97 environmental quality objectives (EOOs), 100 environmental quality standards (EOSs), 101 environmental restoration, 613 environmental spillovers, 264, 265 environmental tolerances, see water quality tolerances and optima epistasis, 140

epitopes, 447, 449 equity, 253, 263 erythromycin, 361, 394 escaping animals, 94, 95, 96, 286, 330, 465, 615 Escherichia coli, 450, 558 essential amino acids (EAAs) for carps, 299 for fish (general), 169-2 for juvenile fish, 171 estuaries, 34, 50 eutrophication, 60, 88 exogenous antigens, 449, 450 exotic species, see translocations extensive culture, 28-9, 164-5 carps, 309 fish larvae, 406 freshwater crayfish, 531-2 shrimp, 481, 482-3 tilapia, 354-5 fallowing, 92, 328 Family Cyprinidae, 294 FAO Fishstat Plus 2009, 5, 17 fatty acids, see lipids and fatty acids favourable spillovers, 264 fecundity, 47 feed additives (non-nutritive), 71, 209-10, 410-11, 504 anti-oxidants, 209-10, 411, 504 feed components fish meal, 204-6 groundnut/peanut meal, 204 maize meal, 204-6 rice bran, 204 shrimp meal, 204 typical components, 207 feed crumbles, 202, 352 feed formulation (general), 176, 177-8, 204-7 protein to lipid ratio, 175 feed formulation for carps, 301, 305 channel catfish, 377 fish, 331, 411-12 salmonids,'180 shrimp, 503-4, 510-11 soft-shelled turtle, 470 tilapia, 350–2 feed input and management, 181, 306, 352 delivery methods, 211-12, 332-3, 412 - 13factors influencing, 354, 504-5, 506

frequency, 181-2, 412 frequency and time, 354, 506 mixed feeding schedules, 182 ration, 210-11, 353, 354, 506-7 feed manufacture compressed pellets, 207-8 dry pelleted feeds, 179-80, 207-8 extruded pellets, 208 farm-made feeds, 178-9 wet and moist feeds, 179-80 feed pathways in ponds, 72-3, 306 feed selection, 180-1 feed storage and deterioration, 208-9 feed-related issues (global), 182 direct use of trash fish, 184-5 fish meal and fish oil, 182-4 principles for aquafeed developments, 185-6 feed trays, 506-7 feed wastage, 86, 333, 473 Fenneropenaeus, 117 Fenneropenaeus indicus, 118 fertilisation of ova by sperm, 150 fertilisers, see pond fertilisation fermentation anaerobic, 61-2 feeds during storage, 209 vaccine preparation, 452 fillet processing, 15 filter-feeding, 542 filters and filtration, 36, 486-7 biological, 36, 111-12 fish (marine and diadromous) culturing systems, 395-6 demersal, 384, 401 early development, 131, 384, 386-7, 418-43 juveniles, 386 larvae, 386-7 planktonic, 384, 386, 401 progressive feeding protocol, 199-200 transformation, 386-7, 418-43 weaning, 381, 402, 406, 408 weaning crumbles, 202, 352 see also information on individual species, 417-43 fish eggs, 384, 386 collection, 396 disinfection, 401, 415-16 fertilisation, 386 quality indicators, 399-400 stripping, 131, 139, 319, 400-1, 549

fish immune systems, 416, 445-9 see also vaccines fish juveniles, optimum conditions, 387-94 fish meal, 183-4, 612 plant substitutes, 412, 503 reduction in use, 186, 411-12 fish muscle structure, 234 texture, 239 fish oil, 182, 184, 494, 611, 612 plant substitutes, 412, 503 fisheries (capture production) bycatch, 4-5 cf. aquaculture, 4-5 environmental impacts, 10 production statistics, 4 fixed costs, 262 flavours see off-flavours and taints and spoilage of products flesh texture, 239 foam fractionation, 36, 392 food conversion efficiency (FCE), 144 food conversion ratio (FCR), 86, 87, 324, 409 food fish, 10, 606, 607 global needs, 609 regional consumption, 10 food security, 609, 613 formalin, 90, 361, 378, 399, 413, 414, 449 fouling, see biofouling freezing products, 242-4 freshwater alkalinity (total), 58-9, 68-9, 76-9 buffering, 390 carbonate system, 58 hardness, 68 freshwater cf. saline water, 53-4 freshwater crayfish biology and habitats, 529-30 culture methods, 530-2 pond management, 531-2 production and markets, 527-9, 532-3 species, 527 freshwater mussels, 545 freshwater ornamentals see ornamentals (freshwater fish) culture

#### 621

freshwater prawns (Macrobrachium species) biology and habitats, 523-5 global production, 524 grow-out farming, 526-7 hatchery and nursery culture, 525-6 freshwater sources, 34 geothermal, 108-12 groundwater, 34, 52, 58-9 storm runoff, 52, 88 frozen storage, 244-6 future opportunities, 615 gas bladder inflation in fish larvae, 389, 393 gas bubble trauma, 66, 393 gas supersaturation, 66 gastropods culture comparison, 580 global production, 568 marine, 567 predators, 554 see also abalone, stromb, trochus gene action, 138, 140 gene expression, 138-9 genetic engineering see transgenic fish genetic improvement, 307, 510 genetic interaction, 95 genetically improved farmed tilapia (GIFT), 343 GenoMar Supreme Tilapia<sup>™</sup>, 343 genomics and QTL mapping, 159-60 genotype-environment interactions, 140, 160-1 geothermal water, 108-12 Germany, 102 giant clam, 257, 259, 544, 562 giant tiger prawn (Penaeus monodon), 177, 214, 223, 479, 490 decline in production, 16, 479 glass eel, 418 global aquaculture production, 4-7, 607 developed countries, 8 developing countries, 8 top ten producers, 8 see also individual country statistics global meat production, 295, 559 animal protein, 5-6 aquaculture, 4-7, 607

fisheries, 4-5, 607

#### Index

food fish, 9-10, 607 livestock, 5 global nitrogen cycle, 59 global production of species/groups aquatic plants, 6, 183 bivalves, 6, 183 carps, 295 crustaceans, 6, 183 fish (all), 6, 183 major fish species, 183 marine and diadromous fish, 419 molluscs, 6, 183 ornamental fish, 583 pangasid catfish, 9 salmonids, 9, 314, 418 seaweed, 268-9 tilapia, 9, 338, 339 GnRHa, 398-9, 422, 424-5, 433 gobies (Gobiidae), 438 gonad index, 570, 572, 591-2 gonad stripping, 131, 139, 319, 400-1, 549 gonadotrophins, 126, 297 grading, 324, 333 grass carp (Ctenopharyngodon idella), 90, 91, 295, 296, 297, 304 Greece (statistics), 419 'green water' culture, 407-8 greenhouse culture, 82, 110, 116, 419, 474 groundwater, 52-3, 58-9, 68, 79 grouper (Serranidae) culture feeds, 426 larval development, 425 spawning, 425 weaning, 426 grouper (Serranidae) species barred-cheek coral trout, 428 brownmarbled, 427 camouflage, 427 Goliath, 428 greasy, 427 kelp, 427 king (giant), 427 Malabar, 427 Nassau, 428 orangespotted, 426-7 polka-dot, 427 redspotted, 426 squaretail, 427 growth, 133-7, 543 absolute growth rate, 133-4 coefficient, 134 compensatory, 182

measurement, 135-6 relative growth rate, 133-4 scope for growth, 543 grunts (Haemulidae) culture silver grunt, 432 threadline grunt, 432 yellowspot grunt, 432 gynogenesis, 149-50 gypsum, 76, 77, 78 Haliotis asinina, 570, 574, 581 Haliotis laevigata, 570 Haliotis rubra, 570 handling stress, 393 hand-sexing, 345, 527 hapas (pens), 25, 348-50 hard clam, 562 hardness of water total, 58-9, 68-9, 76-7 harvesting (principles), 232-4 hatchery culture abalone, 571-3 bivalves, 548-51 carps, 296-9 channel catfish, 369-70 freshwater crayfish, 530-1 freshwater prawns, 525 marine and diadromous fish, 385 mitten crab, 518 mud crabs 535-6 salmonids, 318-22 shrimp, 488-94 soft-shelled turtles, 466-8 stromb, 577 tilapias, 348-50 trochus, 578 hatchery systems (general), 44-6 comparison for tilapia, 348 helper T-cell, 453 heritability, 140, 143, 160 hermaphrodite, 129, 153 protogynous, 425 protandrous, 433, 544 simultaneous, 544 herring culture (Clupea species) Atlantic, 420 Japanese sardine, 420 Pacific, 420 heterogametic, 344 high-density flow-through culture, 551 highly unsaturated fatty acids (HUFAs), see lipids and fatty acids

energetics, 135, 543

homogametic, 344 horizontal axial-flow circulator, 74 hormonal sex reversal, 347 hormones, see reproductive physiology human chorionic gonadotrophin (HCG), 127, 398-9, 425 humoral immune response, 447 Hungary, 103 hybridisation heterosis (hybrid vigour), 140, 145 - 8sterility, 151 hydrogen peroxide spawning induction, 548, 571 sterilising 320, 361, 401 treating ectoparasites, 413, 414 hydrogen sulphide, 391-2 toxicity, 68 hydroponics, 2 hypochlorite sterilising, 197, 404, 550 hypersaline environment, 120-1, 123 illumination coral culture, 598-9 larval rearing, 388-9 mass microalgae culture, 288 solar, 56 immersion freezing, 243-4 in chemotherapeutic treatments, 361 immersion or bath vaccination, 220, 360, 378, 453-7 immune memory, 447, 449-50, 453 immune responses crustaceans, 219 fish, 447-9, 457 shrimp, 494 immunogen, 447 immunoglobulins, 446, 447 impacts of antibiotics, 96 inbreeding, 145, 147, 307 income distribution, 265 increasing salination, 124 India (statistics), 8, 101, 285, 305, 419, 477-8, 524 Indonesia (statistics), 8, 182, 271, 339, 419, 477-8, 524, 584 inorganic N, see ammonia, nitrate, nitrite insect predators, 300 insurance policies, 615

integrated agri-aquaculture, 30-2, 109, 303, 309, 356, 522, 531-2 balance sheet, 309 with saline water, 109-11, 509 integrated biosystem, 104 integrated resource management (IRM), 103 integrated wastewater treatment, 103-4 intensive culture, 27-8, 164-5 fish larvae, 406 freshwater prawns, 527 shrimp, 481, 483 tilapias, 341, 356-7 internal rate of return (IRR), 253, 255, 2.60introductions, see translocations ion concentrations ponds, 54 seawater, 54 ion regulation (animals), 63-4 IP injection, 455 iron bacterial reduction, 61-2 fertiliser supplement, 71 natural levels, 54 plant nutrients, 59 Israel (statistics), 108 jacks (Carangidae) culture, 429-31 gold-striped amberjack, 430 great amberjack, 430

Japanese yellowtail, 429–30 Mazatlan yellowtail, 430 permit, 431 snubnose pompano striped jack, 431 Japan (statistics), 8, 12, 13, 27, 182, 268, 271, 419, 584 Japanese carpet clam, 545, 562

kelp, *see* seaweed
kinetics of immune response, 449
knifejaws (Oplegnathidae) culture
striped knifejaw, 436
Korea (South) (statistics), 8, 271, 419, 570
Korea (North) (statistics), 271
laminar-flow cabinet, 189

Laminaria (Phaeophyta) see Saccharina and seaweed lantern nets, 552 large tank management, 550

larval and juvenile feeds compound feeds, 200-2 live feeds, see Artemia, copepods, microalgae, rotifers microbound diets, 201 microencapsulated diets, 201 plankton harvesting, 202 pond production, 202-4, 406 progressive feeding protocol, 199 larval culture, see hatchery culture lates perches (Latidae) culture, 422-3 barramundi see barramundi Japanese lates (snook), 423 laver, see Porphyra and seaweed life-cycle culture methods (general), 129-33 see also species topics life-cycle diagrams abalone, 571 Atlantic salmon, 316 mud crab, 534 pearl oyster, 130 seaweed, 273-4 tilapia, 345 lime agricultural limestone, 69, 78 burnt, 69 calcite, 58, 69 dolomite, 69 hydrated, 69 lime requirements vs. pH and soil texture, 60-70 liming, see water quality management in ponds limited liability, 263 'Linpe method', 297 lipid and fatty acid requirements carps, 299-300 crustaceans, 173-4 marine fish, 409-10 tilapias, 351 lipids and fatty acids (general fish) dietary requirements, 171-5 dietary requirements and trophic level, 174 energy source, 172, 175 high energy diets (HED), 175 metabolism, 172-3 structure, 172-3 live transport, 232-4 lobsters (spiny, rock and squat), 258 long-line culture bivalves, 552-3 seaweed, 276-7

Index

loss of distinct stock integrity, 95 loss of genetic diversity, 95, 282 luteinising hormone-releasing hormone analogue (LHRHa), 127-8, 297 macroalgae, see seaweed Macrobrachium, see freshwater prawns macrophages, 220, 446-8, 453 magnesium natural levels, 53-4 pH regulation and ions, 69, 71, 79 plant nutrient, 59 magnesium sulphate, 70 main drain canal, 120 major histocompatibility complex, 446 Malaysia, 608, 610 manganese bacterial reduction, 61-2 fertiliser supplement, 71 natural levels 54 plant nutrient, 59 mangroves, 89, 90, 264, 537 depletion, 90 marine mussels (Mytilidae), 545, 560, 561 market acceptance, 15, 457 access, 609-11 demand, 256, 336, 366, 528, 590 equilibrium, 256 model, 256 rate of interest, 254 supply, 256, 326 transaction cost, 253, 259 market size, 46, 47 freshwater prawns, 526 marine fish (various species), 385-442, 443 mitten crab, 521 ornamentals, 603 salmonids, 313 tilapia, 338 mass mortalities bivalves, 214, 555, 556, 557, 559 decapod larvae, 536 shrimp, 214, 223 salmon, 214 Mediterranean mussel, 561 Mekong Delta/river, 14-16, 179, 482 memory  $\beta$  cells, 448 Mexico (statistics), 339, 478, 570

microalgae biochemical composition, 192-3, 403 concentrated and dried forms, 194 morphology, 189 species, 192-3 species used for fish larvae, 405 species used for shrimp larvae, 494 tolerances, 193 use in hatcheries, 188 microalgae, hatchery production induced bloom, 188-9 nutrient media, 191 phases of cell density, 189-90 recent developments, 193-4 scale-up, 189-90 microalgae, large-scale production, 284-5, 291 'big bag' systems, 288 Dunaliella salina, 121-2, 287 flat-panel photobioreactor, 289 for biofuels, 289-90 global production, 285 heterotrophic, 289 intensities of culture, 286-90 photobioreactors, 286, 288-90 production costs, 286 species employed, 285 tubular photobioreactor, 288-9 milkfish (Chanos chanos) juveniles, 10 nutrition, 10 spawning and larvae, 40 stocking, 10 mojarras (Gerreidae) culture striped patao, 432 molybdenum, 54 monogenean flatworms, see pathogens and pathogens of marine fish moonyfishes (Monodactylidae) culture Eastern pomfret, 436 mrigal carp, 295, 296, 304 mud carp, 27, 51, 297, 309 mud crabs (mangrove crabs) (Scylla species) biology and habitats, 533-4 hatchery culture, 535-6 markets, 538 nursery and grow-out culture, 356-8 problems with culture, 536 species, 533 wild-caught 'seed', 534-5 mullet polyculture, 113

mullets (Mugilidae) culture liza, 437 redlip mullet, 437 So-iny mullet, 437 striped mullet, 437 white mullet, 437 multinationals, 611 mussels, 546, 553, 560-1 N and P budgets in ponds, 73 N compounds (non-protein) in seafood, 238-9 nacre, 547, 570 abalone, 570 pearl, 148, 304, 545, 547, 564 naïve T cells, 447, 448 National Prawn Company (NPC), 117, 118 natural aquatic ecosystems, 26-7 natural food availability (carps), 304-5 Negev Desert, 108 net income, 309 net profitability, 260 networks (producers), 280, 614 neurotoxic shellfish, 557 new species in aquaculture development, 48-50 selection, 46-8 New Zealand (production statistics), 570 nitrate, 59-60 in fertilisers, 71 low toxicity, 73, 79, 391 nitrification, 79 neutralising acidity from, 79 nitrifying bacteria, 36, 59, 60, 61, 73 nitrite, 59, 60, 61, 67 and methaemoglobin, 67 toxicity, 67, 391 nitrogen (N<sub>2</sub>) dissolved, 60-1, 318 nitrogen cycling, 92 nitrogen, global cycle, 59 noise, 98, 389-90 nominal rate of interest, 253, 254 nori, see Porphyra and seaweed Norway (statistics), 182, 268, 314, 419 nucleotides, 234-5 nutritional food value of salmon and tilapia. 362 nutritional problems in fish, 411 nutritional requirements (general fish) carbohydrates, 177 energy, 167-9 lipid and fatty acids, 171-5

minerals, 176-7, 410 protein and amino acids, 169-71 vitamins, 175-6, 351 octopuses, 554 off-flavours and taints, 237-8, 361, 375 see also blue-green algae oil-adjuvants, 456 oil-adjuvanted vaccines, 457 open channels, 37, 39 open culture systems, 32-3 open ocean aquaculture, 613, 614 opportunity costs, 254 optimum conditions for juvenile marine fish, 387-94 oral vaccination, 455 Oreochromis (tilapia) species, 340, 342 ornamentals (freshwater fish) culture feeds, 600-2 indoor tank, 599 industry structure, 594-5, 597 large tank and raceway, 599 nutrition, 612-3 pond, 598-9 ornamentals (freshwater) families/ species cichlids, 596 common names, 598 egg-layers, 600 goldfish, 596, 597 gouramis, 596-7 'live-bearers', 595, 600 tetras, 595 ornamentals (marine) culture gastropods, 592 giant clams, 592 'live rock', 392-3 shrimps, 591 see also coral reef fish and corals and anemones ornamentals trade culture vs. field collection (marine), 593-4 global, 583-4, 587, 594-5, 603 shipment, 595 tropical freshwater species, 594-5, 597-8 tropical marine species, 585-6 osmoregulation, 63-4 outflow water pump, 120 oysters, see table oysters ozonation, 392 toxicity, 392

Pacific oyster, 142, 147, 221, 545, 549, 555, 558, 559 packaging products, 246-8 paddy-field aquaculture, 522, 531-2 pangasid catfish, 14-16, 17 'basa' (Pangasia bocourti), 16 culture methods, 16 favourable attributes, 14 industry growth, 16 post-harvest, 16, 17 'tra' (Pangasia hypophthalmus), 16 Paralichthyes olivaceus (Japanese flounder), 13 paralytic shellfish, 557 parasites, see pathogens paratopes, 447 particulate organic matter (POM), 54, 86 optimum levels for bivalves, 543 pathogens bacteria, 215, 216, 221, 224-7, 359-60, 445, 456, 472, 575 crustacea, 96, 215, 335, 360, 413-14 flatworms (helminths/ monogeneans), 215, 379, 413, 555 fungi, 215, 222, 224-5, 226, 320, 360, 378, 413, 530 gastropods, 222 lampreys, 414 leeches, 414, 472 nematodes, 231, 379, 413, 555 polychaete worms, 222, 555, 575 protozoa, 215, 220-2, 226, 228, 260, 378-9, 413, 472, 394, 413 sponges, 222 viruses, 143, 157, 215, 217-18, 221, 222-4, 225, 227-8, 360, 377-8, 413, 450-1, 471, 479-80, 501, 575 pathogens of marine fish, 419-43 see also diseases/pathogens of particular organisms peanut/groundnut cake see groundnut pearl mussels, 148, 304, 545, 547, 564 pearl oysters, 541, 547, 562-3 pearls, 545, 562, 563 pelleted feeds, 179-80 binders, 200, 210, 504 components, 180, 204-8, 352 compressed pellets, 207-8

extruded pellets, 208 formulation, 180-1 non-nutritive components, 210, 410-1, 504 sizes, 352 storage and chemical changes, 208-10, 504 Penaeus monodon, 117 Penaeus semisulcatus, 117 pens, see hapas perches (Percichthyidae) culture Australian bass, 424 Chinese perch (Mandarin fish), 423-4 pesticides, 96, 300 pН defined, 57 influence on un-ionised ammonia, 67 influence on un-ionised hydrogen sulphide, 67 managing, 65, 69-70, 76 toxicity, 64-5, 390 pharmaceuticals (drugs), 361, 417 see also antibiotics phenotypic variation, 138-9, 140 Philippines (statistics), 8, 89, 182, 271, 339, 419, 584 phosphorus (P) as fertiliser, 61, 70, 71, 73, 203, 352-3 effluent content, 88 in metabolism, 172, 175 water content, 54, 59-60, 61, 68 phyllosoma larvae, 538-9 phytoplankton in ponds control with copper, 77-8 effects on pH, DO and water quality, 60-1 fertilising, 69-71, 202-4, 487 levels, 488 plankton harvesting, 202 plasmid construct, 452 plasmid or cosmid vector, 451 pleiotropy, 140, 158-9 plumbing pipes, 37-9 see also pumps poikilothermy, 2, 168, 462 pole culture, 560-1 polyculture, 29-30, 34, 68, 80, 89, 104, 302, 356 polyploidy, 150-2 polyspermy, 549

Index

pond natural productivity, 487 (see also extensive culture) relative productivity, 348 pond components, 19-23, 74-5, 486 pond culture methods aeration, 72-5, 499-500 circulation, 74-5 disinfecting substrate, 485-6 drainage and sludge disposal, 484-5 drying out substrate, 485 excavation, 119 exchange rates, 80 fertilisation, 70-1, 305, 355, 487-8 liming, 486 monitoring frequency, 497-8 population sampling, 500-1 preparation, 119, 300 recirculation, 509 salinity adjustments, 78-9, 494-7 water management, 498-9 poor image, 84-5 Porphyra (Rhodophyta), 273-4 see also seaweed potassium, 53-4, 70, 71, 79 potassium chloride, 548 potassium permanganate, 361 prawns freshwater, see freshwater prawns marine and brackishwater prawns see shrimp pregnant mare serum, 398-9 present discounted value, 253 price inflation, 254 price-makers, 256 price-takers, 256 probiotics, 79-80, 394, 416, 494, 508 processing (post-harvest), 236-7 channel catfish, 380-1 fish fillets, 15 pangasid catfish, 15-16 rohu, 311 salmonids, 336 shrimp, 348, 502 soft-shelled turtles, 473 tilapias, 361-2 product cycle of aquaculture industries, 257 product safety and health, 230-1 profitability, 252, 253-6 farm models, 253-8 promoter of desired gene expression, 451

protein skimmer see foam fractionation public health issues, 96, 98-9 public image, 84-5 prawns (family Penaeidae), see shrimp product cycle stage, 258 pseudofaeces, 558 pumps, 39-42 airlift, 75 net positive suction head, 41-2 selection, 41 vertical aerator, 74 purging, 358 see also depuration PVC, ketones, etc., toxicity, 392-3 pyramid-shaped nets, 552, 553 Q<sub>10</sub> (temperature quotient), 62 QTL (quantitative trait locus) mapping, 159-60 quality assurance (QA) and control (QC), 248 quarantine, 395, 414, 415, 417 queen conch, see conchs rabbit fish, spinefoots (Siganidae) culture marbled (black) spinefoot, 429 pearly (white spotted) spinefoot, 438-9 yellowblotch spinefoot, 438 raceway culture oxygen management, 75-6 solids removal, 81 stocking and feeding levels, 75 structures, 22-3, 358 raceways, tanks and water recycle systems, 357-9 rack culture, 25-6, 554 raft culture, 26, 552, 558 of mussels, 558, 560 rainbow trout (Oncorhynchus mykiss), 315, 317 farming, 325-7 see also salmonids rainfall content gases, 52, 58 specific conductance, 53 total dissolved solids (TDS), 53 real rate of interest, 253 recirculating (closed) systems, 108, 116 recirculating systems, indoor components, 35, 82, 324 DO, 36-7

N wastes, 36 pathogens, 37 waste solids, 35-6 recirculating systems, outdoor, 482, 484 components, 81, 111-12 see also pumps, plumbing Red Sea, 117 redox potential, 61-2 regional consumption of food fish, 10 remote settling (oyster's), 551 reproductive hormones, see reproductive physiology reproductive physiology bivalves, 129 decapod crustaceans, 128-9 fish, 126-8 see also reproduction of particular species and groups reservoir culture, 111-5, 308, 367 restocking, see stock enhancement revenues, 309 rice and aquaculture, 265 see also paddy-field aquaculture rice bran, 204, 206, 301 rigor mortis and nucleotides, 234-5 risk analysis, 262 risk aversion strategy, 263 rohu (Labeo rohita), 295, 296, 304, 310, 311 romet 30, 361 ropes, 276, 552-3 rotifers (Brachionus species) as larval feed, 199-200, 300, 402, 403-9, 420-43, 520, 535, 601-2 culture, 195, 403 enrichment, 195, 197-8, 402 species and sizes, 194, 403 Saccharina (Phaeophyta), 270-1, 273, 276 see also seaweeds safety at work, 98 salinity, 53 effects on aquatic animals, 63-4 freshwater, 53 seawater, 53 see also seawater salmon, see salmonids salmonids (family Salmonidae) biology and habitats, 313-7 broodstock and spawning, 318-20 diseases, 335-6 global production statistics, 314 growout farming, 325-31

harvesting, 336 nursery culture, 320-5 site management, 327-8 species, 314 see also Atlantic salmon Sarotherodon species, 340 Saudi Arabia, 116-20, 610 scallops, 545, 546, 553, 560-2 Scope for Growth, 543 scorpion fish (Scorpaenidae) culture Kasago, 422 Kurosoi, 422 sea bream and porgies (Sparidae) culture black sea bream, 434 common dentex, 434 gilthead sea bream, 433 New Zealand snapper, 433-4 red porgy, 434 red sea bream, 433 sheepshead, 434 silver (goldlined) sea bream, 434 sobaity sea bream, 434 yellowfin sea bream, 434 seacages, see cage culture seafood defined, 1 regional production vs. consumption, 9-10 sea-lice (crustaceans) use of pesticide controls, 92, 96, 98 seashells and sea snails, see gastropods, 567-81 seawater alkalinity, 69 buffering capacity, 390 major ions, 53-4 trace elements, 54 pH, 390 seaweed biology, 272-4 bioremediation, poly- and integrated culture, 279-80, 281, 283 culture methods, 275-80 culture vs. agriculture, 275 diseases, 280-2 future developments, 283-4 genetic aspects, 282 global production and value, 268-71 morphology, 272-4 product uses, 270-1 Secchi disk, 57 sediment oxygen demand, 89

sediment quality and profile, 62 seedstock acclimation and stocking, 495-7 counting and quality control, 495-6 transportation, 494-5 seepage, 119 selection and selective breeding, 141-4 correlated responses, 144-5 DNA and protein assisted, 160 indirect selection, 144-5 semi-closed systems, 33-5 semi-intensive culture, 29, 164-5, 306 carps, 306 fish larvae, 406 freshwater crayfish, 531 microalgae, 286 shrimp, 481, 483 tilapias, 341, 355 sensitivity analysis, 261 serotonin, 548 settleable solids (SS), 88, 388 removal, 35-6, 111-12 settlement and metamorphosis invertebrate larvae, 132, 551, 572, 578 sewage-fed aquaculture, 101-3 sex chromosomes, 344 sex determination, 344 sex reversal, 152-5 salmonids, 334-5 shelf-life, 239-41 'shellfish' defined 1 shellfish poisoning (from bivalves) via biotoxins, 556-7 via gut contents, 558 short-finned eel, 258, 418 shrimp (family Penaeidae) biology and habitats, 479-81 broodstock maturation, 490-1 culture intensities, 481-4 diseases, 507-8, 511 domestication, 510 feed management, 504-7 feeds, 503-4 global production, 476-8 growout farming, 484-8, 497-502 hatchery and nursery culture, 488-97, 508-9 inland production, 509 larval nutrition, 492-4 recommended water quality parameters, 497 taxonomy, 478-9

shrimp seedstock acclimation and stocking, 495-7 counting and quality control, 495-6 transportation, 494-5 shrimp species (main commercial species) Fenneropenaeus chinensis, 480 Fenneropenaeus indicus, 481 Litopenaeus stylirostris, 480 Litopenaeus vannamei, see whiteleg shrimp Marsupenaeus japonicus, 480-1 Penaeus monodon, see giant tiger prawn signalling molecules (cytokines), 447 silver carp (Hypophthalmichthys molitrix), 295, 296, 297, 304 silversides (Atherinidae) culture Atlantic silverside, 422 Japanese silverside, 421-2 Neotropical silversides, 422 pejerry, 422 simultaneous hermaphrodites, 544 single-sex populations (induced) all-female fish, 153, 334-5 all-male fish, 154 all-male Macrobrachium, 527 site rotation, 92, 328 site selection and development, 42-4, 327-8 skeletal deformities in fish, 391, 410, 411 small-scale producers, 609-11 smelts (Osmeridae) culture Ayu, 421 smoking products, 250 snappers (Lutjanidae) culture Asian (mangrove) red snapper, 431 - 2Atlantic (Caribbean) red snapper, 432 golden (John's) snapper, 432 mutton snapper, 432 yellowtail, 432 snooks (Centropomidae) culture common snook, 423 social costs, 252, 264 social responsibility, 613 corporate, 611 socio-economic benefits, 264-6 impacts, 97

627

Index

soft-shelled turtles (Trionyx sinensis) biology and habitats, 462-3 diseases and parasites, 471-2 egg culture, 467-8 feeds and feeding, 462, 469-71 grow-out culture, 468-9 hibernation, 462 indoor tank culture, 464, 470, 472 markets, 473-4 morphology, 462 pond culture, 464, 466, 468-9 production statistics, 461, 464 temperature influences, 462-9 water quality management, 469 solar radiation, 56 South Africa (statistics), 570 soybean cake, meal and milk, 301 Spain (statistics), 314, 560 spatfall of bivalves, 547-8 spawning induction bivalves, 548 carps, 297 decapod crustaceans, 128 fish (general), 127 gastropods, 571, 578 marine fish, 385 ornamental fish, 600 spawning modes of fish ovipary, 384 ovovivipary, 384 vivipary, 384 spillovers. economic, 253, 264 environmental, 264-6 spiny (rock) lobsters (Panulirus and Jasus species), 258 preliminary culture, 538-9 spoilage of products, 240-6 standard aeration efficiency (SAE), 74 starch, 112, 207, 208, 210, 351, 362, 470 static culture systems, 32 steroids, 96, 126 sterols, 172, 173 stock enhancement, 12-14 abalone, 12-13, 580 gastropods, 579-80 Japanese flounder, 13 Queen conch, 580 trochus, 579-80 stonefish (Synanceiidae) culture devil stinger, 422

storage of seafood products chilled, 239-42 frozen, 242-6 strain evaluations, 140-1 stress in fish, 414 acid stress, 65 handling stress, 220, 324, 393 stress-tolerance, 121 stunning, 236 substrate or near-substrate culture, 25 - 6bivalves, 25-6, 552, 556, 561 seaweed, 276-8 sulphate/sulfate, 53, 54, 62, 69, 71 sulphate/sulfate compound treatments for high pH, 76-8 for turbidity, 79 super-intensive culture, 341, 481, 550-1 supplementary feeds, 178, 305-6 supplementary feeding, 355-6 supplementary nutrients, 352-3 supply and demand of markets, 256 supply curve, 257 surface death of fish larvae, 393 surface/suspended culture of bivalves, 552-3 sustainable aquaculture 85, 510-12, 613 table oysters, 541, 545, 559-60 Taiwan, 182, 339, 504, 570 tank systems, 35, 349 T-cell receptors, 446 temperature adverse effects of abrupt changes, 387 - 8affects, 62-3, 387, 462 affects on gas solubilities, 55-6 and metabolic rate, 462 and sex determination, 344 temperatures, optima and critical values common snook, 423 red drum, 435 shrimp, 497 soft-shelled turtles and eggs, 462, 467 various fish species, 64 terramycin, 361 tetraploidy, 150 Thailand (statistics), 8, 182, 339, 477-8, 524

thermal stratification, 56-7, 112 epilimnion, 56 hypolimnion, 56 thermocline, 56 threadfins (Polynemidae) culture fourfinger threadfin, 438 sixfinger threadfin, 438 tilapias (family Cichlidae) attributes for culture, 338-9 biology and habitats, 338-40, 343 breeding, 344-5 diet and feeding habits, 350 disease management, 359-60 feed formulations, 351-3 feeding allowance, 353-4 genetically improved tilapias (GIFT), 343 harvesting, processing and marketing, 361-2 hatchery systems, 348-50 hybridisation, 324, 346-7 monosex production, 345-8, 527 nutritional requirements, 350-1 production statistics, 339 reproductive cycle, 345 sex determination, 344 species, hybrids, strains and distribution, 339-43 translocations, 343-4, 558 T lymphocytes, 446, 447 total dissolved solids (TDS), 53, 54, 388 total solids (TS), 53, 388 total suspended solids (TSS), 53, 54, 388 total volutile solids (TVS), 53 toxins in feeds, 209 trace elements, natural aquatic levels, 54 use in fertilisers, 71 traceability, 249 trade, trends in, 609 transgenic fish, 156, 159-61, 343, bioreactors, 156-7 disease resistance, 157-8 growth enhancement, 156 pleiotropic effects, 158-9 translocations, 94, 343, 558 trash fish used as feeds, 184-5 principles for usage, 185-6 trends in species, consumption and trade, 609 tributyl tin, 556 tributyl tin oxide (TBT), 96

Trionyx sinensis, see softshelled turtle triploidy, 150–2, 549 Pacific oyster, 549 salmonids, 335 trochus (*Trochus niloticus*) biology and habitats, 577–8 commercial importance, 577 culture, 578–9, 580 larval development, 579 settlement and metamorphosis, 578 trout, *see* salmonids turbidity, 57, 68, 78

Ulva (Chlorophyta), 274 see also seaweed United Kingdom (UK) (statistics), 314, 419, 548 United States of America (USA) (statistics), 182, 268, 285, 314, 528, 562, 584 UV irradiation use in chromosome manipulation use in disinfection, 45, 415 vaccination adjuvants, 416, 457

vaccination (non-vertebrate) vallicoltura, 419 vaccination route immersion or bath, 22, 453–5, 456 injection, 22, 452–3, 454, 456 mouth, 22, 455–6 vaccination success factors influencing, 220, 457–8 vaccines, 445 DNA, 450–2, 453 killed or inactivated, 449 live attenuated, 450 plasmid vaccine construct, 452 promoter, 451 recombinant or subunit, 451 R&D, 458–9 Vibrio fluviales, 575 Vietnam (statistics), 8, 14, 16, 182, 339, 419, 477–8 vitamins, 175–6 see also feeds of individual species vivipary, 384

wastewater-fed aquaculture, 101-3 water quality effects on animals NH<sub>3</sub>/NH<sub>4</sub> toxicity, 67, 374-5, 469 carbon dioxide, 66 general patterns, 63 hydrogen sulphide, 68, 391-2 nitrate, 391, nitrite, 67, 391 oxygen (DO), 65, 373-4, 469 pH, 64-5, 390, 469 salinity, 63-4, 388 suspended solids, 388 temperature, 62-3 see also temperature water quality management in ponds drying pond bottom and liming, 73, 464 feeding levels, 72-3 liming, 69-70 monitoring, 497 source of water, 68 see also aeration water quality tolerances and optima

brine shrimp, 196 channel catfish, 373-5 channel catfish larvae, 370 rotifers, 195, 403 salmonids, 317-8 seaweed, 277 shrimp, 490 soft-shelled turtles, 469 some fish species, 64 tilapias, 354 weaning diets, 200, 202, 408 whiteleg shrimp (Litopenaeus vannamei), 479-80 introductions, 16 production increase, 16 wild-caught stocking, 175, 238, 534-5, 587 Wolffishes (Anarhichadidae) Atlantic wolffish, 438 spotted wolffish, 438 White sea wolffish, 438 world production see global production xenogenesis, 161 Yesso scallop (Pecten yessoensis), 545, 560, 561

zebra mussel, 558 zeolite, 79 zinc fertiliser supplement, 71 natural levels, 54 plant nutrient, 59 zooxanthellae, 585, 589

# 629