Appendixes

TABLE A1

Methods available for assessing the impacts of ecological (indirect) interactions between species and fisheries and their implications for fisheries management. Model comparison including comparison of level of complexity and realism, functional responses, dealing with uncertainty, incorporation of environmental effects, spatial representation, handling of migratory species, adequacy re assessing different management controls and effects of ecosystem changes, suitability to conduct assessment and policy exploration, transparency of operation and suitability for data poor areas

TABLE A1a MODEL COMPARISON

Type of model	Whole ecosystem models	Biogeochemical ecosystem models	Biogeochemical ecosystem models	Dynamic multispecies models	Biogeochemical ecosystem models
MODEL	**Ecopath with Ecosim**	**IGBEM**	**ATLANTIS**	**INVITRO**	**ERSEM II**
1. Level of complexity and realism					
a) No. of modelled species/groups	Can be very large; typically around 30	Large: 20-30	> 20 typically, though to date used with 15-61 groups (with multiple stocks per group in some cases)	10-20 groups typically (including habitat groups)	10-20 groups, mostly phytoplankton and zooplankton
b) Representation of size/age structure	Recently full age-structure capability for groups	Vertebrates - age-structured models; invertebrate and primary producer groups - aggregate biomass pools	Vertebrates - age-structured models; invertebrate and primary producer groups (defined based on role and size) - aggregate biomass pools; some invertebrate age structuring	Detailed representations, including age and size structure	Aggregate biomass pools
c) Physical/ biological processes	Can be included to limited extent	Detailed representation of physical processes, input forcing of nutrients and physics	Detailed representation of physical processes with model driven by seasonal variation in irradiance and temperature, nutrient inputs from point sources, atmospheric nutrient inputs and exchanges with oceanic boundary components	Detailed representation of physical forces, but not nutrients (usually)	Detailed representation with e.g. light and temperature forcing functions
d) Technical interactions	Can be included	Fishery discards - target species. Some incidental fishing mortality effects on bycatch groups	Excellent representation; includes bycatch groups e.g. discarded non-target groups, landed and marketed non-target by-product groups	Some bycatch groups, discards and incidental impacts are represented	No
2. Functional responses	Foraging arena formulation (see text) By choosing appropriate parameter combinations, EwE can generate a range of functional responses including Types II and III	Mixed (Type II, Type III)	Flexible e.g. Type II or Type III or other	Depending on agent types used there can be explicit feeding interactions OR the state of the habitat is taken as a proxy for foodweb state and fauna is assumed to be getting its ration if the habitat is in good condition	Type II

TABLE A1a (*continued*)

Type of model	**Whole ecosystem models**	**Biogeochemical ecosystem models**	**Biogeochemical ecosystem models**	**Dynamic multispecies models**	**Biogeochemical ecosystem models**
MODEL	**Ecopath with Ecosim**	**IGBEM**	**ATLANTIS**	**INVITRO**	**ERSEM II**
3. Uncertainties in model structure, parameters and data	ECORANGER - although this should/could be improved; recent improvements include capabilities to balance models based on uncertainty, fitting to time series and quantifying input parameter uncertainty by running ECOSIM using a Monte Carlo approach	Aspects considered by Fulton (2001), Fulton *et al*. (2004a)	Aspects considered by Fulton (2001), Fulton *et al*. (2004a,b) - no formal fitting to data within the modelling software, though limited fitting happens externally to the model (no feedback estimation as yet)	Aspects considered by bounding using "pessimistic", "middle-of-the-road" and "optimistic" parameterisations. Some components (in particular target species, fisheries and biogenic habitat) undergo formal fitting	Explored to a limited extent
4a) Environmental effects	Incorporates a facility in the form of a (seasonal or longer term) forcing function routine to represent the mediation of physical or other environmental parameters	Detailed consideration.	Detailed consideration - light, nutrient, temperature inputs; long-term climate anomaly data	Forcing is typically currents, winds, rainfall and catastrophes	Detailed consideration - light, nutrient, temperature inputs; good representation of river inputs and atmospheric nutrient inputs
4b) Interactions with non-target species	Major focus of approach	More of a focus than target groups	More of a focus than target groups	Some consideration, but main focus is on target, vulnerable and habitat species	N/A
5. Spatial representation					
a) Species interactions	Not explicitly but implicitly to some extent due to foraging arena formulation	Spatially explicit representation	Spatially explicit representation	Spatially explicit	No
b) Habitat related processes	No explicit spatial representation in ECOSIM but ECOSPACE is spatially resolved	Detailed representations	Polygonal geometry matches geographical features; multiple vertical water column layers; subgrid scale representation of physical and habitat properties	Three dimensional in continuous space, with explicit habitats (and habitat related processes)	Good representation of transport processes for plankton groups
6. Migratory species	Doesn't handle particularly well; ECOSPACE has more potential	No - aggregated species groups	Movement (migration and advective transfer) between areas and vertical layers (and also in/out of the model domain)	Movement through and in/out of the modelled area	N/A

TABLE A1a (*continued*)

Type of model	**Whole ecosystem models**	**Biogeochemical ecosystem models**	**Biogeochemical ecosystem models**	**Dynamic multispecies models**	**Biogeochemical ecosystem models**
MODEL	**Ecopath with Ecosim**	**IGBEM**	**ATLANTIS**	**INVITRO**	**ERSEM II**
7. Model adequacy to allow analysis of different types of management controls in use	Good (see e.g. Pitcher and Cochrane, 2002)	Can be used to explore alternative fisheries management strategies (including both ecologically and economically motivated policies)	Can be used to explore alternative fisheries management strategies (including both ecologically and economically motivated policies)	Used to explore alternative strategies and management institutional arrangements (usually in multiple use management context)	None
8. Model adequacy to allow assessment of effects of short-, medium- and long-term ecosystem changes	Good	Good	Good	Good	Good for short-term but not long-term; can predict response to short-term climatic impacts
9. Model suitability to conduct assessment and policy exploration	Excellent (see e.g. Pitcher and Cochrane, 2002)	No	Well suited	Reasonable	No
10. Model transparency of operation and ease of use	By far the easiest model to use; some issues re transparency as code is constantly evolving and not always well documented and described	Not very well documented (due to complexity) and presumably not straightforward to use	Good model transparency but no easy user interface and slow and laborious calibration. Parameterisation and calibration support software is under development	Documented but no easy user interface. Parameterisation and calibration software is under development.	Model details published and relatively easy to use for the North Sea but not straightforward to apply to other systems
11. Data requirements and model suitability for data poor areas	Less data intensive than biogeochemical models but requires data that are difficult to obtain such as diet compositions and species abundance estimates	Not suitable for other than very intensively studied systems e.g. Port Philip Bay, North Sea	Data intensive - not suitable	Mixed (dependent on agent types selected)	Data intensive - not suitable

TABLE A1b MODEL COMPARISON

MODEL	SSEM	KPFM	MRM e.g. Punt and Butterworth (1995)	MSVPA and MSFOR	MSM
1. Level of complexity and realism					
a) No. of modelled species/groups	Lumped model components e.g. fish, plankton, nutrients	Currently 1-4 predator stocks within each SSMU (Small-Scale Spatial Unit)	Typically few e.g. 4 components	Typically few (6-8)	Thus far 2 species (walleye pollock and Pacific cod - and cannibalism) but could be extended
b) Representation of size/age structure	Aggregate biomass pools	Krill: juvenile and adult components; predators: juvenile, breeding and non-breeding components	Detailed representations - age structure	Detailed representations - age structure	Fully age-structured
c) Physical/ biological processes	Detailed representation with e.g. forcing using temperature, current and nutrient loads from land	Coupled to physical model to simulate transport of krill	No physical	Not usually represented	None
d) Technical interactions	No	No	Not included	Can be included	Not currently included
2. Functional responses	Type II	Flexible - Holling Type II and Type III functional responses	Type II	Fixed ration that is independent of prey abundance in forecasts	Based on Type II

TABLE A1b (*continued*)

MODEL	**SSEM**	**KPFM**	**MRM e.g. Punt and Butterworth (1995)**	**MSVPA and MSFOR**	**MSM**
3. Uncertainties in model structure, parameters and data	Unknown	Monte Carlo simulations to investigate numerical uncertainty; robustness to alternative model formulations explored; no formal fitting to data and hence considerable uncertainty re some parameter values which are input	Model fits to available data. Good initial explorations; could perhaps be improved using e.g. Bayesian methods	Explored to some extent	Good consideration of these
4a) Environmental effects	Forcing - currents, nutrient, temperature inputs	Some forcing from e.g. currents and several formulations linked to environmental index	Not included	Can be included	Not included
4b) Interactions with non-target species	N/A	Investigates effects of krill as target species on non-target predator species	Minor only	Minor only	Not currently considered
5. Spatial representation					
a) Species interactions	No	Spatially explicit at scale of SSMUs but not at smaller scales	Not spatial	Not spatial	No
b) Habitat related processes	No	Model's spatial cells match SSMUs which can have different physical and biological features	No	No	No
6. Migratory species	N/A	Simulates movements of krill but not predators	No	No	Not suitable

TABLE A1b (*continued*)

MODEL	**SSEM**	**KPFM**	**MRM e.g. Punt and Butterworth (1995)**	**MSVPA and MSFOR**	**MSM**
7. Model adequacy to allow analysis of different types of management controls in use	None	Designed to address options for subdivision of the precautionary krill catch limit amongst SSMUs	Excellent	Some	Some
8. Model adequacy to allow assessment of effects of short-, medium- and long-term ecosystem changes	Short-term effects of changes in coastal system	Some	No	No	No
9. Model suitability to conduct assessment and policy exploration	No	Designed to address options for subdivision of the precautionary krill catch limit amongst SSMUs	Excellent	Some contributions	No
10. Model transparency of operation and ease of use	Model details published ; easiness of use difficult to assess	Model still being developed so not generally available yet	Detailed model descriptions but complicated and time-consuming to use	Good model descriptions; moderately easy to use	Average transparency but not easy to use
11. Data requirements and model suitability for data poor areas	Data intensive but lumped components mean it may not be as bad as some other biogeochemical models	Can be adapted to match level of data available	Fairly data intensive but focuses on a few target species only for which more data usually exists even in data poor areas	Detailed stomach content data input to model makes it unsuitable for most regions, but there are hybrid versions that require less data	Some potential as focuses on few/target species for which there are typically some data

TABLE A1c MODEL COMPARISON

MODEL	**MULTSPEC**	**GADGET**	**Bioenergetic/ allometric models e.g. Koen-Alonso and Yodzis, 2005**	**OSMOSE**	**SEAPODYM**
1. Level of complexity and realism					
a) No. of modelled species/groups	Typically few (3-5)	Few with potential for many	From 4 to as many as 29	7-20 species	Thus far 3 tuna species (skipjack, yellowfin and bigeye) but could be extended
b) Representation of size/age structure	Detailed representations	Detailed representations - species split by size and age	Not represented	Detailed representations	Detailed representations of age structure of fish; lumped plankton forage components
c) Physical/ biological processes	Could be linked to oceanographic models; Sea temperature affects fish growth, maximal food consumption and cod stomach evacuation rate; climatological data used	Spatial model can be coupled to ocean circulation model	Not represented	Not represented	Time-series of environmental data in the form of temperature, currents etc; can be coupled to physical/ biogeochemical models
d) Technical interactions	Not represented	Included	Not represented	Not included	Not included but the manual notes that important by-catch species (e.g. marine turtles, seabirds) could be included in future versions
2. Functional responses	Marine mammals - fixed ration; cod: feeding affected by individual size at age, prey biomass and temperature; all fish species: curvilinear relationship assumed between food abundance and consumption	Flexible e.g. Type II or Type III or other	Tested 5 different forms: multi-species Holling Type II with predator interference; multi-species generalized Holling; frequency-dependent predation, Evans and Ecosim	Fixed ration; starvation mortality component	Fixed ration model

TABLE A1c (*continued*)

MODEL	MULTSPEC	GADGET	Bioenergetic/allometric models e.g. Koen-Alonso and Yodzis, 2005	OSMOSE	SEAPODYM
3. Uncertainties in model structure, parameters and data	Likelihood function used to estimate maturation parameters - fit to empirical maturation data; also likelihood function re predation parameters - based on extensive stomach content data; several explorations re alternative model formulations and hypotheses (e.g. Bogstad *et al*., 1992, Tjelmeland, 1997) but scope for more	Uses combined simulated annealing and Hooke&Jeeves optimisation methods to estimate best fit parameters according to a pre-specified likelihood function; modular form permits sensitivity investigation to range of alternative model structures	Investigated structural uncertainty by exploring sensitivity to alternative functional response representations; explored parameter uncertainty using the SIR algorithm (Punt and Hilborn, 1997, McAllister *et al*., 1994).	Large uncertainties not rigorously dealt with	Not well explored; Statistical estimation of parameters may be added
4a) Environmental effects	Not explicitly included but plankton described using time-varying functions with different parameters for various areas	Bottom-up explorations e.g. using adapted random walk (Hulse, 2001)	Not included	Carrying capacity constraint can be varied to simulate e.g. random or periodic dynamics	Detailed consideration of effects of temperature, currents, etc.; suitable for investigating climate change scenarios and effect of e.g. ENSO events
4b) Interactions with non-target species	Some representation e.g. polar cod included in model	Represented	Some - sea lions	Explicit consideration of non-target fish species but not other	Considers impacts of these on target species and not really the other way around
5. Spatial representation					
a) Species interactions	Division into areas (7 in Barents Sea) to describe east-west gradients in individual growth of species and migration patterns	Spatially explicit with migration matrices specifying movement between areas	No	Spatially explicit with fish schools moving to areas with highest potential prey biomass	Spatially explicit with one degree cells
b) Habitat related processes	Minor only e.g. different temperatures in different areas	Could be tailored by linking with oceanographic models	No	No	Good (novel) spatial representation of differences in habitat quality (see text for details)
6. Migratory species	Multiple areas with migration between areas	Multiple areas with migration between areas	No explicit modelling of migration	No	Can be handled through movement model linked to habitat quality

TABLE A1c (*continued*)

MODEL	MULTSPEC	GADGET	Bioenergetic/ allometric models e.g. Koen-Alonso and Yodzis, 2005	OSMOSE	SEAPODYM
7. Model adequacy to allow analysis of different types of management controls in use	Some e.g. can explore effects of catches from different areas	Excellent	Minor contributions e.g. questions re culling sea lions	No	Can be used to explore impacts of marine protected areas, no-fishing areas as well as impacts of management options on different tuna (or similar) species
8. Model adequacy to allow assessment of effects of short-, medium- and long-term ecosystem changes	Limited - some climatological data input	Currently minor contribution only possible	No	Some	Good for exploring short to medium term changes in tuna (or similar species) distribution and possibly abundance but not more general ecosystem changes
9. Model suitability to conduct assessment and policy exploration	Contributes to stock assessment process; Some policy explorations e.g. simulations to explore scenarios in which larger cod catches are taken in years with decreased predation pressure from minke whales	Some	Minor contributions e.g. questions re culling sea lions and conversely, extent to which commercially important hake fishery has a negative impact on sea lions	Minor contributions	Minor contributions only
10. Model transparency of operation and ease of use	Good model descriptions but does not appear easy to use	Excellent transparency but large number of options, and sophisticated software and minimisation routines, make it moderately difficult to use	Good model description but not easy to use	Good description of model; ease of use not known but presumably not straightforward	Manual available with good description of model; An executable version is currently available that is relatively easy to run as requires changes to parameter file - more difficult to change the model itself.
11. Data requirements and model suitability for data poor areas	Detailed stomach content data input required for model makes it unsuitable for most regions	Model can be tailored to available data, hence good for data poor areas.	Not suitable, but may be possible to apply if restricted to a few species	Based on fairly general parameters so could be applied but some difficulties	Data intensive hence not suitable for data poor areas

TABLE A1d MODEL COMPARISON

MODEL	CCAMLR models e.g. Mori & Butterworth 2005, 2006	EPOC	SMOM	ESAM	SEASTAR
1. Level of complexity and realism					
a) No. of modelled species/groups	Typically few e.g. 7	2 in current example; being extended	Currently 2 predator stocks within each SSMU	Few - typically 2 (and cannibalism) - 4	Few - typically 2 (and cannibalism) - 4
b) Representation of size/age structure	Not represented	Can select to include detailed age or size-structure; Trial example: krill: spatially and age-structured; predator: age-aggregated	Krill: lumped; predators: juvenile, breeding and non-breeding components	Detailed representations	Detailed representations
c) Physical/ biological processes	Not represented	Various formulations can be accommodated e.g. advance and retreat of sea ice modelled; ocean transport may be included in future	Can be coupled to physical model to simulate transport of krill	Not represented	Not represented
d) Technical interactions	Not represented	Not currently	No	Could be represented	Could be represented
2. Functional responses	Type II and Type III	Type I relationship in trial; designed to be flexible	Flexible - Holling Type II and Type III functional responses	Type I and II considered	Variable e.g. Type I, II or III

TABLE A1d (*continued*)

MODEL	CCAMLR models e.g. Mori & Butterworth 2005, 2006	EPOC	SMOM	ESAM	SEASTAR
3. Uncertainties in model structure, parameters and data	Likelihood function used to fit model to all available data and indices of abundance; sensitivities to alternative formulations explored; need for a more systematic exploration of sensitivity to alternative input parameter choices	Should permit sensitivity to alternative model structures, but no formal statistical testing/fitting	Reference Set used comprises 12 alternative combinations that essentially try to bound the uncertainty in the choice of survival estimates as well as the breeding success relationship; Robustness to alternative model formulations explored; Some formal fitting to data	Bayesian methods; considered as rigorously as in single-species assessment approaches.	Usually considered as rigorously as in single-species assessment approaches; uncertainty evaluated using e.g. bootstrapping
4a) Environmental effects	Not included	Could be linked to other physical oceanographic models but not yet developed	Could be linked to other physical oceanographic models but not yet developed	Not usually included	Not usually included
4b) Interactions with non-target species	Explicit consideration of krill-whale-seal interactions	Could be included	Investigates effects of krill as target species on non-target predator species	Focus is on target species	Focus is on target species
5. Spatial representation					
a) Species interactions	Limited (two spatial strata)	Spatial subdivision into polygons (8 in trial version)	Spatially explicit at scale of SSMUs but not at smaller scales	Not usually	Not usually
b) Habitat related processes	No	Not currently	Model spatial cells match SSMUs which can have different physical and biological features	No	No
6. Migratory species	No explicit modelling of migration	Movement matrix can be included	Simulates movements of krill but not predators	Not usually	Not usually

TABLE A1d (*continued*)

MODEL	CCAMLR models e.g. Mori & Butterworth 2005, 2006	EPOC	SMOM	ESAM	SEASTAR
7. Model adequacy to allow analysis of different types of management controls in use	Mori and Butterworth (2006) not currently sufficiently developed	Designed to achieve this but not tested yet	Designed to address options for subdivision of the precautionary krill catch limit amongst SSMUs	Good	Good
8. Model adequacy to allow assessment of effects of short-, medium- and long-term ecosystem changes	No	Designed to achieve this but not tested yet	Some	No	No
9. Model suitability to conduct assessment and policy exploration	Some potential e.g. to evaluate possible effects of decisions to harvest krill or particular whale or seal species	Designed to achieve this but not tested yet	Designed to address options for subdivision of the precautionary krill catch limit amongst SSMUs	Some	Some
10. Model transparency of operation and ease of use	Model equations very simple but not easy to use as user requires experience re coding and non-linear minimisation	Currently poor model transparency as still being developed but should be moderately easy to use	Model still being developed so code not generally available; Difficult to use by other than experienced programmer.	Good model transparency but not easy to use	Good model transparency but not easy to use
11. Data requirements and model suitability for data poor areas	Requires at least some relative abundance data; can be tailored to make the most of limited data in data poor area	Data intensive	Can be adapted to match level of data available	Detailed data only required for few target species	Detailed data only required for few target species

TABLE A2

Model comparison including rough description of model parameters, some important assumptions, data requirements, technical information, examples where used, model history and additional useful features of each approach

TABLE A2a

Type of model	**Whole ecosystem models**	**Biogeochemical ecosystem models**	**Biogeochemical ecosystem models**	**Dynamic multispecies models**	**Biogeochemical ecosystem models**
MODEL	**Ecopath with Ecosim**	**IGBEM**	**ATLANTIS**	**INVITRO**	**ERSEM II**
1. Broad description of parameters (not fully comprehensive as intended to give a flavour of the sorts of parameters)	For each group: Biomass, P/B, Q/B, Catch, Discards, Refuge parameters. Diet composition matrix for all species. Phytoplankton growth-related parameters such as Michaelis-Menten uptake parameters, maximum P/B ratio for phytoplankton	Requires in excess of 750 parameters to be estimated or input, though many ok at default settings	Many e.g. phytoplankton production parameters such as maximum temperature-dependent growth rate, light limitation factors and half saturation constants; Also needs configuration of foodweb connections; More parameters needed if complex representations (like temperature dependent movement and spawning) options selected	Many, but basics are to do with growth, mortality, fecundity and speed of movement	Many parameters e.g. physiological parameters such as maximum growth rate, half-saturation constant, faecal ratio, excretion ratio, respiration ratio
2. Some important model assumptions	Trophic interactions are important; foraging arena formulation	Fish migration represented using forcing function,fish recruitment constant spatially and temporally	Functional groups describe behaviour of an “average” individual; predators not explicitly included represented using quadratic mortality terms; not all prey available to predators (availability parameter)	Dependent on agent types; habitat as a proxy in regional applications (Little *et al.* 2006)	Many physiological and process-related
3. Data requirements	Preferably data on species biomass and P/B; spatially and temporally appropriate diet composition data; catch history; time series fisheries data for fitting	Very large data requirements.	Spatially explicit biomass, production, consumption, diet composition for major functional groups, spatial and fleet-disaggregated harvest rates; primary production rates and processes; nutrient data; climate data	Physical model data, sediments, initial biomasses and habitat map	Detailed data inputs for the North Sea including hydrodynamical data re advective and diffusive transport, global radiation and temperature, river nutrient loads, fishing mortality
4. Technical details	Runs on Windows PC	C++, could run in Linux	Coded in C++, could run in Linux; Can run on (preferrably fast) PC; Code and exe file available.	Linux; code is open source (i.e. available)	Model coded in FORTRAN90 - both code and executable available and can be run on PC; C++ version developed

TABLE A2a (*continued*)

MODEL	Ecopath with Ecosim	IGBEM	ATLANTIS	INVITRO	ERSEM II
5. Examples where used	Examples globally e.g. Scotian shelf (Bundy, 2002, 2005), Eastern Bering and western Bering Sea shelf and slope ecosystems (Aydin *et al*., 2002), Gulf of California, North Sea, Gulf of Thailand (Christensen, 1998), Strait of Georgia (Martell *et al*., 2002), Southern Benguela Upwelling region (Shannon, Cochrane and Pillar, 2004), Baltic Sea (Harvey *et al*., 2003), Black Sea (Daskalov, 2002), Pacific (Cox *et al*., 2002), efficacy of MPAs in the central North Pacific (Martell *et al*., 2005) and many more	Port Philip Bay - Australia	Port Philip Bay - Australia; EEZ region for south-eastern Australia; other continental shelf, estuaries and bays in Australia and Tasmania; Northern California Current (western US); Continental shelf of north-eastern US	Northwest shelf of Australia	North Sea; see Journal of Sea Research vol. 38; Mediterranean, Irish and Celtic Seas, Adriatic; also Catalan, Cretan and Arabian Seas (Blackford, Allen and Gilbert, 2004)
6. History	ECOPATH based on Polovina (1984) model but developed in user-friendly format; transformed into dynamic ECOSIM version which has become very popular due to ease of use; freely available software with good user interface and unparalled support and training for users; ECOSPACE developed to handle spatial aspects such as MPAs	Based on amalgamating ERSEM (to represent biological processes) and PPBIM (to represent physical processes and introduce spatial structure); Constructed as a first step in understanding effects of model structure and complexity.	Developed from the "Bay Model 2" ecosystem model of Fulton *et al*. (2004); first applied to Port Philip Bay, Australia	Developed to consider multiple use management questions for the marine (especially inshore/shelf) environment	Developed to simulate the ecosystem dynamics of the North Sea
7. Additional useful features	Includes policy optimisation routine; ECOTRACER can be used to predict movement and accumulation of contaminants and tracers; Multistanza populations can be designated as hatchery populations; Permits evaluation of equilibrium MSY reference points and "stock reduction analysis"; ECOSPACE: can analyze impact and placement of marine protected areas and explore fitness-dependent dispersal	Alternative forms of fish movement and migration investigated	Includes discarding, bycatch and management submodels; Includes alternative fisheries submodels with alternative bycatch, habitat dependency, selelctivity,discarding and effort allocation - allows representation of effects such as effort displacement due to local stock depletion and effect of MPAs; novel density-dependent vertebrate movement scheme; Includes starvation; Other sectors represented simply; Socioeconomic submodels available (e.g. so can consider impacts of quota trading); Full MSE cycle represented	Operating system-like asynchronous time-step scheduler; Hydbrid form so best model form (either aggregate state model or IBM/ABM formulation) can be used - best match for component dynamics can be used	Can be linked with models of fish dynamics

TABLE A2b MODEL COMPARISON

Type of Model	**Biogeochemical ecosystem models**	**Whole ecosystem models**	**Dynamic multispecies models**	**Dynamic multispecies models**	**Dynamic system models**
MODEL	**SSEM**	**KPFM**	**MRM e.g. Punt and Butterworth (1995)**	**MSVPA and MSFOR**	**MSM**
1. Broad description of parameters (not fully comprehensive as intended to give a flavour of the sorts of parameters)	Many parameters e.g. physiological parameters such as maximum growth rate, half-saturation constant, faecal ratio, excretion ratio, respiration ratio	Many parameters; Krill e.g. background mortality rate, 4 recruitment parameters including scalar that mediates environmental effects on krill, average weight, historical catches, instantaneous rate of movement parameter, fraction of abundance available for harvest and predation; Predators: natural mortality rate, age at recruitment to adult stage, 3 recruitment parameters, 3 consumption and functional response parameters	For hake and seal species: total daily ration, feeding function saturation parameter, parameter reflecting extent of annual variation in diet; Other predatory fish: maximum number of hake that could be eaten; feeding saturation and annual diet variation parameters; Background mortality rate. Other standard age-structured model parameters	Suitability parameters, predation mortality M2, spawner-recruit parameters, terminal fishing mortality rates, residual natural mortality rates	Initial 2-species application has 124 parameters related to initial age structure of populations, recruitment parameters, fishing mortality parameters and selectivity
2. Some important model assumptions	Many physiological and process-related	Predator recruitment (but not survival) depends on krill consumption; krill in transit between SSMUs do not suffer predation and fishing mortalities; predators and the fishery are competitors	Seals feed mainly in shallow waters, and hence consume mostly shallow-water hake *M. capensis*	Suitability of prey remains constant according to its biomass as a proportion of the total biomass of potential prey; constant M1 (residual mortality); catch-at-age measured without error	Fixed ration model, constant selectivity
3. Data requirements	Input data re temperature, currents, nutrient runoff from land	Data from a physical model re currents; basic biological data for predators; information re predator abundance; historic catch series; areas of SSMUs; estimates of krill density; estimates of predator demand; time series of environmental anomalies	Data re historic catches; trends in abundance e.g. cpue, surveys; length/age composition data; estimates of diet composition and daily ration for each species	Stomach content data to inform re predator rations and feeding preferences; catch-at-age in numbers, abundance indices and mean body weights as for single-species models	Catch-at-age data (landings and discards), maturity-at-age, weight-at-age, predator ration, predator diet information, prey weight-at-age in the predator stomach contents, predator annual ration, residual natural mortality
4. Platform	Can be run on UNIX or Windows PC	S-PLUS, also being recoded in R	Fortran model; needs to be recoded, possibly in ADMB	Runs on Windows PC; typically recoded by user	Solver routine in Microsoft Excel; SIR algorithm (McAllister *et al.*, 1994; McAllister and Ianelli, 1997) implemented in Visual Basic

TABLE A2b (*continued*)

MODEL	SSEM	KPFM	MRM e.g. Punt and Butterworth (1995)	MSVPA and MSFOR	MSM
5. Examples where used	Pesticide inflow and salinity change in drainage canal (Sekine, Nakanishi and Ukita, 1996), Experimental river system (Sekine, Imai and Ukita, 1997)	Antarctic Peninsula region	Southern Benguela Upwelling region	North Sea, Baltic Sea (Sparre 1991), Georges Bank (Tsou and Collie, 2001), Eastern Bering Sea (Livingston and Jurado-Molina, 2000; Jurado-Molina and Livingston, 2002)	Eastern Bering Sea, central Chile
6. History	Developed to predict impact of coastal development activities on fisheries	Developed to assist CCAMLR in evaluating options for subdividing the krill catch among SSMU's (Small-Scale Management Units) in Antarctic Peninsula region	Developed in response to debates whether increasing fur seal numbers were negatively impacting the commercially important hake fishery in the southern Benguela region	Developed by ICES Multi-species working group; main use was in revising predation mortality estimates input to single-species management models	Motivated by desire to incorporate predation equations from MSVPA in a statistical framework that allows the fitting of parameters by considering how errors enter into the models
7. Additional useful features	Can be used to investigate effect of pesticides	Includes a range of performance measures that can be used to evaluate catch-allocation procedures and assess tradeoffs between predator and fishery performance	Takes explicit account of uncertainty and management issues through the use of a simulation framework incorporating feedback control rules actually in place for setting TACs for the fishery	Includes a prediction model MSFOR	Incorporates standard tools such as Bayesian methods and decision analysis into a multi-species context

TABLE A2c MODEL COMPARISON

Type of model	Dynamic multispecies models	Dynamic multispecies models	Dynamic multispecies models	Dynamic system models	Dynamic system models
MODEL	**MULTSPEC**	**GADGET**	**Bioenergetic/allometric models e.g. Koen-Alonso and Yodzis, 2005**	**OSMOSE**	**SEAPODYM**
1. Broad description of parameters (not fully comprehensive as intended to give a flavour of the sorts of parameters)	2 maturation parameters (capelin), 2 predation parameters (cod) (maximum consumption and prey abundance where consumption is half of max. consumption) and 3 migration parameters (capelin)	Varies depending on model but e.g. growth parameters, maturation, fleet selection, recruitment, initial population and consumption	For each species: intrinsic P/B ratio; carrying capacity; competition coefficient; fraction of maximum physiological capacity for production realized by species; allometric coefficients; mean individual biomass; "other mortality" rate; density-dependent mortality term	Growth: 3 von Bertalanffy growth parameters + 1 condition factor per species; reproduction: annual relative fecundity per species and age at maturity; survival: maximal age, age at recruitment and additional annual natural mortality; NB parameter input is predator/prey size ratio determining minimal threshold for predation to occur; also parameter describing food biomass to fulfil vital functions	von Bertalanffy growth parameters; length-weight parameters; age at first maturity; SST limit for preproduction, length of passive transport phase for juveniles; natural mortality; initial stock biomass (equilibrium); several foraging, habitat and temperature parameters; diffusion and advection coefficients
2. Some important model assumptions	Feeding and growth rate of predators (minke and harp seal) assumed to be constant; Curvilinear relationship between food abundance and fish consumption; Mammal predation affects fish but no feedback from fish abundance to marine mammals; Strong herring recruitment simulated two years in row every 8 years	Range of model assumptions depends on modules used as e.g. a number of different growth and consumption formulations from which to choose	Anchovy and squid prey not modelled hence assigned carrying capacities and competition coefficients (to express dietary overlap); density-dependent mortality of sea lions assumed due to crowding-related effects during breeding season; prey-independent digestive pause (see Jeschke, Kopp and Tollrian, 2002)	Fish predation depends on size suitability and spatial co-occurrence between a predator and its prey; carrying capacity constraint; starvation mortality impacts fish when nutritional resources limited	Movement depends on temperature and prey availability; recruitment is independent of adult biomass
3. Data requirements	Large database with stomach content data - primarily cod stomachs but also e.g. herring and haddock; historical data on capelin catch in numbers by length group, month and area; VPA-based estimates of no. of cod; survey data used re area distribution for immature cod and other species; estimates of popln sizes of other species; data re sea temperature; climatological data used	Catch data; Length distributions, age length keys, mean length/ weight at age; survey indices by length or age, catch CPUE, stomach content data, data on proportion mature at age/length. No catch-at-age data necessary; Data series do not need to be continuous. Spatially resolved and fleet-specific data required depending on model; No limit on no. of data files	Catch data and biomass trend information for each species	Data on mean spatial distribution of each species	Detailed data re SST, currents, prey availability; preferably tagging data
4. Technical details	HP935 Workstation	UNIX computing platform tested for Solaris, Linux, Mac OSX and Cygwin; also capable of running on multiple computers in parallel using PVM (Parallel Virtual Machine)	Fortran 77 run on PC	Developed in Java (JdK 1.1.3, SunMicrosystems)	Source code in C++ object oriented language with executables available for Windows and Linux platforms. Also parallel software in Java

TABLE A2c (*continued*)

MODEL	MULTSPEC	GADGET	Bioenergetic/ allometric models e.g. Koen-Alonso and Yodzis, 2005	OSMOSE	SEAPODYM
5. Examples where used	Barents Sea capelin management; Predation by cod on young cod and haddock taken into account in the stock assessment made by the ICES Arctic Fisheries Working Group; Also used to study impact of minke whales and harp seals on the cod, capelin and herring stocks	Cod-capelin-shrimp in Icelandic waters; Barents Sea, North Sea, Celtic Sea groundfish stocks, hake and key pelagic fish species interactions in the Mediterranean Sea	Patagonia marine community (southwest South Atlantic Ocean); Newfoundland shelf model under development	North Sea, Southern Benguela (Shin, Shannon and Cury, 2004)	Pelagic ecosystem of the tropical Pacific Ocean (Lehodey, 2001, Lehodey, Chai and Hampton, 2003)
6. History	Developed in response to an increased demand that fisheries interactions should be taken into account, following the 1983-1986 capelin collapse; Also, interest in Norwegian whaling activity spurred a need for models incorporating fish-marine mammal interactions; Similar in structure to BORMICON thus models merged to some extent e.g. by running MULTSPEC using BORMICON code	Modelling marine ecosystems in fisheries management context; tailored to also examine marine mammal populations; flexible in other contexts too	Developed to explore whether a mechanistically oriented approach can shed light on some common issues in ecosystem modelling	Developed to explore the extent of usefulness of local size-based predation rules in multi-species models	Developed for tropical tunas in the Pacific Ocean in response to a need for a spatial, multigear, multi-species model incorporating an appropriate tuna movement model
7. Additional useful features	Co-operation between IMR, Norway and PINRO, Russia, resulted in establishment of stomach content data base of 80000 cod stomachs	Can represent predation within species; maturation; multiple commercial and survey fleets taking catches from the populations; tagging experiments to follow the migration of the stock; data warehouse	Akaike Information Criterion (AICc) (Burnham and Anderson, 2002) used to rank and select models; behaviour of models explored using continuation and bifurcation analysis (Doedel *et al*., 1998)	Has been used to compare results produced by different models (e.g. ECOPATH/ ECOSIM); one of few studies addressing starvation mortality; allows investigation of ecosystem size spectra (Shin and Cury, 2004; Shin *et al.*, 2005)	Numerical scheme that allows the use of spatial stretched-grids so that resolution can be increased in regions of interest

TABLE A2d MODEL COMPARISON

Type of Model	Dynamic multispecies models	Whole ecosystem models	Whole ecosystem models	Dynamic multispecies models	Dynamic multispecies models
MODEL	**CCAMLR models e.g. Mori and Butterworth, 2005, 2006**	**EPOC**	**SMOM**	**ESAM**	**SEASTAR extension**
1. Broad description of parameters (not fully comprehensive as intended to give a flavour of the sorts of parameters)	Krill: intrinsic growth rate; 2 consumption parameters; Each predator: maximum birth rate; natural mortality; density-dependent mortality or birth rate parameter	Krill example: Natural mortality rate from krill yield assessment; 3 von Bertalanffy growth parameters; 2 weight-length parameters; 4 Beverton-Holt spawning stock recruit relationship parameters; Predator - abundance and feeding function parameters	Krill: intrinsic growth rate; 2 consumption parameters; Each predator: maximum birth rate; natural mortality; density-dependent mortality or birth rate parameter	Hollowed, Ianelli and Livingston, (2000): consumption rate, satiation point and satiation response parameters; other typical single-species age-structured model parameters e.g. catchability coefficient, several recruitment parameters, residual mortality, mean body weight, proportion mature at age, selectivity parameters	Tjelmeland and Lindstrøm (2005) example: Predation and natural mortality rates; prey species-specific suitability parameters, prey-specific switching coefficient, terminal F's, tagging survival
2. Some important model assumptions	Density-dependent mortality parameters are mathematically necessary; presumably reflect the impact of limitations of breeding sites for seals, and intra-species competition effects for whales	Model still being developed	Predators do not move between SSMUs; Predator breeding success depends on krill consumption	Hollowed, Ianelli and Livingston (2000): summer dietary information assumed representative for entire yr i.e. no seasonal changes; abundance of alternative prey assumed a constant proportion of predator's food requirements; Spatial distribution of predator and prey constant over time	Tjelmeland and Lindstrøm example: assumes weak feedback from fish to marine mammal abundance; prey switching of minke whales; no. of whales in study area described by bell-shaped function over time
3. Data requirements	Historic catch data.; abundance trend data	Krill: maturity ogive; weight at age; matrix of probabilities of moving from origin to destination polygons	Basic biological data for predators; information re predator abundance; historic catch series: Areas of SSMUs: Estimates of krill density; Estimates of predator demand	Hollowed, Ianelli and Livingston (2000): multi-species data - time-series of predator abundance, annual predator consumption rates and age composiiton of prey consumed; other usual: total catch biomass, bottom trawl survey estimates of biomass, egg production, fisheries catch-at-age, survey size and age compositions	Tjelmeland and Lindstrøm example: time series of minke whales and alternative prey, tag-return data; other typical single-species data; abundance estimates; biomass of cod input
4. Technical details	AD Model Builder run on PC	R statistical language (R Development Core Team, 2005)	AD Model Builder run on PC	AD Model Builder or other run on PC	Developed in user's preferred code e.g. SeaStar extension in Mathematica

TABLE A2d (*continued*)

MODEL	**CCAMLR models e.g. Mori and Butterworth 2005, 2006**	**EPOC**	**SMOM**	**ESAM**	**SEASTAR extension**
5. Examples where used	**Atlantic Indian and Pacific sectors of Antarctic**	**Antarctic Peninsula region - krill; Heard Island**	**Antarctic Peninsula region**	**Gulf of Alaska (walleye pollock - flounder - halibut - sea lion)**	**northeast Atlantic (minke whale - herring interactions)**
6. History	Developed to test the hypothesis that species interaction effects alone can account for likely trends in the abundances of major Antarctic predator species over the past 50 or so years	Developed in response to perceived need for framework providing flexible structure to insert and delete model components; Also to assist CCAMLR in evaluating options for subdividing the krill catch among SSMU's	Developed to assist CCAMLR in evaluating options for subdividing the krill catch among SSMU's (Small Scale Management Units) in Antarctic Peninsula region	Developed to provide a framework for incorporating predator prey interactions to account for shifts in predation mortality in stock assessments	Developed as a first step to incorporate multi-species considerations into more traditional single-species stock assessment models
7. Additional useful features	Inclusion of density-dependent parameter resulted in some new insights e.g. re krill surplus hypothesis	Flexible plug-and-play structure	Developed for use as an operating model in a formal MP framework. Different MPs are simulation tested with their performances being compared on the basis of an agreed set of performance statistics; Reference Set used comprises 12 alternative combinations that essentially try to bound the uncertainty in the choice of survival estimates as well as the breeding success relationship	Nonparametric smoothing treatment of selectivity permitted greater flexibility in representing predator selectivity patterns	Tjelmeland and Lindstrøm example: consumption parameters estimated as part of likelihood term; prey-switching behaviour modelled, tag-return data incorporated

TABLE A3
Summary of some advantages, disadvantages and limitations of each method, as well as notes on the ease of presentation of model outputs and the user-level of programming and mathematical skills required

TABLE A3a

MODEL	Ecopath with Ecosim	IGBEM	ATLANTIS	INVITRO	ERSEM II
Main advantages	Ease of use, large no. of users, structured parameterisation framework, well-balanced level of conceptual realism, novel representation of predator-prey interaction terms	Detailed representation of processes within well-studied temperate bay, from representation of sediment chemistry to average biomass of fish	Spatially explicit biomass dynamics in response to different fisheries management scenarios; Applications as an Operating Model; simpler but adequate representation of processes than most other biogeochemical models; includes mixotrophy which is considered important	Agent-based so uses a targeted representation across multiple scales and sectors.	Can be used to explore hydrographic and planktonic conditions impacting juvenile fish; includes detailed representations of the benthic system which is important e.g. in shelf seas; decouples carbon and nutrient dynamics; can be coupled to different physical models
Main disadvantages	Ease of use can lead to poorly constructed models that may mislead rather than advance understanding	Very detailed representation of physiological processes; Very data intensive	Data intensive and no easy user interface	No easy user interface	Data intensive; Very detailed representation of physiological processes
Limitations	No explicit spatial structure in ECOSIM; equilibrium structure; foraging arena formulation not always appropriate; no allowance for detailed energetic considerations (Aydin and Friday, 2001; Aydin, 2004) and alternative prey types treated as energetically equivalent; problems re modelling marine mammal populations (Plaganyi and Butterworth, 2004, 2005a&b)	Birds, marine mammals and sharks not represented as dynamic pools but rather simply as mortality terms on fish; Invertebrate fisheries not represented; No bycatch component	Base biological rate parameters are fixed in any one run	Cannot be easily applied to whole-of-ecosystem (in the sense of ATLANTIS or EwE, though agent types do span all trophic levels); must target its use carefully	Not designed for detailed representation of higher trophic levels such as fish and top predators
Ease of presentation of model outputs	Excellent	Visualisation software (Olive) available	Visualisation software (Olive) and Excel and R analysis support sheets available	Visualisation software and R analysis scripts available	Some presentation software developed
User-level of programming and mathematical skills required	Entry point requires no programming or mathematical skills; more advanced users can benefit from these skills	Fair level required	Fair level required	Fair level required	Some programming skills required although explorations with currently existing models should be relatively straightforward

TABLE A3b MODEL COMPARISON

MODEL	SSEM	KPFM	MRM e.g. Punt and Butterworth (1995)	MSVPA and MSFOR	MSM
Main advantages	Useful for exploring effects of nutrient and pesticide runoffs in coastal systems	Has attempted to synthesize state-of-the-art knowledge re the system into a relatively simple model	Rigorous model that fits to data; focuses on groups of interest only with these accounting for 90% of hake mortality in system	Large concerted effort concentrated on approach (e.g. Daan and Sissenwine, 1991) with attendant large sampling effort and studies to test underlying assumptions plus subsequent efforts to improve and modify approach	Provides measures of parameter uncertainty
Main disadvantages	Data intensive; not as well tested as other models	Includes several parameters that are difficult to quantify, hence considerable uncertainty re these	Difficult to implement	Data hungry, Lack of statistical structure to take account of uncertainty in parameter estimates	Difficult for most to implement
Limitations	Not suitable for investigations re fisheries other than coastal impacts	Initialized from uncertain data; does not include growth models and delay-difference dynamics do not capture full age-structured complexity; No fleet dynamics; no framework for fitting to data or formal statistical testing	No feedback between changes in hake abundance affecting seal dynamics; desirability parameters assumed independent of density; No explicit inclusion of environmental effects although noise terms included	Age-based rather than length-based as required for some regions; predation modelled as one-way interaction with predators impacting prey but no effect on predators of changing prey population; Sensitivity to recruitment assumptions	Considers only small subset of ecosystem
Ease of presentation of model outputs	Unknown	Useful parameter visualisation and tuning + summary performance measures in EXCEL; Not fully automated outputs	Not automated	Average	Unknown
User - level of programming and mathematical skills required	Unknown	Not currently generally available although ultimately version in R will be accessible to users with moderate programming skills	Very high - specific examples need to be coded and minimisation process is complex	Fairly high; some user-friendly packages e.g. 4M for the Baltic (Vinther *et al.*, 1998)	High

TABLE A3c MODEL COMPARISON

MODEL	MULTSPEC	GADGET	Bioenergetic/ allometric models e.g. Koen-Alonso and Yodzis, 2005	OSMOSE	SEAPODYM
Main advantages	Time-varying spatial overlaps between predators and prey handled; Detailed stomach content data and consumption formulations incorporated; Includes cannibalism	Flexibility re model as different modules can be substituted; permits efficient optimisation/fitting to data; Sensitivity analysis routine identifies parameters with minor impacts only which can thus be fixed in future runs; Possible to estimate separate parameters for each year e.g. if growth or selectivity differences between years	Explores sensitivity to alternative functional response formulations; detailed explorations re parameter uncertainty; does not require accurate data re diet composition	Recognises that size suitability is fundamental to fish predation as well as spatial co-occurrence between a predator and its prey	Attempts to incorporate environmental data directly into a spatial population-dynamics simulation model; novel movement model; level of implication closely linked to the level of information available on each aspect
Main disadvantages	Detailed stomach content data required plus spatially-resolved information	Current lack of examples demonstrating its use	Requires estimation of a large no. of parameters	Includes a relative fecundity parameter that is difficult to estimate	Insufficient resolution of mid-trophic levels to explore trophic interactions at all levels
Limitations	Model simulates effects of marine mammal predation on fish but no feedback in opposite direction; Prey selection depends on prey species but doesn't account for prey or predator size; Growth depends on feeding level and temperature only, no energetic considerations; Model tailored fairly specifically for Barents Sea region	Difficult (but not impossible) to apply to the whole ecosystem; Lower trophic levels not well represented	No physical/ environmental forcing considered; age-structure not considered	Only fish dynamics explicitly modelled thus e.g. top predators included only as additional mortality term	Tailored very specifically for tuna; absence of a formal fitting procedure for the estimation of parameters
Ease of presentation of model outputs	Unknown	Good e.g. automatic sensitivity analysis plots and postscript output files; print files for comparing output	Not automated	Unknown	SeapodymView software includes tools for manipulating and visualising data and outputs
User - level of programming and mathematical skills required	Fair	Intermediate; some initial training to understand basics of UNIX/Linux; require understanding of e.g. optimisation process but no need to recode oneself; paramin program allows use of multiple computers to speed up runtime but is for the more advanced user	High - ability to code plus experience re nonlinear minimisation	The simulation framework can be defined using a graphical interface	Low level required to run executables but considerably more to alter programs as would be needed to adapt for other regions / species

TABLE A3d MODEL COMPARISON

MODEL	**CCAMLR models e.g. Mori & Butterworth 2005, 2006**	**EPOC**	**SMOM**	**ESAM**	**SEASTAR**
Main advantages	Simple but pragmatic, biologically realistic equations; fits to data	Flexible addition/ substraction of modules	Relatively simple model designed to produce probability distribution rather than a single output; Management Procedure framework	Includes ability to statistically evaluate the fit of the model to the data; results directly applicable to stock assessment e.g. natural mortality shown to vary inter-annually	Focuses on target species of interest, builds models in a stepwise fashion starting from simplest possible, fairly statistically rigorous
Main disadvantages	Age-aggregated and tailored fairly specifically for krill-centric ecosystem	Still under development and hence not tested	Considers only limited subset of the ecosystem	Considers only limited subset of ecosystem	Considers only very limited subset of ecosystem
Limitations	No physical/ environmental forcing considered; can't explicitly represent observed changes in age at sexual maturity due to lack of age structure	No framework for fitting to data or formal statistical testing	Initialized from uncertain data; does not include detailed krill growth model ; no seasonality or fleet dynamics	Typically no physical/ environmental forcing but could be included; lower trophic levels not considered; no feedback effect of prey consumption affecting predator populations	Typically no physical/ environmental forcing but could be included; lower trophic levels not considered; often no feedback effect of prey consumption affecting predator
Ease of presentation of model outputs	Not automated	Good	Not fully automated outputs	Not automated	Not automated
User - level of programming and mathematical skills required	High - ability to code plus experience in nonlinear minimisation	Moderate - knowledge of R required	High - ability to code plus some experience re nonlinear minimisation	High - ability to code plus experience in nonlinear minimisation	High - ability to code plus experience in nonlinear minimisation

TABLE A4

Preliminary comparison of selected different modelling approaches to address a range of EBFM research questions outlined in the text. The shared regions of the table highlight those approaches currently most appropriate or showing potential to address the aims as indicated, as assessed by the author

Type of model	Whole ecosystem models	Biogeochemical ecosystem models	Biogeochemical ecosystem models	Whole ecosystem models	Biogeochemical ecosystem models	Biogeochemical ecosystem models	Whole ecosystem models	Dynamic multispecies models	Dynamic multispecies models	Dynamic system models
	1	2	3	4	5	6	7	8	9	10
RESEARCH QUESTION/ MODEL	Ecopath with Ecosim and ECOSPACE	IGBEM	ATLANTIS	INVITRO	ERSEM II	SSEM	KPFM*	MRM e.g. Punt and Butterworth (1995)	MSVPA and MSFOR	MSM
1a. Understanding - subset of ecosystem		■		■	■	■	■	■	■	■
1b. Understanding - complete ecosystem	■		■							
2. Impact of target species	■		■	■			■	■	■	■
3. Effect of top predators	■		■	■			■		■	■
4. Competition: marine mammals - fisheries	■		■	■				■		■
5. Rebuilding depleted fish stocks	■		■	■				■		
6. Biases in single-species assessment	■		■	■				■	■	■
7. Ways to distribute fishing effort among fisheries	■		■	■						
8. Under-exploited species	■		■	■						
9. Change in ecosystem state	■	■	■	■		■				
10. Spatial concentration of fishing	■		■	■			■			
11. Environmental/physical effects	■	■	■	■	■	■	■			
12. Effects of habitat modification			■	■						
13. Effects of by-catch	■		■	■						
14. Introduction of non-native species	■		■	■						

* Still being developed

Table A4 (*continued*)

Type of model	Dynamic multispecies models	Dynamic multispecies models	Dynamic multispecies models	Dynamic system models	Dynamic system models	Dynamic multispecies models	Whole ecosystem models	Dynamic multispecies models	Dynamic multispecies models	Dynamic multispecies models
	11	12	13	14	15	16	17	18	19	20
	MULTSPEC	GADGET	Bioenergetic/ allometric models	OSMOSE	SEAPODYM	CCAMLR models	EPOC*	SMOM*	ESAM	SEASTAR
1a. Understanding - subset of ecosystem										
1b. Understanding - complete ecosystem										
2. Impact of target species										
3. Effect of top predators										
4. Competition: marine mammals - fisheries										
5. Rebuilding depleted fish stocks										
6. Biases in single-species assessment										
7. Ways to distribute fishing effort among fisheries										
8. Under-exploited species										
9. Change in ecosystem state										
10. Spatial concentration of fishing										
11. Environmental/physical effects										
12. Effects of habitat modification										
13. Effects of by-catch										
14. Introduction of non-native species										

* Still being developed

This report reviews the methods available for assessing the impacts of interactions between species and fisheries and their implications for marine fisheries management. A brief description of the various modelling approaches currently in existence is provided, highlighting in particular features of these models that have general relevance to the field of ecosystem approach to fisheries (EAF). The report concentrates on the currently available models representative of general types such as bionergetic models, predator-prey models and minimally realistic models. Short descriptions are given of model parameters, assumptions and data requirements. Some of the advantages, disadvantages and limitations of each of the approaches in addressing questions pertaining to EAF are discussed. The report concludes with some recommendations for moving forward in the development of multispecies and ecosystem models and for the prudent use of the currently available models as tools for provision of scientific information on fisheries in an ecosystem context.

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