ECOPATH MODELLING OF TUNDRA ECOSYSTEMS

Alice J. Kenney, University of British Columbia
Charles J. Krebs, University of British Columbia

PURPOSE

To describe ECOPATH and the data required to build an ECOPATH model of a tundra site.

ECOPATH HISTORY

ECOPATH is a simulation tool developed for fisheries research by Carl Walters, Daniel Pauly and Vily Christiansen at the Fisheries Centre at UBC and at ICLARM in the Philippines (Christensen and Pauly 1992). It is a static, mass-balanced snapshot of an ecosystem that analyzes the flow of biomass between species (or groups) in an ecosystem. It has a heavy fisheries orientation, and some of the terminology must be translated to apply it to a terrestrial ecosystem (Pauly et al. 2000).

As of 2007 it is being combined with *Ecosim* – a time dynamic simulation module for policy exploration; and *Ecospace* – a spatial and temporal dynamic module primarily designed for exploring impact and placement of marine protected areas. The Ecopath software package can be used to:

- Address ecological questions;
- Evaluate ecosystem effects of harvesting;
- Explore management policy options;
- Analyze impact and placement of marine protected areas;
- Predict movement and accumulation of contaminants and tracers (Ecotracer);
- Model effect of environmental changes.

A link to it can be found at: http://www.ecopath.org/.

The idea is to link the production of each species group with the consumption of all other species groups in the community. The program then uses these linkages to estimate missing parameters of the model. The fundamental equation of ECOPATH is:

$$B_r\left(\frac{P_r}{B_r}\right)EE_r + I_r = \sum_c\left(B_c\left[\frac{Q_r}{B_c}\right]d_{rc}\right) + \Delta B_r + E_r$$

where:

B = biomass
EE = ecotrophic efficiency (proportion of production utilized by the system
E = emigration
Q = consumption rate
r = resource (e.g. *Carex*)
P = production
I = immigration
d = proportion of r in c diet
c = consumer (e.g. caribou)

Given all the data in this model, the ECOPATH computer program solves for the missing parameter *ecological efficiency*. Typically we assume a steady state if the change in biomass is zero and there is no emigration. By linking ECOPATH with ECOSIM it is possible to develop a time-dynamic model rather than a static one. We have so far only used the simple static model.

ECOPATH modeling is useful in its simple form to answer the question of where does the production of trophic level *x* go, and in particular how much of the production of trophic level *x* goes to trophic level *x+1*. We have used it to analyze the 10-year cycle of snowshoe hares and their predators (Ruesink et al. 2002) and to summarize the findings of the Swedish Tundra Northwest 1999 Expedition (Krebs et al. 2003).

Step # 1 – Define taxa

What taxonomic/ecological groups do you wish to include in the model?

- species (the best level if you have the data)
- functional groups (may have to use this for plants or insects?)
- groups with little data (difficult if they are important in the ecosystem)
- groups with little importance (probably easily ignored in the analysis)

Step # 2 – Estimate Biomass

What is the standing crop of each taxonomic/ecological group in the model? The units are kg wet weight per sq. km.

The decision has to be made as to the 'study zone' and clearly it must be large enough to encompass the species of most interest home ranges. You have to decide if you want very local or more regional estimates.

As an example (not that we should follow this!) in the Swedish Expedition:

(1) We estimated plant cover along snap trap lines (n = 200 points at each site). We then converted these cover estimates to standing crop using regressions for each plant group that we worked out empirically.

(2) We estimated consumer abundance for lemmings by winter nest estimates, and for muskox, caribou, arctic hares, geese, and ptarmigan by fecal pellet transects. Abundance estimates were converted to biomass based on coversions found in the literature for each species.

(3) We estimated predator abundance for arctic foxes, ravens, gulls, hawks, jaegers, snowy owls, and falcons by predator walking surveys.

(4) For missing species that were important like ermine we used winter nest kills and literature estimates of density.

(5) For some groups like insects we had no data. For others we ignored the consumer species grizzly bears, passerine birds, waders.

Step # 3 - Estimate Production

Typically we would use a yearly time step for production data. ECOPATH does this very simply (and inaccurately?) by estimating production / biomass ratios (P/B) for all species and groups in the ECOPATH model for both vegetation and herbivores.

Vegetation Production:

(1) Convert standing crop to net primary production using literature data.

(2) Estimate production / biomass ratios (P/B) for ECOPATH model.

(3) For mosses and lichens we estimated above-ground production from the literature.

Consumer Production:

(1) For each species we need Production / biomass ratios for the ECOPATH model.

(2) Minimum P/B : maximum observed rate of population growth (r_{max})

(3) Maximum P/B : clutch size or litter size adjusted for sex ratio.

Step # 4 - Estimate Consumption

We used a yearly time step for consumption data. Again ECOPATH uses a simple assumption for all species. We estimate the consumption / biomass ratios (Q/B) for each species group for herbivores and predators.

Consumption Estimation

We used the field metabolic rate (FMR) regressions of Nagy (1987) to estimate energy use. We obtained body mass estimates from literature or from our data. We assumed food energy of 1 kcal/g for herbivores and 1.75 kcal/g for predators.

Consumption Estimation:

We estimated the Annual Q/B = proportion time present * daily FMR * 365 days / body mass

We assumed migratory species are present for 20% of the year (10.4 weeks).

Step # 5 – Diet Composition

For herbivores we used groups of plant species only (grasses, lichens etc.).

For herbivores – data from literature

For predators – data from scats collected on our walking surveys.

Major problems in estimating diet composition:

(1) From the literature, diets are highly variable among different sites

(2) For some sites the main species in the diet are missing!

(3) Some species like caribou are eaten only by wolves on which we have no data!

Step # 6 – Run ECOPATH

The computer program solves the basic ECOPATH equation to compute ecotrophic efficiencies.

Ecotrophic efficiencies must by the laws of conservation of mass be between 0 and 1.0. Often when the model is run, they are above 1.

If EE > 1, there must be an error in biomass, production, consumption, or diet data. This often happens when the literature values have to be used in the data.

Sample ECOPATH Results from Tundra Northwest 1999 Expedition

For plants to herbivores, the ecotrophic efficiencies average 11%.

For small herbivores to predators, the ecotrophic efficiencies average 70%.

For muskox and caribou subject to wolf predation EE's average 10%.

Possible inference from these data: the terrestrial Canadian arctic tundra is for small herbivores a top-down system driven from above by predation.

Large mammals (caribou, muskox) are neither food nor predator limited but possibly are weather limited.

LITERATURE CITED

Christensen, V. & Pauly, D. (1992) ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling*, **61**, 169-185.

Krebs, C.J. et al. (2003) Terrestrial trophic-dynamics in the Canadian arctic. *Canadian Journal of Zoology*, **81**, 827-843.

Pauly, D., Christensen, V., & Walters, C. (2000) Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science*, **57**, 697-706.

Ruesink, J.L., Hodges, K.E., & Krebs, C.J. (2002) Mass-balance analyses of boreal forest population cycles: merging demographic and ecosystem approaches. *Ecosystems*, **5**, 138-158.