Valuation of Ecological Benefits: Improving the Science Behind Policy Decisions

PROCEEDINGS OF

SESSION IV: TALES OF OTTERS, EAGLES, AND OWLS: VALUING WILDLIFE HEALTH AND BIODIVERSITY

A WORKSHOP SPONSORED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS (NCEE) AND NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH (NCER)

October 26-27, 2004
Wyndham Washington Hotel
Washington, DC

Prepared by Alpha-Gamma Technologies, Inc.
4700 Falls of Neuse Road, Suite 350, Raleigh, NC 27609

ACKNOWLEDGEMENTS

This report has been prepared by Alpha-Gamma Technologies, Inc. with funding from the National Center for Environmental Economics (NCEE). Alpha-Gamma wishes to thank NCEE's Cynthia Morgan and the Project Officer, Ronald Wiley, for their guidance and assistance throughout this project.

DISCLAIMER

TABLE OF CONTENTS

Contingent Valuation for Ecological and Noncancer Effects within an Integrated Human Health and Ecological Risk Assessment Model

James Hammitt and Katherine von Stackelberg
Harvard Center for Risk Analysis, 718 Huntington Avenue, Boston, MA 02115

Objectives:

The objective of this research is to contribute to the understanding of practical and credible approaches for estimating the benefits and costs of environmental policies and to improve decisionmaking regarding environmental issues. Our approach is to develop an integrated human health and ecological risk model using data from a case study, which also incorporates economic information from two contingent valuation surveys. The case study focuses on potential human health and ecological receptor exposure to polychlorinated biphenyl (PCB) compounds via fish ingestion. The risk model integrates the results of two contingent valuation (CV) surveys to quantify the benefit of potential risk reductions under assumed exposure conditions using a publicly available database. The integrated model uses the results of a web-based contingent valuation questionnaire to estimate willingness-to-pay of the general public to reduce potential risks associated with exposure to PCBs. These risks include reproductive effects in birds and mammals and developmental effects in children exposed *in utero*. The integrated risk model can be used to evaluate the economic role ecological and noncancer human health outcomes play under specific exposure conditions. The contingent valuation surveys are designed to inform the growing literature on the value individuals place on the ecological and noncancer benefits of risk reductions.

During the past year, we focused on working through methodological issues related to survey development. We also conducted an extensive literature search and evaluated this literature on the potential effects of exposure to PCBs in order to develop dose response models for developmental noncancer effects in humans and reproductive effects to ecological receptors. These dose response models provide the basis for the relevant endpoints used in survey development. Finally, we developed an Excel-based two-dimensional Monte Carlo modeling framework to predict dietary exposures to human and ecological receptors. We integrated the dietary exposure model with the dose response models to obtain probabilistic estimates of potential risks.

Potential Effects of PCBs

We have conducted an extensive literature search on the potential effects of PCBs in both humans and animals, focusing specifically on potential developmental effects in humans and reproductive effects in wildlife. This information is used to develop the specific endpoints for valuation within the CV survey, and to develop dose-response models for the integrated risk assessment.

Ecological Endpoints

Typical responses to PCB exposure in animals include wasting syndrome, hepatotoxicity, immunotoxicity, neurotoxicity, reproductive and developmental effects, gastrointestinal effects, respiratory effects, dermal toxicity, and mutagenic and carcinogenic effects. Some of these effects are manifested through endocrine disruption.

PCBs are typically present in the environment as complex mixtures. These mixtures consist of discrete PCB molecules that are individually referred to as PCB congeners. PCB congeners are often introduced into the environment as commercial mixtures known as Aroclors. PCB toxicity varies significantly among different congeners and is dependent on a number of factors. Two significant factors relate to the chemical structure of the PCB congener, including the degree of chlorination and the position of the chlorines on the biphenyl structure (Safe *et al.* , 1985a). In general, higher chlorine content typically results in higher toxicity, and PCB congeners that are chlorinated in the *ortho* position are typically less toxic than congeners chlorinated in the *meta* and *para* positions. Metabolic activation is believed to be the major process contributing to PCB toxicity.

Reproductive effects tend to be the most sensitive endpoint for animals exposed to PCBs. Indeed, toxicity studies in vertebrates indicate a relationship between PCB exposure, as demonstrated by AHH induction, and functions that are mediated by the endocrine system, such as reproductive success. A possible explanation for the relationship between AHH activity and reproductive success may be due to a potential interference from the P450-dependent MFO with the ability of this class of P450 proteins to regulate sex steroids. In fact, the induction of cytochrome P450 isozymes from PCB exposure has been shown to alter patterns of steroid metabolism (Spies *et al.*, 1990).

Historically, the most common approach for assessing the ecological impact of PCBs has involved estimating exposure and effects in terms of totals or Aroclor mixtures. It is important to note that, since different PCB congeners may be metabolized at different rates through various enzymatic mechanisms, when subjected to processes of environmental degradation and mixing, the identity of Aroclor mixtures is altered (McFarland and Clarke, 1989). Therefore, depending on the extent of breakdown, the environmental composition of PCBs may be significantly different from the original Aroclor mixture. Furthermore, commercial Aroclor mixtures used in laboratory toxicity studies may not represent true environmental exposure to this Aroclor. Thus, there are considerable uncertainties associated with estimating the ecological effects of PCBs in terms of total PCBs or Aroclors.

Ecological risk assessments follow an established framework in which there are assessment and measurement endpoints (EPA, 1993). Assessment endpoints represent that which is being protected, for example, protection and sustainability of wildlife populations. There are one or more measurement endpoints, which are the specific ways in which impacts on the assessment endpoints will be evaluated. For example, one of the associated measurement endpoints for that assessment endpoint might include comparing predicted doses to the selected species with doses from the toxicological literature associated with specific effects. Assessment endpoints are broadly defined while measurements endpoints are the specific analyses that will quantify potential impacts.

There are two distinct ways in which potential impacts to an ecosystem can be evaluated within a risk assessment context. The first focuses the analysis on a single species designed to represent high-end exposure and sensitivity. A set of representative receptors is selected that serve as proxies for the many species that the ecosystem supports. Potential impacts are evaluated by developing dose-response models, generally from laboratory data, to predict outcomes. The very simplest analysis involves developing a toxicity reference value (TRV) against which to compare exposures at the site. This deterministic analysis can be expanded to include a joint probability model that quantifies the probability of an increasing magnitude of effect using the dose-response model for a single species (e.g., reduction in fecundity), or one can model the probability of exceeding a threshold value. Under this representative receptor approach, a valuation for a single "high-profile" species will implicitly value those aspects of the ecosystem that support the species (Loomis and White, 1996). Management actions are designed to reduce risks for the presumed highest risk species. The corresponding valuation asks respondents about their willingness to pay to reduce the probability of an effect on a single species.

The second approach is slightly different. Rather than relying on a single dose-response relationship for one species, the analysis relies on species sensitivity distributions. These distributions quantify the probability of the proportion of species that will be affected (e.g., there is a 20% probability that 80% of the species will experience adverse reproductive effects). Under this approach, the analysis does not focus on one particular species but rather considers the probability of impacting multiple species. Both approaches are used in this analysis (and both kinds of endpoints valued in the survey).

In both cases, the exposure model incorporates a probabilistic bioaccumulation model to describe uptake of PCBs into the aquatic food web based on a model developed for the Hudson River RI/FS (EPA, 2000a; 2000b). Both benthic and pelagic invertebrates, aquatic vegetation and fish are consumed by ecological receptors. Risks are described across an increasing magnitude of effect (e.g., there is a 50% chance of an 80% reduction in fecundity) or across an increasing percentage of species (e.g., there is a 50% chance that 80% of the species will experience adverse reproductive effects).

The individual species of concern in this analysis is the bald eagle *(Haliaeetus leucocephalus*). We selected this receptor for modeling because:

- It is one of the most important receptors in the Hudson River RI/FS, which provides the exposure estimates;
- It consumes a variety of fish and fish-eating organisms;
- It only produces one or two nestlings per year;
- It is a threatened species.

Several field studies were identified that examined the effects of PCBs in eggs of bald eagles, but not dietary doses. Clark et al. (1998) presented information on concentrations of total PCBs (range = 20 to 54 mg/kg egg) and TEQs in eggs from two sites in New Jersey where reproductive failures have occurred, but the data could not be used to develop dose-response relationships. Studies by Wiemeyer et al. (1984, 1993) reported adverse effects on mean 5-year production in bald eagle with egg concentrations greater than 3.0 mg PCBs/kg egg. Wiemeyer et al. (1993) studied bald eagle production over a long time period (i.e., 5- year intervals from 1969 through 1984), and examined production rates in the field. However, significant intercorrelation of many contaminants made it difficult to determine which contaminants caused the adverse effects (Wiemeyer, 1993), thus, it is not possible to estimate individual dose-response relationships.

We are using a laboratory study by Dahlgren *et al.* (1972) as the basis for the individual dose-response modeling in this analysis. These authors found significantly reduced ($p<0.01$) egg production by hens that had been fed Aroclor 1254 for a period of 16 weeks. Egg production by hens fed PCBs at the lowest observed adverse effect level was 32-97% that of control hens. The Aroclor 1254 was administered weekly in capsules into the esophagus. A Generalized Linear Modeling (GLM) framework is used with a log link function and Poisson error distribution to estimate the dose-response relationship (Moore et al., 1999; EPA, 2000b).

The species sensitivity distribution (SSD) approach uses the distribution of effects concentrations for all species. Just as typical dose-response curves can be used to estimate the probability of effects for an individual species, the SSD can be used to estimate the probability of effects on a species or the probability of effects across species. We are relying on an SSD developed by Suter (2003), based on the survival and development of avian embryos and chicks. These effects were chosen because of data availability, comparability among studies and the clear relevance of reproductive success to avian populations. That report focuses on the potential effects of the dioxin-like congeners.

SSDs may be used quantitatively to estimate the proportion of a taxon (e.g., herons), trophic group (e.g., piscivorous birds) or community that will be affected by an exposure (Suter, 2003). This is equivalent to using a conventional dose-response function to estimate the proportion of a population that will be affected. It requires fitting some function to the SSD so that, as in other exposure-response models, the response can be estimated from the exposure level. The most common functions are the log normal or its linearized version the log probit and the log logistic or its linearized version the log logit, depending on how the outcomes are expressed (e.g., continuous versus dichotomous). The use of tested species to represent communities relies on the assumption that the tested species are an unbiased sample of the community. Test species are not chosen randomly, but, since species sensitivities are not known prior to testing, there is no reason to expect that the selection is biased.

Human Health Endpoints

The weight-of-evidence for a relationship between *in utero* polychlorinated biphenyl (PCB) exposure and developmental outcomes has been well established and continues to grow (Schantz et al., 2003). However, as with most epidemiological studies, discrepancies exist among measures of exposure and the strength of the relationships between the measures of exposure and developmental outcomes. Some of those discrepancies are attributable to differences in analytical methods, particularly in older studies (Longnecker et al., 2003) that had higher detection levels and less sophisticated quantitation techniques.

The primary difficulty in quantifying the relationship between dietary levels of PCBs associated with developmental effects based on epidemiological studies is in the lack of an association between exposure metrics and outcomes. Ingestion of food is likely the most significant exposure pathway (Longnecker et al., 2003; Laden et al., 2000). However, the studies that show significant associations between PCB exposure expressed as cord blood, maternal serum or breast milk concentrations and developmental outcomes in children (ranging in age from birth to 11 years) typically show little or no correlation between those metrics and seafood or other dietary item consumption (Schell et al., 2001;).

It is not a goal of the analysis to develop a definitive dose response model for potential developmental effects. Therefore, we selected data from one cohort specifically which has been well-documented in the literature, follows a cohort whose exposure is specifically tied to fish ingestion, and for which the evidence of *in utero* exposure is greatest. In addition, this cohort has been followed for 11 years with documented effects still at this age, as opposed to other studies which only have a few years worth of followup.

The Michigan Cohort: this cohort was recruited through four maternity hospitals in western Michigan from 1980 to 1981. Two hundred and forty two mothers who had at consumed more than 12 kg of Lake Michigan fish during the previous six years and 71 mothers who had not eaten any Lake Michigan fish participated in the study. The authors assessed prenatal exposure using umbilical cord serum collected at delivery, and maternal serum and breast milk collected shortly after delivery. Testing thus far has been conducted on the newborns, at 4 years, and at 11 years.

Newborn testing was conducted on 242 exposed and 71 control infants. Behavioral outcomes were assessed using the Brazelton neonatal Scale (NBAS), which showed that the most highly exposed infants were more likely than controls to be classified as "worrisome" (Jacobson et al., 1984). The four-year followup collected data from two separate visits – the first at four years and the second three months later. During the first visit, 236 exposed and 87 unexposed children were evaluated using the McCarthy Scales of Children's Abilities, while the second visit involved a series of reaction time tests (Jacobson et al., 1990). Both visits involved extensive discussions with the mother, including completing the Peabody Picture Vocabulary Test-Revised and Buss and Plomin Emotionality Activity Sociability Temperament Survey for Children. The three ratings were transformed into standard scores and summed to provide a composite measure of activity, what was then standardized to a mean of zero and a standard deviation of one. The 11-year sample evaluated 178 children tested using the Wechsler Intelligence Scale for Children-Revised (WISC-R).

We are relying on the data presented in Jacobson et al. (2000), which presents a linear relationship between lipid-normalized breast milk concentration of PCBs and outcomes.

SURVEY DEVELOPMENT

We completed a pre-test version of the survey (see Appendix A). The survey is divided into two parts. In the first part, half the respondents see questions related to ecological effects first, and the other half see questions with human health effects. The second part asks for the total amount that a household would be willing to pay for the combined health and ecological benefits of PCB removal.

Environmental effects can be broadly categorized in one of two ways: a small probability of a fairly dramatic outcome (e.g., risk of developing a serious illness or cancer food poisoning, etc.), or a relatively large probability of a very small effect. There are a number of studies that have evaluated willingness to pay of the first category. This study is designed to evaluate willingness to pay for a very small effect (in humans) that occurs with a fairly large probability (50% chance if exposed). The ecological effect (e.g., reproductive impairment) occurs with a relatively high probability and is considered a large effect, but of course does not impact humans directly. For that outcome, we are interested in how people perceive environmental threats to ecological resources, what they might be willing to pay to reduce that threat, and how those results can be incorporated into a specific regulatory context – namely, risk assessment.

The human health component of the survey asks respondents about two potential developmental endpoints associated with PCB exposures: a probability of a 6 point reduction in IQ and a probability of a 7-month deficit in reading comprehension. The survey asks about a 50% risk of these endpoints decreasing to either 10% or 25%. The ecological endpoints include a probability of reproductive effects in eagles such that the ability of the population to sustain itself would be severely compromised, and a probability of an effect on 25% of the species (using a species sensitivity distribution). The ecological endpoints correspond to the two different management alternatives that are currently used in typical ecological risk assessments. The risk of adverse effects in eagles is 20% decreasing to 10% or 5%.

Willingness to pay is elicited using a double-bounded dichotomous choice format. Respondents are presented with an initial bid randomized from a bid vector ranging from $25 to $400. If the respondents agree to the initial bid, they are presented with a bid that is double the first bid (if they agree to $400 initially, then they are asked if they would be willing to pay at $800). If respondents do not agree to the initial bid, then they are presented with a bid that is half as much ($10 if they did not agree to $25 initially). The survey is currently undergoing pretest and depending on those results, the bid vector may be adjusted for the final survey.

We are interested in evaluating differences in willingness to pay values and predictors for ecological versus noncancer outcomes, both in relative and absolute terms. Respondents are asked about one set of effects (either human or ecological), and then asked the total amount they would be willing to pay for both sets of risk reductions. Because of potential embedding and ordering effects, there may inconsistencies in responses. Ideally, we would like to have the same respondents provide values for both sets of endpoints. However, it is difficult for people to disaggregate their willingness to pay. Respondents may not be willing to pay any additional amount for an additional benefit (e.g., under the first willingness to pay question, the PCBs will have been removed, therefore, both sets of benefits will occur regardless of any additional money that is spent). We could split the survey and administer it to half the respondents, or take the entire survey and administer it to all respondents. We chose the latter design, since ideally we are interested in evaluating risks of small, noncancer effects in humans versus ecological effects in addition to determining willingness to pay for each endpoint separately.

We have conducted several informal focus groups and discovered that among respondents who are not involved with environmental issues in some way (e.g., work for an environmental company or are involved in local or national environmental groups), there was greater skepticism about the potential effects of PCBs on ecological receptors relative to human receptors. That is, people readily accepted the concept that PCBs could cause developmental delays in children exposed *in utero*, but required greater justification for potential effects to ecological receptors, and, additionally, required greater assurances that the proposed cleanup would actually achieve the stated risk reduction.

Current Status

The survey is programmed and undergoing final edits for pretest. We anticipate going into pretest the week of October 18 and administering the final survey two weeks after that. The current survey is attached as Appendix A.

RISK MODELING

The risk models use the data presented earlier to develop dose-response relationships, which are combined with exposure data from the Hudson River case study to predict the probability of an increasing magnitude of effect.

Human Health Model

The dose of PCBs via fish ingestion is most simply modeled using a first-order uptake model assuming distributions for percent absorbed, lipid content, and elimination half-life.

First order uptake is given as:

$$C_{ms} = \frac{f * ADD * t^{1/2}}{\ln(2)} \quad (1)$$

where:

C_{ms} = concentration in maternal serum (mg/kg)
f = fraction absorbed (0.5 – 0.9)
ADD = average daily dose (mg/kg-day)
$t^{½}$ = elimination half life (considered constant during lifetime) 7.5 years

Because PCBs are lipophilic and partition into the organic fraction of the environmental media they are in, the concentration of PCBs in breast milk is related to the concentration in serum through lipid content. Thus, the predictions for serum concentration are normalized for the overall tissue lipid content in pregnant women (Kopp-Hoolihan, 1999)

$$C_{LN} = \frac{C_{ms}}{L_b} \qquad (2)$$

C_{LN} = mg PCB per kg lipid
C_{ms} = concentration in maternal serum (mg/kg)
L_b = lipid content of all tissues (fraction body fat)

The maternal average daily dose (ADD) is given as:

$$ADD = \frac{IR * C_{fish} *}{BW} \qquad (30$$

ADD = average daily dose from fish consumption (mg/kg-day)
IR = ingestion rate (kg/day)
C_{fish} = concentration in fish (mg/kg)
BW = body weight (kg)

TABLE 1: Modeling Parameters

Parameter	Units	Variable or Uncertain	Distribution	Reference
Ingestion rate	kg/day	Variable and uncertain	From Hudson River RI/FS	EPA,
Body weight	kg	variable	Normal (64.8, 7.8)	Kopp-Hoolihan, 1999
PCB concentration in fish	mg/kg	uncertain	Lognormal (depends on scenario)	modeled
Fraction absorbed	fraction	uncertain	Uniform (0.5, 0.9)	assumption
$t^{1/2}$ (half-life)	1/year	uncertain	7.5	WHO
Total body fat	fraction	variable	Normal (31, 5.5)	Kopp-Hoolihan, 1999

The model uses two-dimensional Latin Hypercube to sample from each of the input distributions. It is iterative in that it first fixes all uncertain parameters, then runs an inner "variability" loop in which it samples from the variable distributions, and then returns to the outer loop to run another set of uncertain parameters.

Ecological Risk Model

The first ecological risk model quantifies the probability that a particular fraction of the eagle population will experience a particular effect (*e.g.,* 10% probability that there will be a 50% reduction in fecundity in the eagle population). The potential for population-level effects is evaluated by convolving the dose-response functions (based on Dahlgren et al., 1972) with cumulative distributions of exposure estimated using data from the Hudson River (EPA, 2000b). The second risk model quantifies the probability that a fraction of the species will experience a particular effects (*e.g.,* 10% probability that 50% of the species will experience egg death).

In both cases, the dose-response functions are obtained by fitting a probit or logit model to appropriate toxicity data. The probit model takes the following form:

$$P(d) = \frac{1}{\sqrt{2\pi}\log\sigma_g} * \int_{-\infty}^{\log d} \exp\left\{-\tfrac{1}{2}\left(\frac{x-\log d_{50}}{\log\sigma_g}\right)^2\right\} dx \qquad (4)$$

where:

d_{50} = median or geometric mean; dose at which 50% of the population responds
σ_g = geometric standard deviation; a measure of dispersion of the responses

The inverse of the cumulative probability of effect corresponding to these concentrations is obtained by using the NORMSINV function in Excel. This function provides the inverse of the standard normal cumulative distribution assuming a mean of 0 and a standard deviation of 1. The log-transformed concentration is thus linearly related to the inverse of the cumulative probability of effect. These points are then used to derive a linear relationship that follows the general form:

$$\Phi^{-1}(Y) = \beta_0 + \beta_1 X \qquad (5)$$

where:

Φ^{-1} = inverse of the normal cumulative probability (z) function (NORMSINV)
Y = probability of response
β_0 = intercept ($-d_{50}/\sigma_g$)
β_1 = slope of the line ($1/\sigma_g$)
X = log (concentration in mg/kg)

The following procedure is used to compare the cumulative exposure distributions with the dose response curves. First, Monte Carlo exposure models are used to generate the cumulative frequency of predicted dietary doses for each receptor. Output concentrations are log-transformed, and the associated cumulative frequencies, expressed as fractions, are transformed by the inverse of the normal cumulative distribution. The log-transformed Monte Carlo concentrations and the transformed cumulative frequencies yield straight lines when plotted against each other. The parameters of these regressions are used to obtain the cumulative frequency for the specified doses in the dose-response curves from the literature. The resulting curves can then be compared directly by plotting the probability of exccedence on the y-axis (obtained from the cumulative distribution of exposure) and the percent reduction in fecundity on the x-axis (obtained from the dose-response curves from the literature).

This estimate takes the following form substituting concentration *c* for dose *d*:

$$R = \int_{-\infty}^{\infty} P(c)\phi(c)dc \qquad (6)$$

where:

ϕ = the lognormal probability density function
R = risk

At each log concentration, a probability of effect is estimated from the probit model and a frequency of occurrence is estimated from the lognormally distributed body burdens. This model has been developed and applied in several site-specific applications (EPA, 2000b; Moore et al., 1999).

NEXT STEPS

We plan to derive willingness to pay estimates for the specified outcomes from the survey data. We also plan to incorporate the willingness to pay estimates into the risk assessment model to quantify the benefits of risk reductions using actual data from the Hudson River RI/FS. Management decisions have already been made for this site, therefore, it is used strictly for demonstration purposes.

We will also evaluate differences in willingness to pay between the human health and ecological endpoints. The risk model can also be used to estimate the probability of developing cancer and these results compared to the noncancer and ecological results. The exposure and risk models are largely complete and were used to derive the specific risk reductions that are the focus of the contingent valuation survey.

REFERENCES

Andrle, R.F. and J.R. Carroll (Editors). 1988. The Atlas of Breeding Birds in New York State. Cornell University Press. Ithaca, New York. 551 pp.

Clark, K. E., L. J. Niles, and W. Stansley. 1998. Environmental contaminants associated with reproductive failure in bald eagle (*Haliaeetus leucocephalus*) eggs in New Jersey. *Bulletin of Environmental Contamination and Toxicology*. 61:247-254.

Dunning, J.B. Jr. 1993. CRC Handbook of Avian Body Masses. CRC Press. Ann Arbor Michigan. 371 pp.

Elliott, J.E., R.J. Norstrom, A. Lorenzen, L.E. Hart, H. Philibert, S.W. Kennedy, J.J. Stegeman, G.D. Bellward, and K.M. Cheng. 1996. Biological effects of polychlorinated bibenzo-p-dioxins, dibenzofurans, and biphenyls in bald eagle (*Haliaeetus leucocephalus*) chicks. *Environmental Toxicology and Chemistry* Vol. 1(5):782-793.

(EPA) United States Environmental Protection Agency. 1993a. Wildlife Exposure Factors Handbook. Volume I of II. USEPA Office of Research and Development. Washington, D.C. EPA/600/R-93/187a.

(EPA) United States Environmental Protection Agency. 1993b. Wildlife Exposure Factors Handbook. Volume II of II. USEPA Office of Research and Development. Washington, D.C. EPA/600/R-93/187b.

(EPA) United States Environmental Protection Agency. 2000b. Further Site Characterization and Analysis, Volume 2E - Revised Baseline Ecological Risk Assessment (ERA), Hudson River PCBs Reassessment RI/FS. Prepared for USEPA Region 2 and USACE, Kansas City District by Menzie-Cura & Associates, Inc. and TAMS Consultants, Inc., August 1999.

Jacobson, J.L., Jacobson, S.W., Schwartz, P.M., Fein, G.G., and J.K. Dowler. 1984. Prenatal exposure to an environmental toxin: A test of the multiple effects model. *Developmental Pyschology* 20(4):523-532.

Jacobson, S.W., Fein, G.G., Jacobson, J.L., Schwartz, P.M., and J.K. Dowler. 1985. The effect of intrauterine PCB exposure on visual recognition memory. *Child Dev* 56:853-860.

Jacobson, J.L., S.W. Jacobson and H.E.B. Humphrey. 1990a. Effects of in utero exposure to polychlorinated-biphenyls and related contaminants on cognitive functioning in young children. *J. Pediatr* 116(1):38-45.

Jacobson, J.L., S.W. Jacobson and H.E.B. Humphrey. 1990b. Effects of exposure to PCBs and related compounds on growth and activity in children. *Neurotoxicol Teratol* 12:319-326.

Jacobson, J.L., S.W. Jacobson. 1996a. Intellectual impairment in children exposed to polychlorinated biphenyls in utero. *N Engl J Med* 335(11):783-789.

Jacobson, J.L., S.W. Jacobson. 1996b. Sources and implications of interstudy and interindividual variability in the developmental neurotoxicity of PCBs. *Neurotoxicol Teratol* 18(3):257-264.

Jacobson, J.L., S.W. Jacobson. 1997. Evidence of PCBs as neurodevelopmental toxicants in humans. *Neurotoxicology* 18(2):415-424.

Jacobson, J.L., Janisse, J., Banerjee, M., Jester, J., Jacobson, S.W., and J.W. Ager. 2002. A benchmark dose analysis of prenatal exposure to polychlorinated biphenyls. *Environ Health Perspect* 110(4):393-398.

Kopp-Hoolihan, L.E., M.D. van Loan, W.W. Wong, and J.C. King. 1999. Far mass deposition during pregnancy using a four-component model. *J Appl Ph*ysiol 87(1):196-202.

Laden, F., Neas., L.M., Spiegelman, D., Hankinson, S.E., Willett, W.C., Ireland, K., Wolff, M.S. and D.J. Hunter. 1999. Predictors of plasma concentrations of DDE and PCBs in a group of U.S. women. Environmental Health Perspectives 109(1):

Longnecker, M.P., Wolff, M.S., Gladen, B.C., Brock, J.W., Grandjean, P., Jacobson, J.L., Korrick, S.A., Rogan, W.J., Weisglas-Kuperus, N., Hertz-Picciotto, I., Ayotte, P., Stewart, P., Winneke, G., Charles, M.J., Jacobson, S.W., Dewailly, E., Boersma, E.R., Altshul, L.M., Heinzow, B., Pagano, J.J. and A.A. Jensen. 2003. Comparison of polychlorinated biphenyl levels across studies of human neurodevelopment. *Environ Health Perspect* 111(1):65-70.

Moore, D.R.J., Sample, B.E., Suter, G.W., Parkhurst, B.R. and R.S. Teed. 1999. A probabilstic risk assessment of the effects of methylmercury and PCBs on mink and kingfishers along East Fork Poplar Creek, Oak Ridge, Tennessee, USA. *Environ. Tox. Chem.* 18(12):2941-2953.

Schantz, S.L., Wiholm, J.J. and D.C. Rice. 2003. Effects of PCB exposure on neuropsychological function in children. *Environ Health Perspect* 111(3):357-376.

Schell, J.D. Jr., Budinsky, R.A., and M.J. Wernke. 2001. PCBs and neurodevelopmental effects in Michigan children: An evaluation of exposure and dose characterization. *Reg Tox Pharm* 33:300-312.

Todd, C. S., Young, L. S., Owen, R.B., Jr. et al. 1982. Food habits of bald eagles in Maine. *J Wildl Manage* 46: 636-645.

Wiemeyer, S.N., T.G. Lamont, C.M. Bunck, C.R. Sindelar, F.J. Gramlich, J.D. Fraser, and M.A. Byrd. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs- 1969-79- and their relationships to shell thinning and reproduction. *Arch Environ Contam Toxicol* 13: 529-549.

Wiemeyer, S.N., C.M. Bunck, and C.J. Stafford. 1993. Environmental contaminants in bald eagle eggs – 1980-84- and further interpretations of relationships to productivity and shell thickness. *Arch Environ Contam Toxicol* 24:213-227.

PCB Exposure Valuation Survey

September 2004

– Study Details –

Note: This page may be removed when the questionnaire is sent to the client. However, it must exist in the version sent to Operations.

SNO	**7960**
Survey Name	**Willingness to Pay for Noncancer Developmental and Ecological Effects Pretest**
Client Name	**Harvard University**
Great Plains Project Number	**K0499**
Project Director Name	**Stefan Subias**
Team/Area Name	**TM Dennis**

Sample Criteria	**General population adults**
Samvar	**Standard demos only.**
Specified Pre-coding Required	**No**
Timing Template Required	**Yes**
Multi-Media	**Images**
Incentive	**No**
Disposition Information (Provide exact descriptions with reference to question numbers and answer list responses for all groups that daily counts are desired)	

Note: The change request log can be deleted, if you do not require it.

Change Request Log
(Operations Please Disregard)
Note: Do not change Question numbers after Version 1; to add new question, use alpha characters (e.g., 3a, 3b, 3c)

Author	Ver-sion	Description of Change (Q#, plus change)	Approval Name	Date Apprv'd	Com-pleted (Y/N)

Willingness to Pay for Noncancer Developmental and Ecological Effects Pretest

September 2004

– Questionnaire –

NOTE TO SCRIPTER: RANDOMIZE SECTIONS B/C AND D SO THAT HALF SEE B/C FIRST AND HALF SEE D FIRST.

[DISPLAY]
We are conducting this survey to get your opinion on issues such as education, crime, and the environment facing people in your state. The study will provide information so that State policy makers can understand how people like you feel about these issues.

A. INTRODUCTORY QUESTIONS

NOTE TO SCRIPTER: I CONVERTED THE 3-POINT SCALES IN A1 AND A2 INTO 5-POINT ONES—THIS IS HARD TO SEE IN THE TRACKED CHANGES.

[GRID – SP BY ROW]

A1. There are many issues that require resources facing residents in your State. Some of them may be important for you personally and others may not. Please identify whether the listed issue is not important, somewhat important, or very important to you personally:

	Not Important		Somewhat Important		Very Important

Reducing crime
Cleaning up the environment
Improving education
Protecting State waterways
Reducing State taxes
Reducing air pollution
Improving library services
Providing more security at public events

[GRID – SP BY ROW]

A2. Your State government must allocate financial resources among many different programs. Below you will see a list of different programs. For each one, please indicate whether the amount of money being spent should be reduced, stay the same, or increased, keeping in mind that overall expenditures cannot be increased without an increase in revenue:

	Reduced A Lot	Reduced A Little	Stay the Same	Increased A Little	Increased A Lot

Public transportation in metropolitan areas
Providing homeless shelters
Protecting endangered wildlife
Increased funds for education
Building new prisons
Updating water treatment facilities

Maintaining the court system
Increasing security around public buildings

[DISPLAY]
Every year, the State must decide how to allocate money for the State budget. Sometimes new programs are proposed, and the State is interested in knowing how taxpayers feel about these programs in order to decide whether they should be funded or not. Surveys like this are used to explore how people like you feel about the various programs that the State can spend money on in the coming year. Everyone feels differently, and it's important to hear from as many people as possible in order to capture all the different points of view.

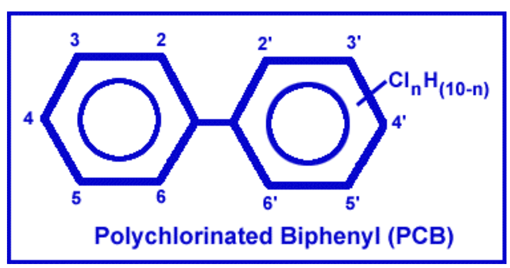
This survey is asking specifically about a program involving the potential effects of chemicals in the environment on both humans and animals. The next part of this survey will provide some background information on the situation and the potential effects of these chemicals. After that, the survey will ask you whether you think anything should be done about the situation. Finally, we are interested in knowing why you feel the way you do.

[DISPLAY]
Studies have shown that babies developing in the womb (fetuses) are affected later in life by some chemicals found in fish and other foods that are eaten by their mothers. Developing fetuses are exposed to the same things as their mothers – but because they are so small, and their organs are still developing, even very small amounts of substances that have little or no effect on the mother can have a big impact on a developing fetus. The effects, typically different kinds of developmental delays, can be observed even in small infants. Scientists have studied the issue, and have determined that the trouble is a result of being exposed to a specific chemical that is found in the sediment (dirt) of several rivers, streams, and lakes in your State. Scientists representing the State, Federal government, and academic institutions have spent years studying this issue. They agree that the known deposits of a specific chemical in the riverbeds bears some responsibility in causing these reproductive effects. The chemical is called polychlorinated biphenyls, or PCBs.

[SP]
A3. PCBs are chemicals that were developed in the early 1940's for electrical transformers and for other industrial purposes. They were an ideal insulating fluid because they are not flammable. Have you ever heard of PCBs?

Yes 1
No 2
Not Sure 3

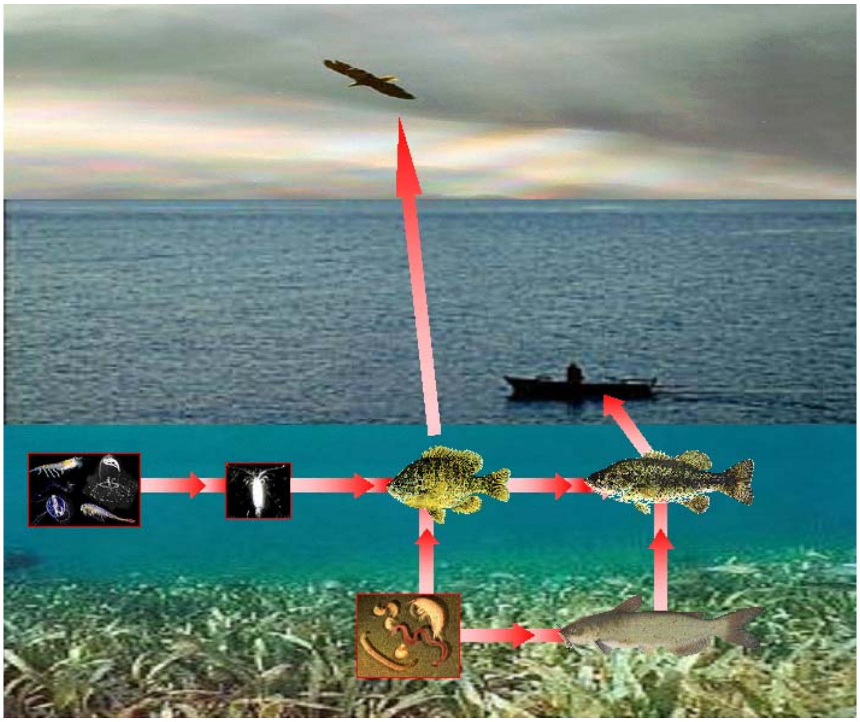
[DISPLAY]



Up until the early 1970's, people didn't realize that PCBs could affect fish, wildlife, and humans. Several companies that manufactured electrical transformers, or provided other industrial services, were located on different rivers in the State. Some of these companies are out of business now, but in the 1940's, 50's and 60's, they were allowed to discharge PCBs with other wastes from their manufacturing processes. Even though there have been no new PCBs discharged into rivers in at least 20 years, the amounts that were historically released continue to affect wildlife in the State. PCBs are very oily and do not dissolve in water. Once they are in water, they fall to the bottom of the river and remain in the sediment. Sediment, which is just sand and dirt at the bottom of the river, is very stable, except when there is a big storm. As a result, there are layers and layers of sediment containing PCBs.

[DISPLAY]

INSERT FOODWEB GRAPHIC HERE WITH AUDIO.



As this graphic shows, insects and shellfish living in the sediment absorb PCBs and transfer them to fish. Animals, including humans, eat the fish and in this way PCBs accumulate through the food web. You may have heard of fish consumption advisories in your State. These are due to PCBs as well as other chemicals.

The State is proposing to either clean up or remove the contaminated sediment from the river to make sure that humans and wildlife are no longer exposed. If the sediments are not cleaned up, they will continue to be a source of PCBs to the system.

[DISPLAY]
Eventually, PCBs in the sediments will grow less and less due to natural causes. New, clean sediment will deposit over the dirty sediment over a period of many years. The insects, as they continue to work the sediment, will eventually release or use up much of what is there. Scientists using models developed just for this system have shown that PCBs in the sediment will decrease to levels that aren't expected to have effects on animals and humans in approximately 100 years. A clean up remedy, such as dredging, is expected to take one year, will decrease these levels immediately after the clean up is completed. It will still take a few years for the species to recover, but they will not be exposed to any new PCBs during that time.

In order to pay for this cleanup, the State is proposing a one-time additional amount on next year's state income tax. Only this one time payment is required and the money will go into a special fund just for this purpose. There are lots of reasons why you might vote for or against such a program.

B. QUESTIONS RELATED TO HUMAN RECEPTOR EXPOSURE TO POLYCHLORINATED BIPHENYLS

PROGRAMMING NOTES:

SHOW "READ AT 7 MONTHS BELOW GRADE LEVEL" OR "EXPERIENCE A 6 POINT DECREASE IN IQ AS MEASURED BY STANDARD IQ TESTS" RANDOMLY; 50% SEE ONE AND 50% SEE THE OTHER. PLEASE CREATE A DATA-ONLY VARIABLE INDICATING WHICH STATEMENT WAS SHOWN.

SHOW "25%" AND "10%" RANDOMLY; 50% SEE ONE AND 50% SEE THE OTHER. PLEASE CREATE A DATA-ONLY VARIABLE INDICATING WHICH PERCENTAGE WAS SHOWN.

[DISPLAY]
Studies involving children exposed *in utero* to PCBs have shown that these children perform less well on a variety of developmental tests. For a unit exposure, IQ can decrease by six points, the average decrease in reading comprehension is 7 months, children perform less well on mathematical and quantitative tests. The chemical doesn't cause the exact same effects in every child, but it does cause some effect in every child. One specific effect that regulators are worried about is the evidence that exposure to PCBs causes decreases in reading comprehension below levels considered normal in school-age children. There is a 50% chance that children exposed to PCBs in this area will **[READ AT 7 MONTHS BELOW GRADE LEVEL /EXPERIENCE A 6 POINT DECREASE IN IQ AS MEASURED BY STANDARD IQ TESTS]**. If the sediments are removed and the river is cleaned up, scientists estimate that the risk will decrease to **[25% / 10%]**. There will always be some small chance of effects because the sediments can't be 100% cleaned up.

NOTE TO SCRIPTER: RANDOMLY SELECT THE VALUE FOR COST_H FROM THE FOLLOWING CHOICES: $25, $50, $100, $200, $400, $800; EACH VALUE SHOULD BE ASSIGNED FOR APPROXIMATELY 16.7% OF THE RESPONDENTS (I.E., 100/6). PLEASE CREATE A DATA-ONLY VARIABLE INDICATING WHICH VALUE WAS CHOSEN.

PLEASE MAKE THE HIGHEST BID FOR PEOPLE ASSIGNED TO THE $800 CATEGORY EQUAL TO $1000.
PLEASE MAKE THE LOWEST BID FOR PEOPLE ASSIGNED TO THE $25 CATEGORY EQUAL TO $10.

[SP]

B1. The State estimates that this program will cost $**[COST_H]**. Your household would pay this one time tax on next year's income tax and the money would go into a special fund set up to clean up the river. There will be a referendum to decide whether the river will be cleaned up and how much the one-time tax should be. If the election were being held today and the total cost would be a one time additional tax of $**[COST_H]**, would you vote for or against it?

For 1
Against 2

PROMPT ONCE.
SHOW B2 IF B1 = "FOR".
FOR B2, CREATE A DATA-ONLY VARIABLE INDICATING WHAT BID HIGHER THAN COST_H WAS SELECTED.

[SP]

B2. $**[COST_H]** represents the best estimate of the engineering costs. It could be that the cost to each household would be as high as $**[NEXT BID UP FROM [COST_H]** instead of $**[COST_H]**. If this was the case, and the one time tax would be $**[NEXT BID UP FROM [COST_H]]**, would you vote for or against it?

For 1
Against 2

SHOW B3 IF B1 = "AGAINST" OR SKIPPED.
FOR B3, CREATE A DATA-ONLY VARIABLE INDICATING WHAT BID LOWER THAN COST_H WAS SELECTED.

[SP]

B3. $**[COST_H]** represents the best estimate of the engineering costs. It could be that the cost to each household would be lower and would only be $**[NEXT BID LOWER THAN [COST_H]]** instead of $**[COST_H]**. If this was the case, and the one time tax would be $**[NEXT LOWER BID THAN [COST-H]]**, would you vote for or against it?

For 1
Against.. 2

SHOW B4 IF B2 = "AGAINST" OR SKIPPED OR B3 = "AGAINST" OR SKIPPED.

[MP]

B4. The State is interested in knowing why you would vote against the program. There are lots of different reasons why you might vote against the program, like it just isn't worth that much money, or it would be difficult for your household to pay that much even though you support the program. Or there might be some other reason.

Isn't worth the money 1
Difficult for my household to pay 2
Don't believe the cleanup would work 3
Some other reason, please specify: _______ 4

SHOW B5 AND B6 IF B1, B2 OR B3 = "FOR".

[SP]

B5. People have lots of different reasons for voting for the program. Could you briefly describe why you would be willing to pay for it?

I'm worried about the potential risks to unborn babies 1
I support a cleanup no matter what 2
Some other reason, please specify: _______ 3

[SP]

B6. Thinking back on your responses, how confident would you say you are in your willingness to pay on a scale of 1 to 5 where 1 is "Not confident at all" and 5 is "Very confident"?

Not confident at all				Very confident
1	2	3	4	5

C. QUESTIONS RELATED TO QALYS

[SP]

C1. Now we're going to ask a slightly different question. Assume for a moment that your child was exposed to PCBs and has a slight reading comprehension deficit. Further assume there is a treatment available to remedy the impairment, but that it comes with a very small chance of dying as a result of the treatment. Would you accept a risk of death of 10 in 100,000 for your child to cure the deficit for the rest of the child's life (assuming all other risks remain the same)? This is also randomized – respondents see either 10 in 100,000 or 1 in 100,000 and then half that or double that for C2 and C3 respectively depending on whether they answered no or yes, respectively

Yes 1
No 2

[SP]
C2. If the risk of death was only 5 in 100,000, would you take the treatment?

Yes 1
No 2

[SP]
C3. If the risk of death was as high as 20 in 100,000, would you take the treatment?

Yes 1
No 2

D. QUESTIONS RELATED TO EAGLE RECEPTOR EXPOSURE TO POLYCHLORINATED BIPHENYLS

[DISPLAY]

PCBs can have effects on the environment and the birds and mammals that use the environment. This part of the survey is to find out whether you would be willing to pay an additional tax for the additional benefit of protecting ecological receptors like eagles. Many years ago, eagles were in danger of becoming extinct. Now, they are successfully hatching young and maintaining their populations in some places in the United States. But that is not the case along several waterways in this State. Studies have shown that eagles are sensitive to chemicals in the environment, particularly ones like PCBs that build up in the food chain. Sensitive receptors like eagles will show effects at lower concentrations than humans. As exposure to PCBs increases, there is an increase in the probability of a decline in reproductive capability. Scientists aren't sure what probability of a decline in reproductive capability leads to extinction, but any decline is likely to have a noticeable effect in the population of a species like an eagle, which only produce one or two young per year and which have small populations to begin with.

PROGRAMMING NOTES:

PLEASE SHOW ONE OF THE NEXT TWO DISPLAY SCREENS RANDOMLY; 50% SEE ONE VERSION, 50% SEE THE OTHER. PLEASE CREATE A DATA-ONLY VARIABLE INDICATING WHICH SCREEN WAS SHOWN.

IN THE FIRST DISPLAY SCREEN, PLEASE SHOW "10%" AND "5%" RANDOMLY; 50% SEE ONE AND 50% SEE THE OTHER. PLEASE CREATE A DATA-ONLY VARIABLE INDICATING WHICH PERCENTAGE WAS SHOWN.

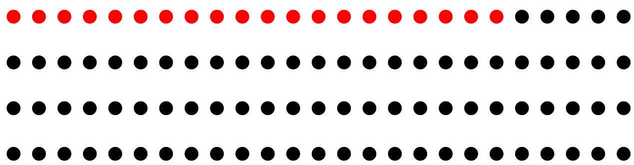
IN THE SECOND DISPLAY SCREEN, PLEASE SHOW "25%" AND "10%" RANDOMLY; 50% SEE ONE AND 50% SEE THE OTHER. PLEASE CREATE A DATA-ONLY VARIABLE INDICATING WHICH PERCENTAGE WAS SHOWN.

[DISPLAY]
Because of exposure to PCBs, scientists have estimated there is a 20% chance that eagles will experience a decline in reproductive capability that could impact the population.

If the sediments are removed and the river is cleaned up, scientists estimate that the risk decreases to **[10% / 5%]**.

Each dot below represents one eagle: The red dots represent the eagles that will not be able to reproduce.

[SHOW IMAGE WITH 20 RED DOTS.]

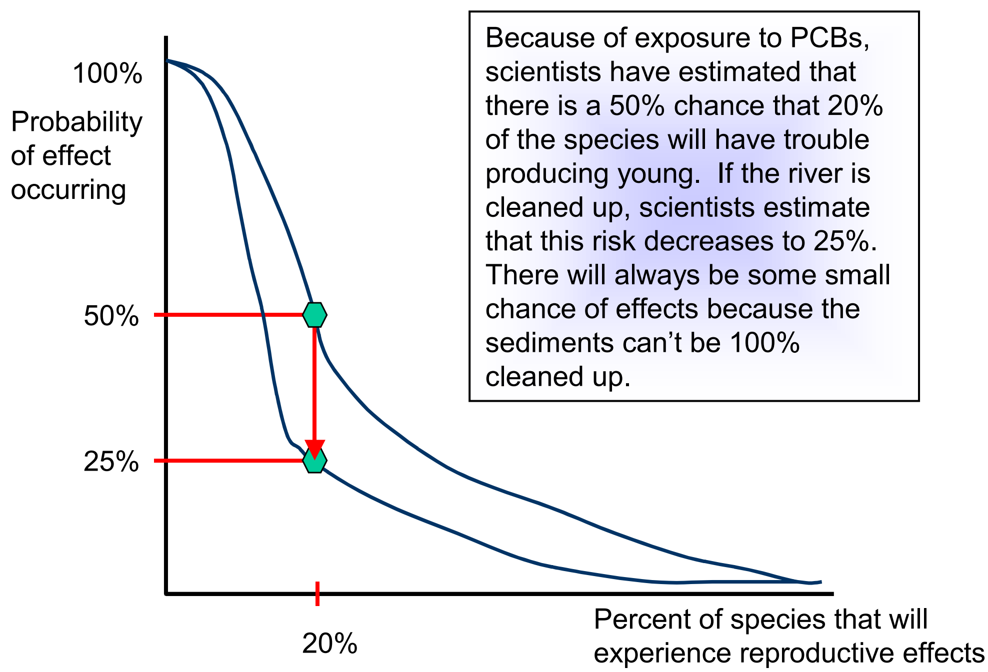


If the river is cleaned, scientists predict that **[10 / 5]** eagles will have trouble reproducing. There will always be some chance of effects because the sediments can't be 100% cleaned up.

[SHOW IMAGE WITH 10 OR 5 RED DOTS DEPENDING ON CONDITION SELECTED.]

[DISPLAY]

INSERT RISK GRAPHIC HERE.



NOTE TO SCRIPTER: RANDOMLY SELECT THE VALUE FOR COST_E FROM THE FOLLOWING CHOICES: $25, $50, $100, $200, $400, $800; EACH VALUE SHOULD BE ASSIGNED FOR APPROXIMATELY 16.7% OF THE RESPONDENTS (I.E., 100/6). PLEASE CREATE A DATA-ONLY VARIABLE INDICATING WHICH VALUE WAS CHOSEN.

ALSO NOTE THAT FOLLOWUP ITEMS USE THE NEXT HIGHEST/LOWEST BID.

IMPORTANT: THE FIRST BID THAT IS SELECTED HERE SHOULD CORRESPOND TO COST_H THAT WAS AGREED TO EARLIER. IF THE RESPONDENT SAID YES TO BOTH BIDS IN B, THEN COST_E = NEXT HIGHEST BID AMOUNT. IF RESPONDENT SAID YES THEN NO, COST_E = TO

LAST (REJECTED) BID AMOUNT FROM B. IF RESPONDENT SAID NO, THEN COST_E IS RANDOMLY SELECTED FROM THE FULL BID VECTOR.

PLEASE MAKE THE HIGHEST BID FOR PEOPLE ASSIGNED TO THE $800 CATEGORY EQUAL TO $1000. PLEASE MAKE THE LOWEST BID FOR PEOPLE ASSIGNED TO THE $25 CATEGORY EQUAL TO $10.

[SP]

D1. The State estimates that this program will cost each household $**[COST_E]**. Your household would pay this one time tax on next year's income tax and the money would go into a special fund set up to clean up the river. There will be a referendum to decide whether the river will be cleaned up and how much the one-time tax should be. If the election were being held today and the total cost would be a one time additional tax of $**[COST_E]**, would you vote for or against it?

For 1
Against.. 2

PROMPT ONCE.

SHOW D2 IF D1 = "FOR".

[SP]

D2. $**[COST_E]** represents the best estimate of the engineering costs. It could be that the cost to each household would be as high as $**[NEXT BID UP FROM [COST_E]]** instead of $**[COST_E]**. If this was the case, and the one time tax would be $**[NEXT BID UP FROM [COST_E]]**, would you vote for or against it?

For 1
Against.. 2

SHOW D3 IF D1 = "AGAINST" OR SKIPPED.

[SP]

D3. $**[COST_E]** represents the best estimate of the engineering costs. It could be that the cost to each household would be lower and would only be $**[NEXT BID DOWN FROM COST_E]** instead of $**[COST_E]**. If this was the case, and the one time tax would be $**[NEXT BID DOWN FROM [COST_E]]**, would you vote for or against it?

For 1
Against.. 2

SHOW D4 IF D2 = "AGAINST" OR SKIPPED OR D3 = "AGAINST" OR SKIPPED.

[MP]

D4. The State is interested in knowing why you would vote against the program. There are lots of different reasons why you might vote against the program, like it just isn't worth that much money, or it would be difficult for your household to pay that much even though you support the program, or you are opposed to dredging as an alternative. Or there might be some other reason.

Isn't worth the money 1

Difficult for my household to pay 2
Don't believe the cleanup would work 3
Some other reason, please specify: _______ 4

SHOW D5 AND D6 IF D1, D2 OR D3 = "FOR".

[SP]
D5. People have lots of different reasons for voting for the program. Could you briefly describe why you would be willing to pay for it?

I'm worried about the eagles 1
I support a cleanup no matter what 2
Some other reason, please specify: _______ 3

[SP]
D6. Thinking back on your responses, how confident would you say you are in your willingness to pay on a scale of 1 to 5 where 1 is "Not confident at all" and 5 is "Very confident"?

Not confident at all				Very confident
1	2	3	4	5

E. QUESTIONS RELATED TO MOTIVATION

[DISPLAY]
It is important for regulators to know how you came to your decision.

[SP]
E1. How concerned are you about chemicals in the environment?

Not at all concerned.. 1
Somewhat concerned....................................... 2
Quite concerned 3
Very concerned 4

[SP]
E2. How concerned are you about PCBs in the environment?

Not at all concerned.. 1
Somewhat concerned....................................... 2
Quite concerned 3
Very concerned 4

[SP]
E3. Do you believe that PCBs could cause the reproduction problems in eagles?

Yes 1
No 2
Not Sure 3

[SP]

E4. Do you believe that PCBs could cause developmental delays in young children exposed in the womb?

Yes 1
No 2
Not Sure 3

[SP]

E5. Did you feel like the survey pushed you to vote a particular way or did you feel like you really made up your own mind based on the best available information?

Pushed to vote for it 1
Pushed to vote against it 2
Made up my own mind 3
Not Sure 4

[LARGE TEXT BOX]

E6. What is it about the survey that made you feel that way?

[SP]

E7. Thinking back on all the information, would you say the reproduction problems facing eagles in this state are…

Not serious at all 1
Somewhat serious 2
Very serious 3
Extremely serious 4
Not sure 5

[SP]

E8. Thinking back on all the information, would you say the risks facing unborn babies due to exposure to PCBs in this state are…

Not serious at all 1
Somewhat serious 2
Very serious 3
Extremely serious 4
Not sure 5

F. QUESTIONS RELATED TO RECREATIONAL ACTIVITIES

[SP]

F1. How often do you personally watch television programs about wildlife?

Never	1
Rarely	2
Sometimes	3
Often	4
All the time	5

[SP]

F2. Do you live near a river, lake or stream?

Yes	1
No	2

[SP]

F3. How often does your family spend time near a river, lake or stream?

Never	1
Rarely	2
Sometimes	3
Often	4
All the time	5

[SP]

F4. How often do people in your household eat fish?

Never	1
A few times a year	2
A few times a month	3
Every week	4

[GRID – SP BY ROW]

G2. You receive a lot of information from a lot of different sources. In general, how much confidence do you have in information you obtain from:

	No Confidence	Some Confidence	A Lot of Confidence
Federal government			
Scientists who work for industry			
Scientists who work for universities			
Television media			
Internet sources **[NO SELECTION FOR THIS HEADER ITEM]**			
Government web sites			
Commercial web sites			
Non profit web sites			
Academic web sites			
Print media (newspapers, magazines)			

Joint Determination in a General Equilibrium Ecology/Economy Model*

David Finnoff
dfinnoff@bus.ucf.edu

John Tschirhart
jtsch@uwyo.edu

Department of Economics and Finance
Department 3985 • 162 Ross Hall
University of Wyoming
Laramie, WY 82071

October 2004

*To be presented at the EPA Valuation of Ecological Benefits: Improving the Science Behind Policy Decisions - A STAR Progress Review Workshop. This research is supported by the U.S. Environmental Protection Agency grant # RD-83081901-0.

1. Introduction

This work is part of the ongoing effort by economists and ecologists to better integrate their disciplines in order to improve policymaking. The motivation for the work is the realization that all economic activity ultimately depends on the natural resource base and the ecosystems contained therein, but the extent to which the base is tapped has limits (Arrow, et al., 1995). By some accounts the limits have been reached and a depleted resource base is having negative impacts on living standards (Norgaard 1994). Monitoring depletion and predicting future resource limits requires a better understanding of the interplay between the ecology of natural systems and economic activity (Nordhaus and Kokkelenberg, 1999). The objective here is to develop a method to better capture the interplay. The method is useful for addressing the numerous conflicts that arise when economic development and environmental conservation appear at odds. Familiar examples include logging, harvesting wildlife, preservation of biodiversity (Weitzman, 1993) and endangered species (Shogren and Tschirhart, 2000), bioprospecting (Simpson, Sedjo and Reid, 1996), and, more generally, conserving the essential human services supplied by natural environments (Daily, 1997).

In many economic papers that examine biological renewable resources, logistic growth functions are employed to capture the resources' characteristics. Usually, a single growth function is employed to study one species, thereby omitting the other species in the community. Occasionally, two or three species are studied in a predator-prey relationship, or, as in Brander and Taylor (1998), humans are the predator. The point is that in all this work entire communities are reduced to one or two species, and a few parameters must summarize the numerous interactions that occur in real ecosystems. Moreover, the logistic growth functions depend on entire species' populations and as such they take a macro view in which species interactions, if present at all, are at an aggregated level.

An alternative is to model many interacting species in food webs and to do this at the micro level so that individual organism behavior yields community populations. Of course, modeling a community with many species is a challenge because everything depends on everything else (Amir, 1979; Crocker and Tschirhart, 1992). Economists face a similar challenge in modeling an economy in which everything depends on everything else. Economists address the challenge by developing computable general equilibrium (CGE) models, and this is the tack taken here. By exploiting the three themes fundamental to economics - rational behavior, efficiency and equilibrium, a general equilibrium model of an ecosystem is built. The general equilibrium ecosystem model (GEEM) is then tied to a general equilibrium of an economy to examine the ecosystem/economy interplay.

GEEM is a new adaptive approach that appeals to the oft-made analogies between economies and ecosystems in both the economic and ecological literatures (Tschirhart, 2000, 2002, 2004).[1] Like CGE models that rely on micro foundations of individual consumer and firm behavior to drive the macro outcomes, the individual plant and animal behavior in GEEM appeals to the micro principle that success depends on their energy utilization, and this drives the ecological macro outcomes (i.e., population changes). Population updating uses general equilibrium results from individual plant and animal net energy optimization aggregated to species levels, similar to how CGE economic models start with individual consumer and firm demands and supplies and aggregates them to market levels.

In this paper, CGE/GEEM is applied to the Alaskan economy that is linked via its fishing and tourism industries to an eight species marine ecosystem that includes an endangered species. The fisheries sector is modeled as a regulated open access fishery (Homans and Wilen, 1997) but is significantly modified to be compatible with the general equilibrium framework. Each general

[1] However, the similarities only go so far and there are features in GEEM that are not found in economic models (Tschirhart, 2003). For example, predators and prey do not engage in voluntary exchange, but in biomass transfers.

equilibrium calculation corresponds to one year, but the fishing season is considerably shorter than one year. The fishing off season is explicitly modeled by allowing for fishing factors to receive rents in season that carry them through the off season, and by including in welfare the off-season leisure enjoyed by unemployed fishery labor.

Results from the linked models include period-by-period gross state product, prices and quantities for final goods and factors in the economy, and predator/prey biomass consumption, energy prices, and species populations in the ecosystem. In addition, welfare comparisons of alternative fishing regulations are presented. Welfare is increased with mandatory reductions in fish harvests to protect the endangered Steller sea lions that feed on fish for two main reasons. First, and as expected, capital and labor move from the regulated open access fishery sector to other sectors where they both earn more on an annual basis, and second, the tourism industry grows owing to increased numbers of marine mammals.

In what follows a brief description of GEEM for the marine ecosystem is provided. This is followed by a presentation of how the fishery is merged into the CGE model and what welfare measure may be appropriate for the linked systems.

2 The Ecology Model

GEEM is applied here to an oft studied marine ecosystem comprising Alaska's Aleutian Islands (AI) and the Eastern Bering Sea (EBS). The ecosystem is represented by the food web in Figure 1. All energy in the system originates from the sun and is turned into biomass through plant photosynthesis. Photosynthesis is carried out in the AI by individuals of various species of algae, or kelp, and in the EBS by individuals of various species of phytoplankton. All individual animals in the system depend either directly or indirectly on the kelp and phytoplankton plant species. In the EBS, zooplankton prey on phytoplankton and are prey for pollock. The pollock are a groundfish that support a very large fishery. Steller sea lions, an endangered species, prey on pollock, while killer whales prey on the sea lions. In the AI, killer whales also prey on sea otter that in turn prey on sea urchin that in turn prey on kelp.

In GEEM, demand and supplies are developed somewhat similarly to CGE. Species are analogous to industries, and individual plants and animals are analogous to firms. Plants and animals are assumed to behave as if they maximize their net energy flows. Where perfectly competitive firms sell outputs and buy inputs taking market-determined prices as signals, plants and animals transfer biomass from prey to predators taking 'energy prices' as signals. (Plants can be thought of as preying on the sun.) An energy price is the energy a predator loses to the atmosphere when searching for, capturing and handling prey. A key difference between economic markets and ecological transfers, however, is that in the latter the prey does not receive this energy price. Therefore, the biomass transfer is not a market because there is no exchange (Tschirhart, 2003). Nevertheless, predators' demands and preys' supplies are functions of the energy prices.

A brief sketch of GEEM is provided here, but for details see Finnoff and Tschirhart (2003, 2004). The three basic equations that comprise GEEM are given by (2.1) – (2.3). The first equation is a general expression for the net energy flow through a representative animal from species i.

$$R_i = \sum_{j=1}^{i-1} [e_j - e_{ij}] x_{ij} - \sum_{k=i+1}^{m} e_i [1 + t_i e_{ki}] y_{ik} - f^i (\sum_{j=1}^{i-1} x_{ij}) - \beta_i \tag{2.1}$$

$$N_i x_{ij}(\boldsymbol{e}_i) = N_j y_{ji}(\boldsymbol{x}_j(\boldsymbol{e}_j)) \tag{2.2}$$

$$N_i^{t+1} = N_i^t + N_i^t \left[\frac{1}{s_i} (R_i(\cdot) + v_i) - \frac{1}{s_i} \right] \tag{2.3}$$

R_i is in power units (e.g., Watts or kilocalories/time).[2] The species in (2.1) are arranged so that members of species i prey on organisms in lower numbered species and are preyed on by

[2] According to Herendeen (1991) energy is the most frequently chosen maximand in ecological maximization models, and energy per time maximization as adopted here originates with Hannon (1973) and expanded to multiple

members of higher numbered species. The first term on the right side is the inflow of energy from members of prey species (including plants) to the representative individual of species i. The choice variables or demands, x_{ij}, are the biomasses (in kilograms/time) transferred from the member of species j to the member of species i, e_j are the energies embodied in a unit of biomass (e.g., in kilocalories/ kilogram) from a member of species j, and e_{ij} are the energies the member of species i must spend to locate, capture and handle units of biomass of species j. These latter energies are the energy prices. There is one price for each biomass transfer between a predator and prey species. As in economic CGE models, the prices play a central role in each individual's maximization problem, because an individual's choice of prey will depend on the relative energy prices it pays. Individuals are assumed to be price takers: they have no control over the energy price paid to capture prey, because each is only one among many individuals in a predator species capturing one of many individuals in a prey species.

The second term is the outflow of energy to animals of species k that prey on i. The e_i is the embodied energy in a unit of biomass from the representative individual of species i, and y_{ik} is the biomass supplied by i to k. The term in brackets is the energy the individual uses in attempts to avoid being preyed upon. It is assumed to be a linear function of the energy its predators use in capture attempts: the more energy predators expend, the more energy the individual expends escaping. t_i is a tax on the individual because it loses energy above what it loses owing to being captured. The third and fourth terms in (2.1) represent respiration energy lost to the atmosphere which is divided into a variable component, $f^i(\cdot)$, that depends on energy intake and includes feces, reproduction, defending territory, etc., and a fixed component, β_i, that is basal metabolism.

Time in the Alaskan model is divided into yearly reproductive periods. Each year a

species in Crocker and Tschirhart (1992) and to the individual level in Tschirhart (2000). Energy per time is also the general equilibrium is determined wherein the populations of all species are constant, each plant and animal is maximizing its net energy (using the derivatives of (2.1) for first-order conditions), and aggregate demand equals aggregate supply between each predator and prey species. For each price that equates a demand and supply transfer there is an equilibrium equation given by (2.2). Each plant and animal is assumed to be representative individuals from its species; therefore, the demand and supply sums are obtained by multiplying the representative individual's demands and supplies by the species populations given by the *N* terms.

A representative plant or animal and its species may have positive, zero or negative net energy in equilibrium. Positive (zero, negative) net energy is associated with greater (constant, lesser) fitness and an increasing (constant, decreasing) population between periods. (The analogy in a competitive economy is the number of firms in an industry changes according to the sign of profits.) Net energies, therefore, are the source of dynamic adjustments. If the period-by-period adjustments drive the net energies to zero, the system is moving to stable populations and a steady state. The predator/prey responses to changing energy prices tend to move the system to steady state.

The adjustment equation for the i^{th} species is given by (2.3) where $R_i(\cdot) = R_i(x_{ij}; \boldsymbol{N}^t)$ is the optimum net energy obtained by substituting the optimum demands and supplies as functions of energy prices into objective function (2.1). $\boldsymbol{N}^t$ is a vector of all species' populations and it appears in $R_i(\cdot)$ to indicate that net energies in time period t depend on all populations in time period t. In the steady state, $R_i(\cdot) = 0$. Also, s_i is the lifespan of the representative individual, v_i is the variable respiration, v_i^{ss} is the steady-state variable respiration, and N_i^{ss} is the species steady-state population. The first and second terms in brackets in (2.3) are the birth and death rates. Expression (2.3) reduces to the steady state if $R_i(\cdot) = 0$ (in which case $v_i = v_i^{ss}$ and $N_i^t = N_i^{ss}$).

individual's objective in the extensive optimum foraging literature (e.g., Stephens and Krebs 1986).

Because the biomass demands depend on the period *t* populations of all species, the population adjustment for species *i* depends on the populations of all other species. In addition, out of steady state $R_i(\cdot)$ and v_i change across periods. These changes distinguish the GEEM approach from most all ecological dynamic population models, because the latter rely on fixed parameters in the adjustment equations that do not respond to changing ecosystem conditions.

3 The Economy Model

The CGE model pioneered by Ballard et al. (1985) and applied in the OECD GREEN model (Burniaux et al, 1991) is most appropriate for linking with GEEM. The approach Ballard et al. developed may be termed "myopically dynamic," because it consists of a sequence of static optimizations and resulting equilibria connected through the evolution of factor stocks and household savings. Households are intertemporal optimizers whose savings decisions are based on myopic expectations over future prices.

The economy is modeled as having three production sectors: the fishery *F*, recreation and tourism *R*, and composite goods *C*.[3] The fishery is modeled as a single, vertically integrated industry consisting of catcher vessels, catcher processors and, motherships and inshore processors. Recreation and tourism represents the Census Bureau's classification of Wildlife Related Recreation, and composite goods are a catch all for the residual private industries in Alaska. Profit-maximizing, price-taking firms employ harvests of pollock in the fishery, non-consumptive use of marine mammals (Steller sea lions, killer whales and sea otter) in recreation, and capital and labor in all sectors, to produce their outputs in a continuous, nonreversible, and bounded process. Outputs from the fishery, recreation, and composite goods are sold in regional markets and exported out of the region, while regional production is differentiated from imports

[3] The sector and regional profiles follow the Steller Sea Lion Supplemental Environmental Impact Statement (SEIS, U.S. Department of Commerce, 1991).

for fish and composite goods following Armington (1969). Capital *K* and labor *L* are homogeneous and defined in service units per period. They are also perfectly mobile between sectors and between periods, but not within periods which is pertinent for the fishery. Sector *i* factor employment levels are given by K_i and L_i ($i = F, R, C$).

The linkage between the fishery and the ecosystem is presented in detail. The treatment of the tourism industry that depends on the marine mammals, the households, the composite goods, and trade and price relationships are presented in detail in Finnoff and Tschirhart (2004).

3.1 Fishery Incorporating a fishery into a CGE framework raises issues that require two modifications to the standard fishery models. First, where most of the fishery literature employs effort as the single human factor of production, capital and labor must be included in CGE so that the fishery interacts with other sectors. Second, the non-fishery sectors hire capital and labor in service units per year, but in the fishery factors are employed considerably less than one year and may earn rents.

Expressions (3.1) – (3.4) summarize production in the fishery sector:[4]

$$TAC_t = a + bN_4^{0,t} \tag{3.1}$$

$$H_F = d_F T^{a_F} N_4 \tag{3.2}$$

$$\text{minimize} \quad \hat{w}L_F + \hat{r}K_F \quad \text{subject to} \quad T = d_F^m L_F^{a_F^m} K_F^{(1-a_F^m)} \tag{3.3}$$

Equation (3.1) introduces government into the model in the form of a fishery manager. Homans and Wilen (HW, 1997) developed a model of a regulated open-access fishery to reflect that fishery managers set total allowable catch, *TAC,* and fishing season length, *T*. The heavily-regulated Alaskan pollock fishery fits this institutional arrangement. To mesh an HW type model with the CGE framework, the fishery manager chooses period *t'*s *TAC* according to (3.1) where N_4 is the population of pollock. No harvests are allowed whenever the actual biomass is less than the minimum level set by the manager. For given *TAC* and technology, the season length is determined from the aggregate harvest function in (3.2), where a_F and d_F are parameters and H_F is aggregate harvest. The industry is assumed to harvest up to their limit so that $H_F = TAC$.

The season length is the time needed to land the *TAC* given the fish stock and is increasing in *TAC* (Homans and Wilen, 1997). Following the fishery manager's choices for *TAC* and *T*, the industry is assumed to minimize the cost of harvesting according to (3.3) by employing capital and labor to work time *T*. The production function exhibits constant returns to scale, $a^m{}_F$, and $d^m{}_F$ are parameters, and $\hat{w}$ and $\hat{r}$ are the fishery wage and rental rate of capital that may diverge from the market wage and rental rate in other sectors. The associated cost function is linearly homogenous in time, allowing the total costs of harvesting to be written as $C(\hat{w},\hat{r})T$. This setup with the industry choosing *K* and *L* for a given season length incorporates the two modifications defined above.

The divergence of fishery factor prices from market factor prices in the other sectors arises from the restricted season length and is an important feature of the model. Entry is assumed to dissipate all rents in open access models. But these are partial equilibrium models and factors are either not defined over time or if they are defined, they are instantaneous rates or daily rates as in Clark (1976). What these factors are doing off season is not an issue, because there is no off season in the models. In the CGE setting where all other sectors are operating year round, the fishery experiences an off season during which factors are either unemployed or employed elsewhere, often outside the region. In reality, unemployment is common and it may be either voluntary, or involuntary owing to factor immobility between seasons.[5] In either case,

---

[4] We are indebted to Robert Deacon for his invaluable input in the development of this section.

[5] The Alaskan Department of Labor and Workforce Development provides information about fishing jobs in Alaska on various websites (e.g., http://www.labor.state.ak.us/esd_alaska_jobs/careerstreams.htm). The job descriptions suggest that workers can save money, and pay can be substantial if the fishing is good. College students are encouraged to apply and then return to college in the off season. Boyce (2004) examines rents in fisheries and assumes that fishing inputs cannot be redeployed during the off season.

rational factors may demand higher than market payments in season in anticipation of being unemployed off season. If they do, seasonal factor payments will not be driven down to market levels in season, leaving positive seasonal rents. One might argue that these above market payments are not really rents, because they are merely covering the opportunity costs of factors in the off season. This is certainly not true for voluntary unemployment because the factors are enjoying leisure. But even for involuntarily unemployment, rational factors will anticipate some transition time before reemployment, and will enjoy rents if the transition time is equal to or less than what they anticipate.

Let W and R be the market determined factor prices for labor and capital in other sectors. Because labor and capital are defined in service units per year, W and R are annual payments. Let $\beta \in (0, 1)$ be the percent of the year the fishery is active so that market factor prices in the fishery are $\beta\, W$ and $\beta\, R$. If there are intra-seasonal rents in the fishery, they must be reflected in factor prices that deviate from these market prices such that $C(W\beta, R\beta) < C(\hat{w}, \hat{r})$. Assuming any rents impact labor and capital uniformly and linearly, let δ be a rent divergence term so that the factor prices in the fishery are:

$$\hat{w} = \beta\, \delta\, W \quad \text{and} \quad \hat{r} = \beta\, \delta\, R$$

$$\text{where } \delta = 1 \Rightarrow \text{ no rents and } \delta > 1 \Rightarrow \text{ positive rents.}^{6} \qquad (3.4)$$

In developing the simulation model the available data provides estimates for β and δ. But the data is inadequate to determine whether factors were voluntarily or involuntarily unemployed or whether they were reemployed during the off season. Therefore, the assumption made here is that labor is voluntarily unemployed, i.e., enjoying leisure, and capital is idle or employed outside the Alaskan economy. Labor's leisure time in the off season will be accounted for in

[6] Factor price distortions commonly enter the CGE literature in the form of taxes (Harberger, 1974, Shoven and Whalley, 1976, Ballard et al., 1985, and Bovenberg and Goulder 1996). The divergences here are not distortions in the usual sense: β is merely an accounting adjustment to correct for a shorter work year, and a $\delta > 1$ may be welfare enhancing since some positive rents are desirable.

welfare measures below.

Equilibrium for the industry is given by a pseudo zero-profit condition that allows for intra-season rents:

$$\pi_F = P_F H_F - C(\beta\delta W, \beta\delta R)T = 0 \qquad (3.5)$$

In this representation, the total factor payments over the season equal the total revenue divided by the season length, or an average revenue per time. An exogenous increase in *TAC or* H_F increases season length for a given fish stock and δ falls to maintain equality in (3.5). Intuitively, the longer season implies less off-season time for the factors, and they require less rent in season to get through the off season. To summarize, after the fishery manager sets *TAC* by (3.1) and *T* by (3.2), the factor demands and the rent divergence δ are determined by (3.3) and (3.5).

3.2 Equilibrium and Dynamics The economic system is in equilibrium when households and firms optimize, there exists a set of prices and level of output at which all firms break-even, Walras Law holds, and all markets clear. Incomes are derived through a two-stage process. Regional households are endowed with labor ω_L^{AK} and capital ω_K^{AK}. While foreign value added expenditures (from foreign factor employment in the fishery) accumulate elsewhere, regional value added expenditures flow first to factor "institutions", and then redistributed to households. We close the model through the region's current account and savings investment balance. Economic dynamics are recursive, consistent with the evolution of species populations. Given myopic expectations, the time path of the economy is represented by a sequence of competitive equilibria, one for each period. The periods are linked through factor accumulation, where savings in each period (and therefore regional investment $\mathbf{I}_t$) expand the capital service endowment for the subsequent period, and the effective labor force grows at an exogenous rate. If the capital stock grows at the same rate as the effective labor force, the economy is on a balanced growth path; however, balanced growth is not a feature of the linked model, because species populations cannot grow continually.

3.3 Welfare Measures The welfare impacts of alternative policies are evaluated in terms of modified Hicksian equivalent variational measures similar to those developed in Ballard et al. Each policy change leads to changes across prices and income in relation to a reference/benchmark sequence of business as usual. Let the Hicksian expenditure function associated with consumption in period *t* be given by $M_t(.)$. Vectors of prices in any period *t* of the reference scenario *b* or policy alternate *a* are given by $\underline{P}^b{}_t$ and $\underline{P}^a{}_t$, with corresponding indirect utility functions $V^b{}_t$ and $V^a{}_t$. In the results we employ annual equivalent variations $EV_t = M_t(\underline{P}_t^b, V_t^a) - M_t(\underline{P}_t^b, V_t^b)$ [7] to calculate welfare changes for any single period across policy scenarios. Cumulative aggregate (or multi-market) welfare measures are found using discounted summations of EV_t (P_{EV}) which is possible as the measure is based upon a common baseline price vector. Future welfare changes are discounted both by consumers' rate of time preference and by the human population growth rate. Also, given the exogenous time horizon a termination term is added to account for welfare impacts after the final period *T*. In this we assume that by *T* the economy is close to a steady state.

4. Model Specification

4.1 Ecological Specification and Data In applying GEEM to the Alaskan ecosystem, ecological studies of the Alaskan and other ecosystems were used. Time series of pollock biomass estimates exists for the period 1966 through 1997, and the rest of the data are from 1966 or interpolated to that date. Data were obtained for plant and animal populations, benchmark plant biomasses and animal biomass demands, and parameters that include embodied energies, basal metabolisms, and plant and animal weights and lifespans. Sources include numerous

[7] Defined as the difference between initial expenditure and that expenditure necessary to achieve the post-policy level of satisfaction at initial prices.

National Marine Fisheries Service publications and ecological journal articles. Details on data sources can be found in Finnoff and Tschirhart (2003).

Using this data, calibration yielded estimates for parameters in the plant and animal respiration and supply functions (Finnoff and Tschirhart, 2003). Calibration consists of simultaneously solving for each species the net energy expressions set to zero, first-order conditions or the derivatives of the net energy expressions set to zero, and the equilibrium conditions.

4.2 Economic Specification and Data In a similar fashion as with the ecosystem model, the economic specification is based on a chosen benchmark year, and the data were used in calibrations to estimate parameters. The benchmark dataset constructed in the analysis is shown in Table 1 where all values are in millions of dollars. The data sources include reports from the U.S. Department of Commerce, Bureau of Census, Bureau of Labor Statistics, the Alaskan Bureau of Economic Analysis, and others. Details on data sources are in Finnoff and Tschirhart (2004).

5. Policy Analysis

The NMFS in 2001 issued a Supplemental Environmental Impact Statement (SEIS) containing alternative management strategies that specify various pollock catch limits and no fishing zones to protect both the sea lions and the fishery. Using the linked CGE models, the effects of the management strategies on economic welfare are examined, and then the linked model is compared to a business-as-usual model that does not account for economy/ecosystem interactions.

The management strategies are differentiated here by the regulator's choice of b in the quota function (3.1). Holding $N_4^{\min}$ constant, b is varied by 30% and 170% of its 1997 harvest levels. (Numerous other harvest levels were examined but not reported. The 30% (170%) results are indicative of all runs below (above) the benchmark harvest.) All general equilibrium calculations and population updates were made with the nonlinear programming software package GAMS. The calculations consist of four steps: 1) Given current species populations, a GEEM equilibrium is found, determining species net energies, energy prices, biomass demands and supplies. 2) Given current species populations, the fishing manager determines the *TAC* (that is adjusted in separate scenarios by the two percentages above). 3) Given current species populations and capital and labor endowments, a CGE is found, delivering prices, fish harvests and other outputs, incomes, investment, savings, factor employment and the rent divergence, δ. 4) In the ecosystem, given the findings from step 1) and the *TAC* from step 2), the species populations are updated. In the economy, given current endowments and the findings form step 3), factor endowments are updated. The updated populations and endowments from steps 3) and 4) are then used to start the next period by retuning to step 1). The steps are repeated each period of the time horizon across each trade elasticity specification.

A benchmark scenario is initiated using the 1997 benchmark dataset, then simulated for 50 and 100 years.[8] Given natural resource stocks (species populations) whose growth is limited by biological carrying capacities, balanced growth is not a feature of the benchmark scenario. This is a departure from Ballard et al. or numerous other applications, where balanced growth is characterized by all quantities increasing by the same rate and constant relative prices. In the benchmark scenario, all quantities evolve at a constant rate, but the rate may vary over sectors owing to the reliance of the fishery and recreation sectors on biological natural resource inputs. Further, given heterogeneous growth of the natural resources, benchmark relative prices do not remain constant.

[8] Sequence lengths of 100 years and a discount rate of 4% were chosen as representative for Federal projects.

5.1 Ecosystem Impacts The impacts on populations of pollock, sea lions, sea otter and killer whales for the 30% and 170% management strategies are shown in Figure 2. Predicted populations (given actual harvests) prior to the 1997 calibration year and projections beyond 1997 are displayed. All populations move to new steady states, in as little as 10 years for phytoplankton (not shown) but as many as 30 years for killer whales. Phytoplankton are short-lived (less than one year) and reproduce rapidly, whereas killer whales are long-lived (twenty years) and reproduce slowly.[9] Reduced pollock harvests (30%) result in long-term increases in phytoplankton, sea urchins, sea lions and killer whales, and long-term decreases in zooplankton, kelp, and sea otters. The recreation sector will benefit from more sea lions and killer whales, but will be hurt by fewer sea otter.

To appreciate the general equilibrium nature of the population changes, consider the 170% harvests in some detail. The immediate affect of the higher harvest is to lower the pollock population. In the subsequent period the lower population increases the energy price sea lions pay to capture pollock and the sea lion demand for pollock decreases. Sea lion net energy decreases as a result and their population falls. These changes work their way up the food web as the killer whale population reacts in the same way to the fall in sea lions as the sea lion population reacted to the fall in pollock. The further up the food web from pollock, the less pronounced the impact. Where pollock populations fall by about 24%, sea lion and killer whale populations fall by about 13% and 9%, respectively.

5.2 Economic Impacts – Following changes in fishing policies, there occur many simultaneous changes in prices, incomes and profits. We can trace the flows of outputs, capital and labor between industries and between domestic and foreign sectors. More detail is in Finnoff and Tschirhart (2004). Here we concentrate on welfare impacts. The welfare impacts of

[9] Average lifespan enters into the population update equation, (2.9), similar to the way the less tangible species growth rates enters into the often-used but simplistic logistic update equation; thus, the lifespans are important in

alternative management strategies are quantified as discussed in Section 3.4. Welfare changes (from the reference) presented in Table 2 are the present value of the cumulative sum of equivalent variations P_{EV}[10] over 50 and 100 year planning horizons. For both horizons, leisure accruing to regional labor in the fishery during the off-season was valued at full, three quarters and half the wage rate. Under both horizons and across leisure values, decreasing the quota always results in cumulative aggregate welfare gains (P_{EV}). The longer the horizon and the greater the leisure values, the smaller the gains. For brevity, in the following discussion we focus on the30% reduced quota, noting that the 170% increased quota produces opposite results.

Figure 3 is helpful in understanding the fishery's contribution to the welfare changes. Starting from a steady state, T^0 is the season length and the average revenue per time from (3.5) is downward sloping as shown by the solid line. At T^0 factor payments are $C(\hat{w}^0, \hat{r}^0)$ which exceeds market-based factor payments $C(W, R)$ owing to rents. In the next period the fishery manager lowers the harvests and because the fish stock has not changed, the season length falls to T^1. The shorter season means less labor and capital in the fishery, but these remaining factors enjoy higher rents ($C(\hat{w}^1, \hat{r}^1) - C(W, R)$) per time employed as δ adjusts upward. As explained above, for labor the shorter season results in fewer fishery workers who enjoy higher rents per time worked and greater off-season leisure, while the workers who leave the fishery are employed at market wages in other sectors for the full year with no leisure.

In the second period the fish population is greater and the price of fish is higher because of the reduced harvest strategy. Both changes cause the average revenue curve to shift upward. The fishery manager sets a greater TAC by (3.1) because of the greater fish population, and the

---

determining whether population oscillations occur and how quickly populations will converge to steady state.

[10] In the absence of balanced growth in the reference sequence, we deflate all prices to 1997 levels using a modified Laspeyres formula $CPI_t = \left[\sum P_t Q_0 / \sum P_0 Q_0\right] * 100$ where CPI_t is the price index in period t, P_t current price of each commodity, Q_0 is the market quantity of each commodity in the baseline period (1997) and P_0 is the price of each

season length increases to T^2 although it is less than the initial season length. δ adjusts downward and rents fall to $C(\hat{w}^2,\hat{r}^2)-C(W,R)$. Some workers now return to the fishery from the other sectors, leaving their full-year market wages for higher part-year wages and leisure. In addition, because the fish population is greater, the fishery factors are more productive. Over the remainder of the planning horizons, the season lengths remain between T^0 and T^1 and the rents remain between the initial low value and the second period high value.

In a demonstration exercise, we quantify those portions of welfare changes attributable only to changes in ecosystem populations. The simulations were rerun with marine mammal inputs to recreation held at their reference sequence levels across the two *TAC* strategies. The portion of welfare change attributable to changes in marine mammals can then be inferred as the difference in periodic equivalent variations between the simulations with and without the impacts fishing has on the food web.[11] The ecosystem valuations for alternative quota rule are displayed in Table 3. While the magnitudes of the ecosystem valuations are small due to assumptions made in parameterizing the model, they are consistent for increases or decreases in ecosystem inputs. They loosely indicate the direct value to the economic system of marginal changes in ecosystem quality. Each one percent annual improvement in ecosystem quality in relation to the reference is worth roughly $110,000. Further, these values demonstrate that under a reduced *TAC*, if these ecosystem values were to be ignored the welfare impacts will be understated. Increased quota rules will result in overstated welfare benefits

6. Conclusion

We demonstrate that Steller sea lion recovery measures via alternative pollock quotas have consequences throughout the ecosystem and economy owing to the joint determination of

commodity in the baseline period. This follows the same general fashion of the BLS Consumer and Producer Price indices important variables. Quota changes cause altered levels of all ecosystem populations, economic factor reallocation, changes in all regional prices, incomes, demands, outputs, imports, exports, and differential rates of factor accumulation. Without a jointly- determined analysis, the benefits from a reduced quota accruing to the ecosystem inputs would be understated as would the costs of a slower growing capital stock. The mediating behavior of each system to shocks arising from the other is important for policy analysis.

Of the eight species modeled, four are used directly in the economy either as consumption goods (fish) or non consumption goods (marine mammals). Nevertheless, all species matter for the economy because the other four species are used indirectly as support for ecosystem functions. A portion of the regional welfare gains from reduced quotas follow from an economy relying less on resource extraction and more on resource non extraction. This result is consistent with a report from the Panel on Integrated Environmental and Economic Accounting which states: “economic research indicates that many renewable resources, especially in the public domain, are today more valuable as sources of environmental service flows than as sources of marketed commodities.” (Nordhaus and Kokkelenberg, 1999, p. 177)

Our reported welfare impacts of alternative fishing policies may be understated for three reasons. First, all species apart from pollock are at or close to a steady state in 1997. Changing pollock harvests, therefore, result in relatively small changes in other species. Second, the three marine mammals are assumed to be a small fraction of Alaska's ecological systems inputs to the economy. Third, non-use values associated with the ecosystem (e.g., existence values) are not considered. Turcin and Giraud (2001) conducted a willingness to pay survey that asked how much households were willing to pay for continuing the Federal Steller Sea Lion Recovery Program. They found Alaskan households willing to pay in total $25 million, and extrapolating

---

[11] Values attributable to ecosystem inputs were found as $EV^{L}{}_{t} - EV^{NL}{}_{t}$ where *L* refers to ecosystem impacts (or

to U.S. households the figure is $8 billion. Interestingly, household in the area of Alaska that contains critical habitat for the sea lions were willing to pay considerably less and in some cases negative amounts. These results do not indicate the existence value for changes in the sea lion populations, but they do suggest that the value may be substantial

Extensions of this work will include enlarging the community of species by admitting other harvested fish species (Pacific cod and herring), whale species (blue and sperm) and another marine mammal (Northern fur seal). This will allow for more testing of ecological hypotheses concerning how the economy and human actions impact the ecosystem. In addition, more economic sectors will be added by using IMPLAN data for the Alaskan economy.

CGE models are useful in judging alternative economic policies for their effects on resource allocation and on the distribution of net benefits. The objective of linking GEEM to CGE is to account for resource allocation in ecosystems as well so that the scope of policies that can be judged is broadened. While the economic and ecological underpinnings of this linked approach can be extended and improved in many ways, CGE/GEEM is a step toward integrating disciplines with common structures and goals.

---

linkages) being accounted for, and *NL* not accounted for (not linked).

References

Amir, S. 1979. “Economic Interpretations of Equilibrium Concepts in Ecological Systems,” *Journal of Social Biological Structures*, 2, 293-314.

Armington, P., 1969. "A Theory of Demand for Products Distinguished by Place of Production," *IMF Staff Papers*, 16, 159-178.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C. S. Holling, B.-O. Jansson, S. Levin, K.-G. Maeler, C. Perrings and D. Pimentel. 1995. “Economic Growth, Carrying Capacity and the Environment.”*Science*,268, April,520-21.

Ballard, C. L., D. Fullerton, J. B. Shoven, and J. Whalley, 1985. *A General Equilibrium Model for Tax Policy Evaluation*, The University of Chicago Press, Chicago.

Boyce, John R. 2004. Instrument choice in a fishery. *Journal of Environmental Economics and Management*, 47, 183-206.

Bovenberg, A. L. and L. H. Goulder, 1996. “Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analyses,” *American Economic Review*, **86**(4), 985-100.

Burniaux, J.M., J.P. Martin, G. Nicoletti and J.O. Martin, 1991. "A Multi-region Dynamic General Equilibrium Model for Quantifying the Costs of Curbing CO_2 emissions: A Technical Manual," *OECD Dept. of Economics and Statistics Working Paper # 104,* OECD.

Clark, C. W. 1976. *Mathematical Bioeconomics: The Optimal Management of RenewableResources*. 2nd ed. (1990) New York: Wiley.

Crocker, T.D. and J. Tschirhart, 1992. “Ecosystems, Externalities and Economies,” *Environmental and Resource Economics*, 2, 551-567.

Daily, G.C. 1997. *Nature's Services*, ed. G.C. Daily, Washington, D.C.: Island Press.

Finnoff, D., and J. Tschirhart, 2003. " Protecting an Endangered Species while Harvesting Its Prey in a General Equilibrium Ecosystem Model," *Land Economics*, 79, 160-180.

Finnoff, D., and J. Tschirhart, 2004. Linking Dynamic Economic and Ecological General Equilibrium Models. Working paper, University of Wyoming.

Hannon, B. 1973. "The Structure Of Ecosystems." *Journal of Theoretical Biology* 41: 535-546.

Harberger, A.C. 1974. *Taxation and Welfare*. Chicago: University of Chicago Press.

Herendeen, R. 1991. "Do Economic-Like Principles Predict Ecosystem Behavior Under Changing Resource Constraints?" In *Theoretical Studies Ecosystems: The Network Perspective*. eds. T. Burns and M. Higashi. New York: Cambridge University Press.

Homans, F.R. and J.E.Wilen, 1997. "A model of regulated open access resource use," *Journal of Environmental Economics and Management*, 32, 1-21.

Nordhaus, William D. and Edward C. Kokkelenberg, eds. 1999. *Nature's Numbers*, Washington, D.C.: National Academy Press.

SEIS (Supplemental Environmental Impact Statement). 2001. *Steller Sea Lion Protection Measures in the Federal Groundfish Fisheries off Alaska*. NMFS, Alaskan Region.

Shogren, J. F. and J. Tschirhart. 2000. *Protecting Endangered Species in the United States: Biological Needs, Political Realities, Economic Choices.* New York: Cambridge Un. Press.

Shoven, J.B., and J. Whalley. 1992. *Applying General Equilibrium*. Cambridge: Cambridge University Press.

Simpson, R. David, Roger A. Sedjo and John W. Reid. 1996. "Valuing Biodiversity for Use in Pharmaceutical Research." *Journal of Political Economy*, 104, 163-185.

Stephens, D.W. and J.R. Krebs. 1986. *Foraging Theory*. Princeton: Princeton University Press.

Tschirhart, J. 2000. "General Equilibrium of an Ecosystem." *J. Theoretical Biology,* 203: 13-32.

Tschirhart, J. 2002. "Resource Competition Among Plants: From Optimizing Individuals To Community Structure." *Ecological Modelling* 148: 191-212.

Tschirhart, J. 2003. "Ecological Transfers Parallel Economic Markets in a General Equilibrium Ecosystem Model." *Journal of Bioeconomics*, 5, 193-214.

Tschirhart, J. 2004. "A New Adaptive System Approach to Predator-prey Modeling" *Ecological Modelling,* 176, 255-276.

Weitzman, M. L. 1993. "What to Preserve? An Application of Diversity Theory to Crane Conservation," *Quarterly Journal of Economics*, CVIII, 157-183.

Table 1 Value of Benchmark Variables, in Million $

Variable	Value	Definition	Variable	Value	Definition
K_F	365.608	Fishery Capital	ω_K^{AK}	11263.681	Regional Capital Endowment
L_F	293.567	Fishery Labor	ω_K^{w}	307.325	Foreign Capital
$Q^M{}_F$	0.244	Fish Imports	ω_L^{AK}	9625.415	Regional Labor Endowment
Q_F	659.420	Aggregate Fish Output	ω_L^{w}	190.064	Foreign Labor
K_R	894.368	Recreation Capital	$C^T{}_{AF}$	24.443	Household Fish Demand
L_R	766.398	Recreation Labor	$C^T{}_R$	737.244	Household Recreation Demand
Q_R	1660.766	Aggregate Recreation Output	$C^T{}_{AC}$	19925.646	Household Composite Goods Demand
K_C	10311.029	Composite Goods Capital	S	201.764	Household Savings
L_C	8755.514	Composite Goods Labor	I_F	7.638	Fishery Investment
$Q^M{}_C$	10938.005	Composite Goods Imports	I_R	15.554	Recreation Investment
Q_C	30004.549	Aggregate Composite Goods Output	I_C	178.572	Composite Goods Investment
$X^D{}_F$	32.080	Regional Fishery Demand	$X^E{}_F$	627.340	Fish Exports
$X^D{}_R$	752.798	Regional Recreation Demand	$X^E{}_R$	907.968	Recreation Exports
$X^D{}_C$	20104.217	Regional Composite Goods Demand	$X^E{}_C$	9900.331	Composite Goods Exports

Table 2 **Discounted Cumulative Welfare Impacts**

Welfare Measure	Value of Leisure	Quota Rule	**50 Year Horizon (Million 1997 $)**	**100 Year Horizon (Million 1997 $)**
P_{EV}	100% Wage	30%	$1,117.77	$1,210.54
		170%	-$7,811.23	-$8,665.10
	75% Wage	30%	$1,530.77	$1,674.54
		170%	-$7,334.98	-$8,129.02
	50% Wage	30%	$1,943.77	$2,138.54
		170%	-$6,858.73	-$7,592.94

Table 3. Ecosystem Valuation Per Percentage Change in Ecosystem Inputs:

Welfare Measure	Value of Leisure	Quota Rule	**Average Annual Welfare Change Per 1 % Change in Ecosystem Inputs: Linked Model – Non-Linked(1997 $)**
EV_t	100%	30%	$109,626.43
		170%	$114,458.27
	75%	30%	$109,677.71
		170%	$114,493.98
	50%	30%	$109,728.99
		170%	$114,529.69

Figure 1 Economy Ecosystem Interaction

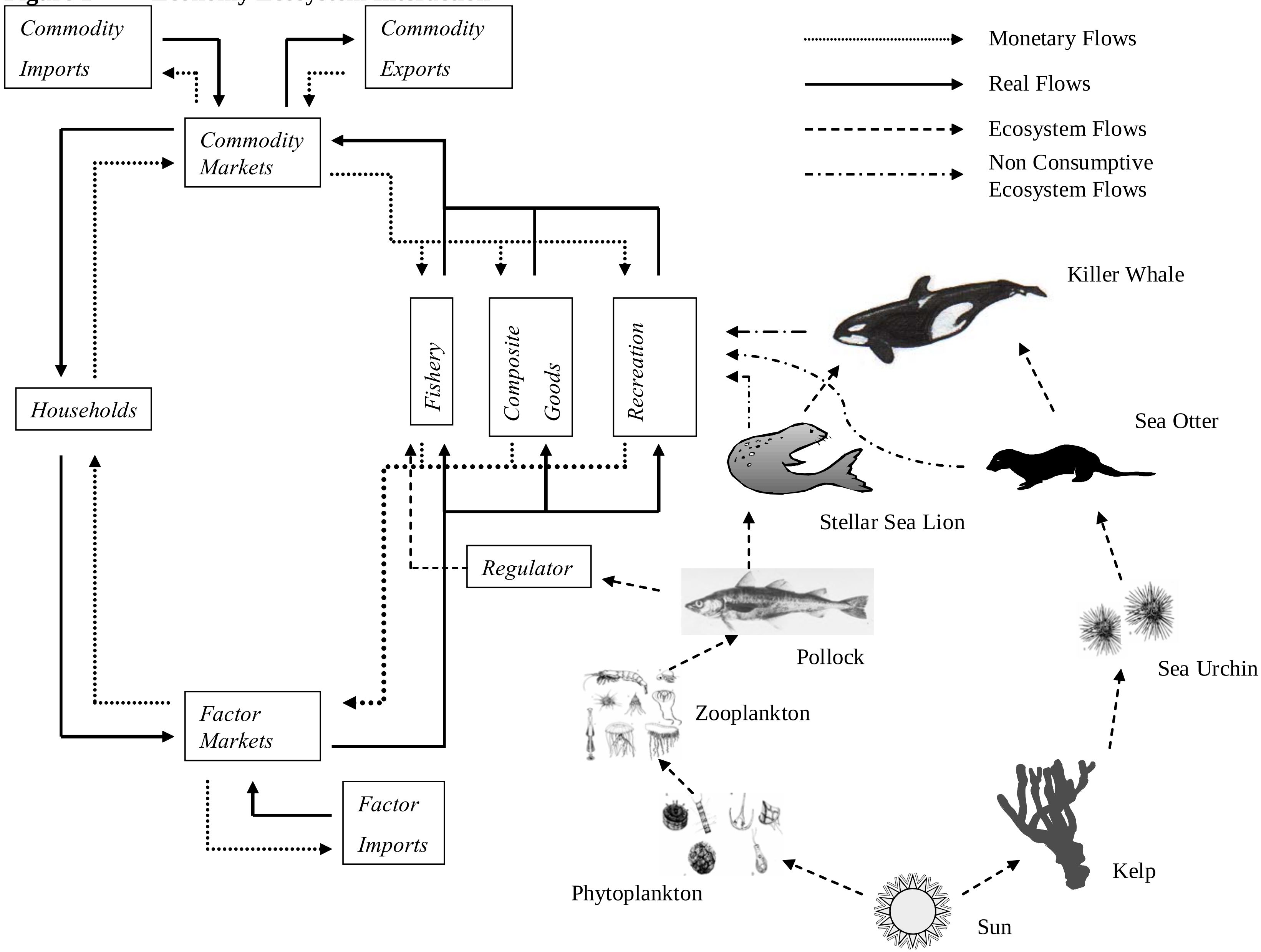
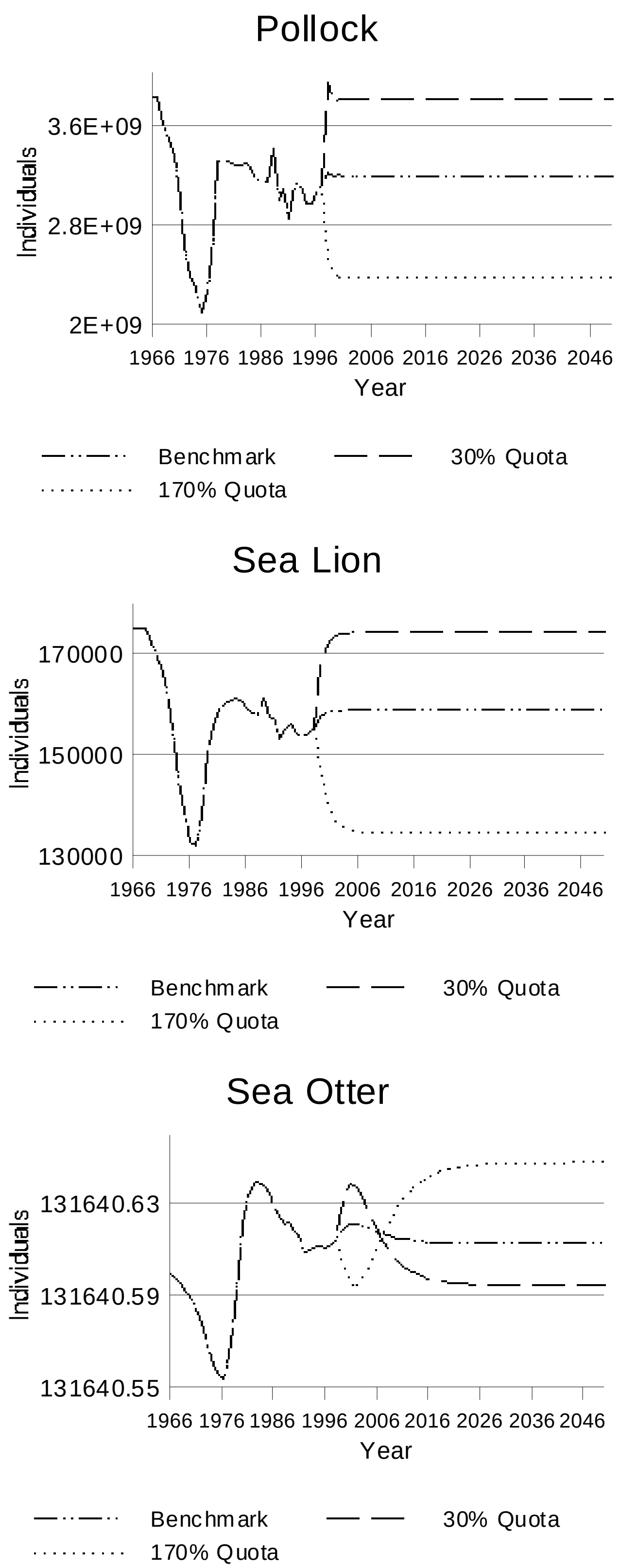


Figure 2 Ecosystem Populations



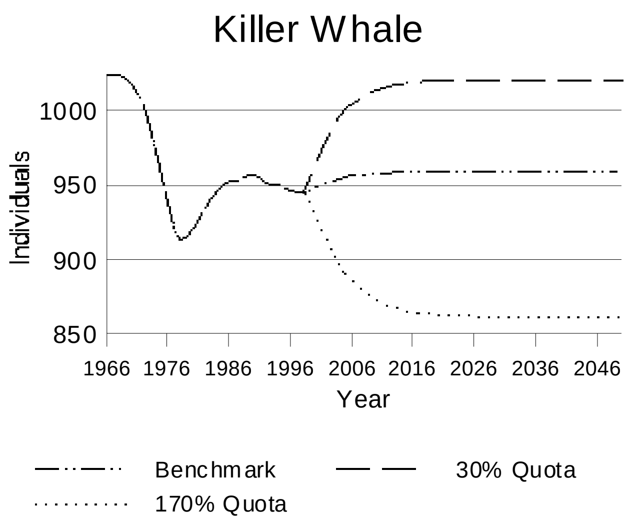
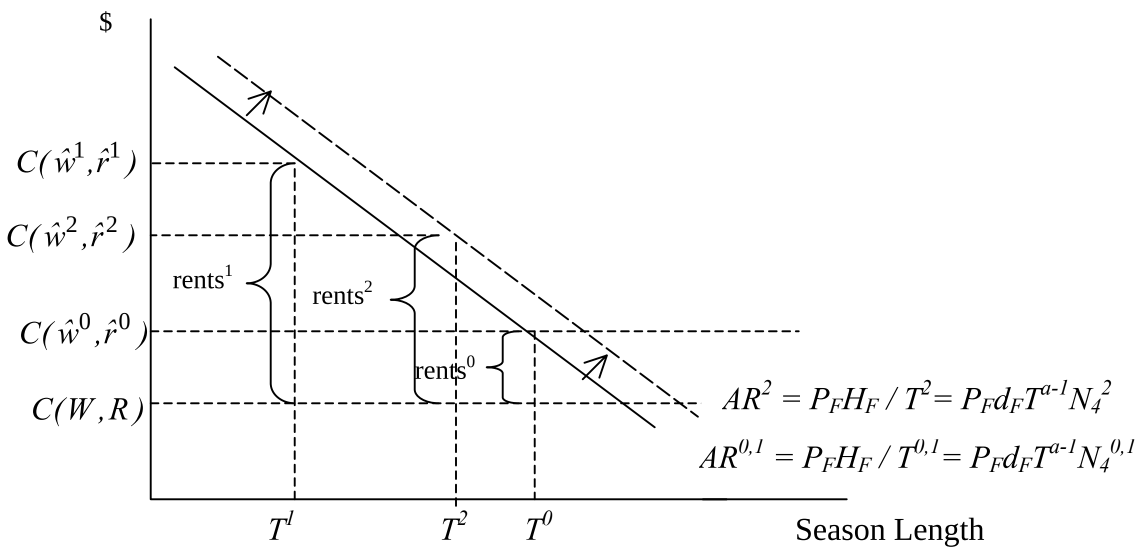

Killer Whale
Individuals
1000
950
900
850
1966 1976 1986 1996 2006 2016 2026 2036 2046
Year
Benchmark
30% Quota
170% Quota

Figure 3 Fishery Intra-season Rents



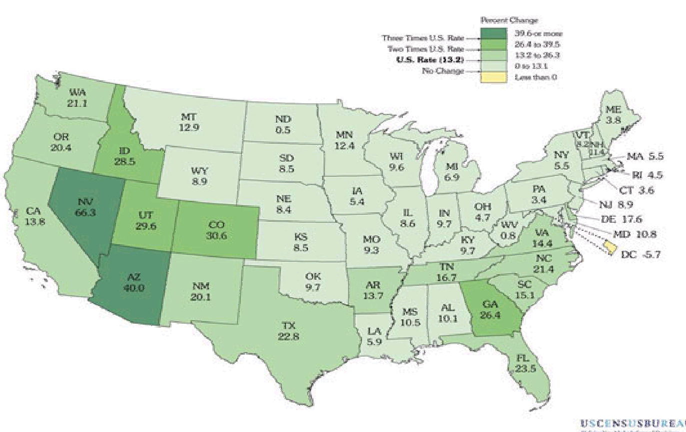
Integrated Modeling and Ecological Valuation

David Brookshire (PI)
Julie Stromberg (Co-PI)
Arriana Brand, Janie Chermak
Bonnie Colby, Mark Dixon, David Goodrich
John Loomis, Thomas Maddock
Holly Richter, Steven Stewart (Co-PI)
Jennifer Thacher

The University of New Mexico

Demographic Changes: Population Has Grown Fastest in the West, Particularly in the "Public Land States"

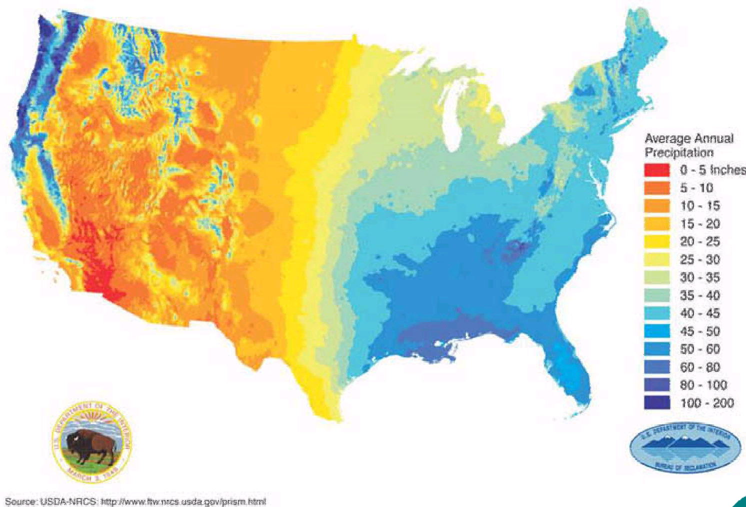
Percent Change in Resident Population for the 48 States and the District of Columbia: 1990 to 2000



- Darker areas denote faster growth rates.
- Nevada (66%) and Arizona (40%) lead the nation.
- Intermountain states average about 30%.

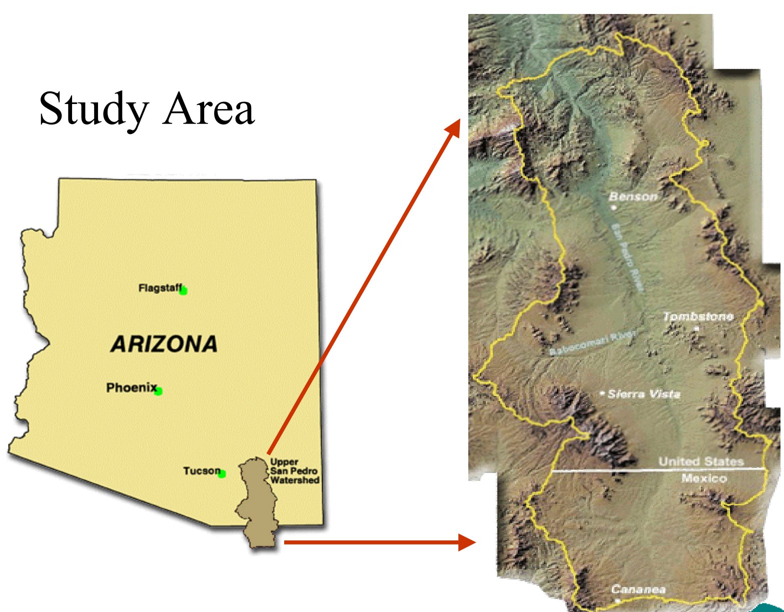
The University of New Mexico

Average Inches of Annual Precipitation in the United States 1961-1990



The University of New Mexico

Study Area



The University of New Mexico

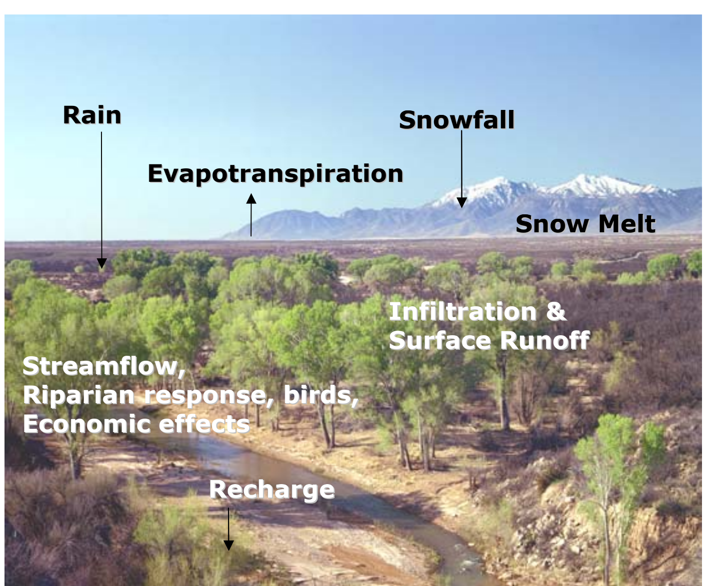
Study Areas

San Pedro
River Region

Bosque Del Apache
National Wildlife Refuge

The University of New Mexico

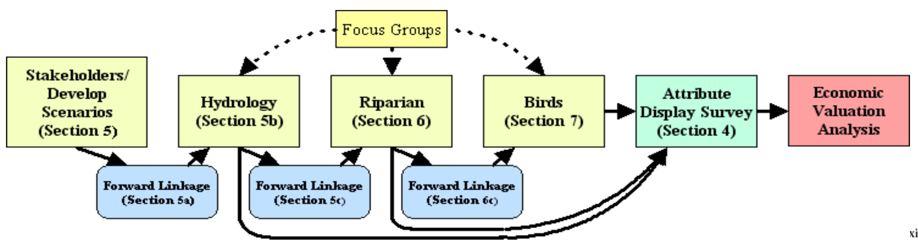
SAHRA/UA/UNM Research



The University of New Mexico

Objectives

- Integrate a hydrologic, vegetation, avian and economic models into an integrated framework
- Couple natural science information with socio-behavioral information to better understanding of both intra-site and inter-site data transfer functions
- Determine the value of changes in ecological systems caused by changes in hydrological profiles
- Introduce the non-market derived demand for water into an integrated demand management framework



Scenarios And Study Framework

- 2-anthropogenic and 2-climatic
- Use two stated preference techniques for valuation
  - Contingent valuation and choice models
- 3 information gradients
  - Fully integrated science models
  - 2 Transferable indexes
- 2 test sites through an internet-based visualization survey
- San Pedro River and Rio Grande

The University of New Mexico

Rio Grande

San Pedro

Alternative Sites to Bosque Del Apache

<u>Alternative Sites:</u>

- Rio Grande Nature Center - Albuquerque
- Randal Davey Nature Center – Santa Fe
- Riverside Nature Center - Farmington
- The Nature Conservancy's Bear Mountain Lodge – Silver City
- Guadalupe Canyon – Douglas, AZ
- McKitrrick Canyon - Carlsbad

<u>Site Attributes:</u>

- Riparian areas without the extensive wetland influence
- Gila, Animas and McKitrrick Creek are un-damned
- All have similar issues with urban competition for water
- Lower visitation

The University of New Mexico

Why Two Study Sites?
Issues Of Transferability

•Don't always have the ability to collect original data.

- –Timeframe
- –Lacking of basic science

•Cost of a primary studies (both economic and scientific) may be greater than value added from improved accuracy.

The University of New Mexico

Data Transfer Issues

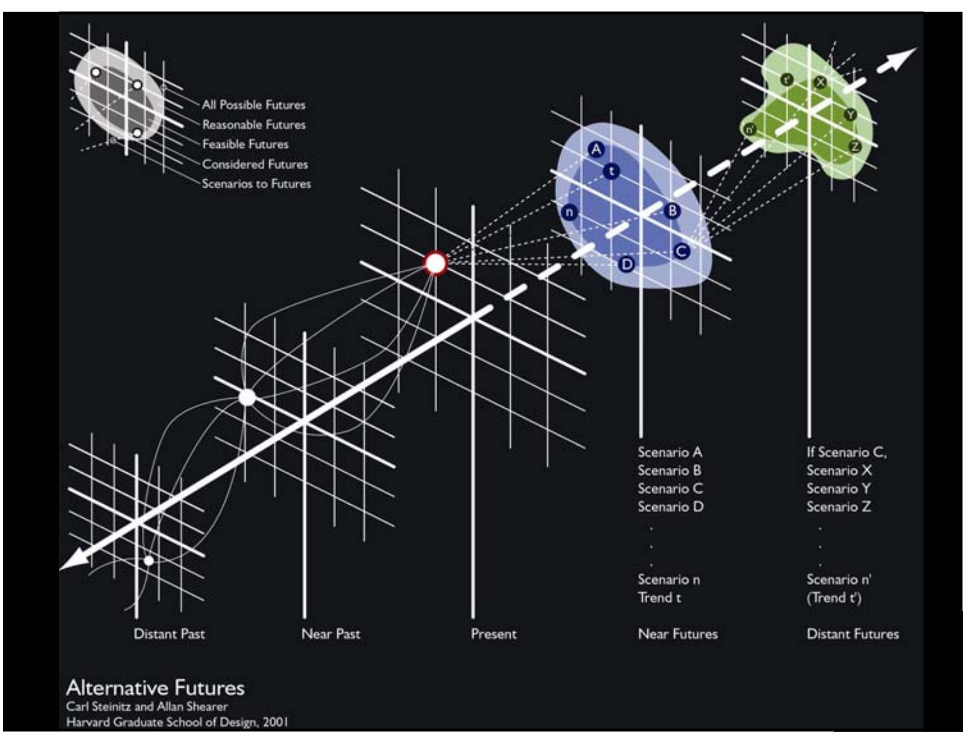
- What is the information we take from other disciplines in our economic analysis?
- Does this information itself rely on some type of transfer?
- What predefined conditions, if any, is the policy analyst to assume?

The University of New Mexico

Alternative Futures Study

- Explores how urban growth and change in the rapidly developing Upper San Pedro Basin might influence the hydrology and biodiversity of the area.
- Evaluation of individual scenarios from the present time (1997-2000) to 20 years in the future (2020).
- Provides information to stakeholders in the area regarding issues and planning choices, and their possible consequences.
- Alternative Futures study conducted by Department of Defense, Desert Research Institute, Harvard Graduate School of Design, IMADES, and The University of Arizona.

The University of New Mexico



The Alternative Futures

◦ **PLANS** -- based on interpretation of the current Arizona and Sonora plans, and a forecast population of 95,000 in 2020 in the Arizona portion of the study area.

◦ **CONSTRAINED --** assumes lower than forecast population growth in Arizona. Development is concentrated in existing developed areas.

◦ **OPEN --** assumes higher than forecast population growth in Arizona, with major reductions of development control. Sonora remains as forecast.

The University of New Mexico

Focus Groups

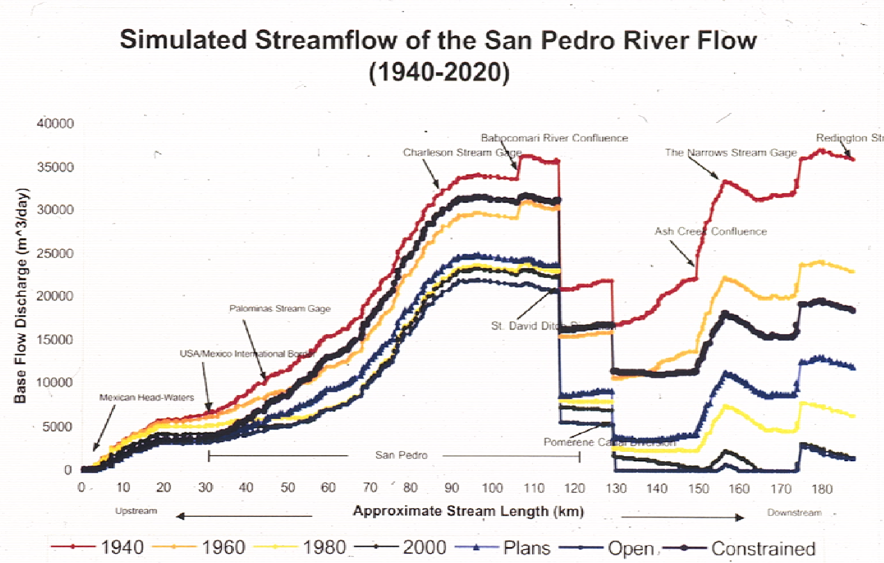
- Unique aspect of this study
- Necessary to bridge the gap between the specialized science of scientists and general knowledge/perception of public
- Groups will help determine what information is collected and how that correlates with water management changes
- Groups will identify important attributes
  - Those will be measured by natural scientists and included in the choice model

The University of New Mexico

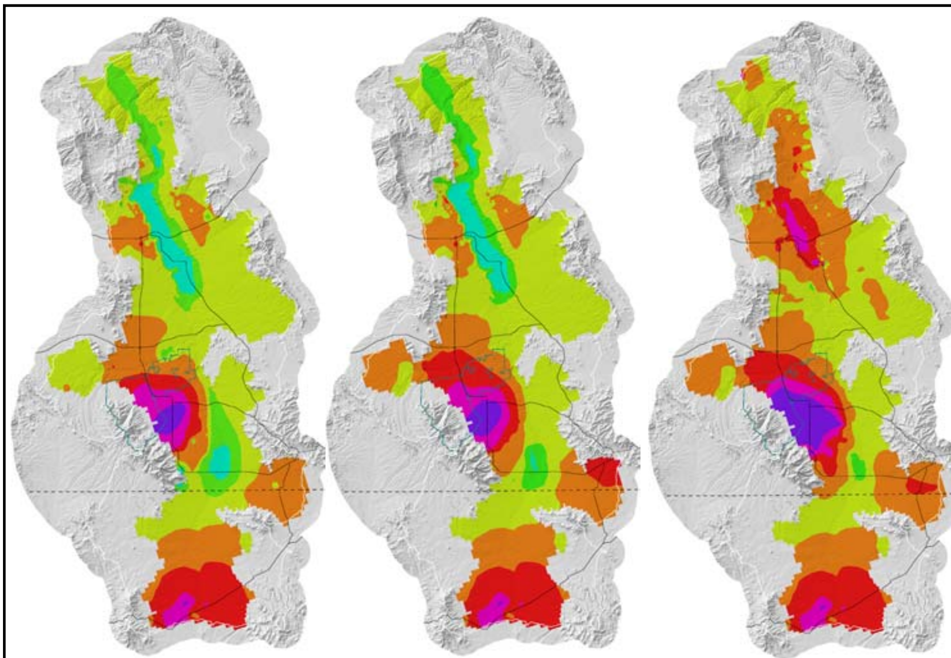
Valuation and Visualization Projections

- Web-enabled science-based Economic Valuation and Visualization System (EVVS)
  - Geographic information technologies
    - Geo-databases
  - Geographic information system (GIS)
  - Internet-enabled mapping technologies
  - Integrating technologies

The University of New Mexico



The University of New Mexico



Two Stated-Preference Methods

- Choice models (CM)
- Dichotomous choice contingent valuation models (CVM)
- We will examine:
  - Convergent validity for single attribute and policy (multiple attribute)
  - Valuation across methods
  - Conduct traditional tests of scope and embedding
  - Examine differences between on-site and Internet survey formats

The University of New Mexico

Treatments

Sample Size	Model	Internet	In Person	Total Surveys
San Pedro				
	IM CM	300	100	400
	Index CM	150	50	200
	Trad CM	150	50	200
San Pedro				
	IM CM	600	200	800
	Index CM	300	100	400
	Trad CM	300	100	400
Bosque Del Apache				
(Or Similar Site)	IM CM	150	50	200
	Index CM	150	50	200
	Totals	2100	700	2800

IM – Integrated Model

CM- Choice Model

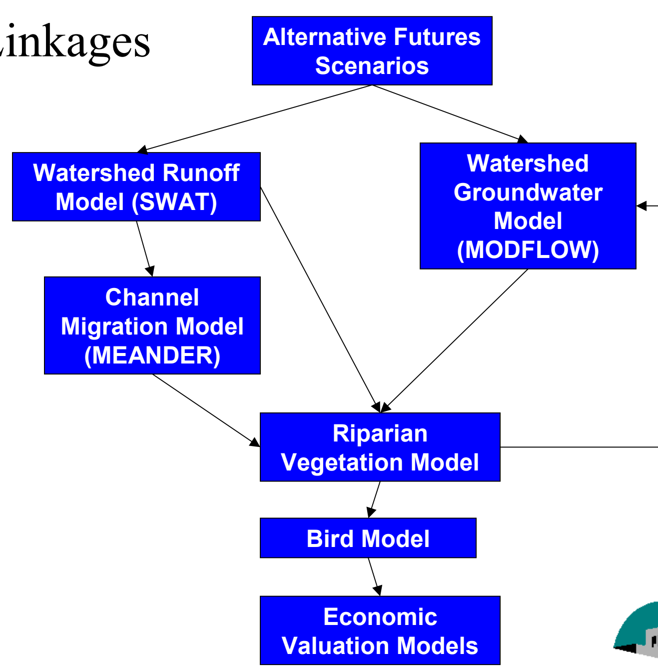
Trad – Traditional Model – (Not Significantly Anchored In Science)

Index- “Off The Shelf” Scientific Information

CVM – Contingent Valuation

The University of New Mexico

Model Linkages



The University of New Mexico

Hydrology Component

- Analysis of anthropogenic and climate changes in San Pedro River Region
- Alternative Futures Study (AFS)
- Hydrological Models
  - GIS-Based Modflow
  - Water Runoff
  - Penman-Monteith Riparian Evapotranspiration

The University of New Mexico

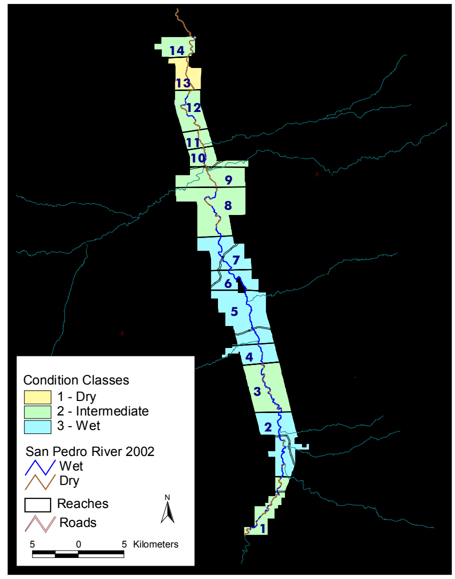
Riparian Component

- How changes in surface flow and ground water levels effect
  - Riparian vegetation distribution
  - Composition
  - Structure
- Use existing information and backward linkages to:
  - Identify relationships
  - Develop reach-scale indices
  - Model finer-scale, patch level riparian vegetation change in response to scenarios

The University of New Mexico

Coarse-scale Vegetation Modeling

- Divided river into 14 reaches based on physical characteristics
- Determined relationships between vegetation traits (e.g., cottonwood vs. tamarisk abundance) and site hydrology
- Classified reaches into 3 condition classes (dry, intermediate, wet) based on vegetation traits (bioindicators) indicative of site hydrology
- Will project reach-scale vegetation changes based on changes in condition class under alternative futures



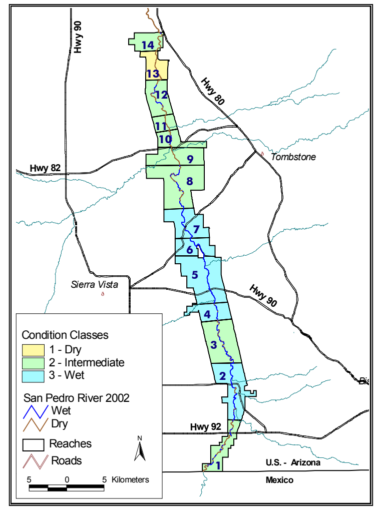
Bird Component

- Objective
  - To determine the impact of vegetation changes on bird populations and communities for differing type of reaches of the SPR
  - Provide characteristics of bird abundance, productivity, richness, and diversity

The University of New Mexico

Coarse-Scale Bird Modeling

- Classified bird sampling locations by 3 condition classes (following Stromberg et al.) and 5 habitats (cottonwood, mesquite, salt cedar, grassland, and desert scrub).
- Quantified avian abundance, nest success, and species richness as a function of habitat / condition class.
- Can project habitat/condition class changes affecting birds under alternative futures.



The University of New Mexico

Major Issues

1. How do individuals value marginal changes in indices of ecosystem health and can such indices be used as proxies for specific benefits?
2. Which benefits contribute most directly to human well-being, what are their relative values, and what are the most efficient methods of valuing them?
3. What is the tradeoff between the accuracy associated with more detailed benefit transfers and the more costly information necessary to provide them?
4. To what extent can simpler “reduced form” transfer functions mitigate inaccuracies?

The University of New Mexico

Expected Results For Determining Derived Demand For Water

- A fully integrated valuation framework using the best science and alternative valuation methods.
- Methodological insights into non-market valuation techniques.
- Alternative data transfer functions that rely upon alternative information gradients.
- Non-market water demand valuation functions for integrated modeling.

The University of New Mexico

Thank You

The University of New Mexico

Comments on the Papers by Finoff and Tschirhart and Hammitt and von Stackelberg

R. David Simpson
NCEE

A good place to start my discussion of these innovative and stimulating contributions may be by repeating the commonplace observation that economics and ecology both stem from the same Greek root: *oikos*, meaning house or household. Ecology is the study of "nature's household"; economics, that of the society's. Before Ernst Häckel coined the term *oecologie* in 1869, though, the disciplines were even more closely tied in their terminology. The natural historian Gilbert White wrote in 1789 that " . . . nature, who is a great economist, converts the recreation of one animal to the support of another!" and "The most insignificant insects and reptiles are of much more consequence, and have much more influence in the Economy [of] nature, than the incurious are aware of".

Contacts between the disciplines continued. Charles Darwin credited his reading of Thomas Malthus's *Essay on Population* for providing the insight that motivates the "survival of the fittest" in *The Origin of Species*, while Karl Marx is said to have intended to dedicate one of the volumes of *Das Kapital* to Darwin—at least until Engels persuaded him to identify a less bourgeois inspiration.

Cross-fertilization continued into the next century, including John Maynard-Smith's application of game theory in the spirit of John von Neuman and Oskar Morgenstern and John Nash to animal behavior, and Richard Nelson and Sidney Winter's explorations of evolutionary principles in economics.

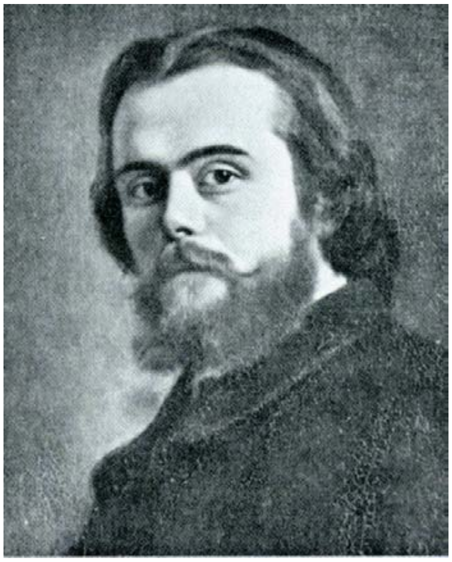
So, the first of the papers I discuss has a long list of illustrious antecedents—and in whose distinguished company, I would venture to say, it is not misplaced. David Finoff and John Tschirhart's work is insightful and innovative. If I ask some questions and note some possible limitations in what follows, my remarks are intended in no way to temper my general impression that their work is original and valuable.

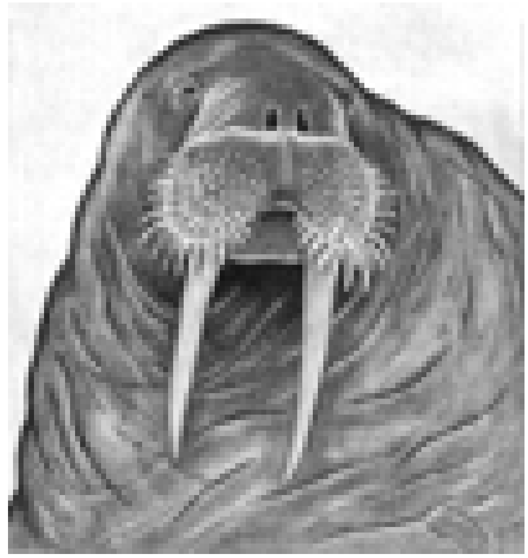
I must confess that while reading a paper combining fundamental principles of general equilibrium analysis with an application to large Alaskan marine mammals my imagination began to work overtime (see figures 1a and 1b). As it did, though, perhaps the couplet I composed captured some essential element of Finoff and Tschirhart's analysis:

The time has come, the Walras said, to speak of new devices
For getting rich, by sparing fish, when Joules mark their prices

Figure 1a
Marie-Ésprit Léon Walras
1834-1910

Figure 1b
Odobenus Romarus
The Pacific Walrus





While I do think it's ingenious to think of the ecological "prices" of fish and other marine organisms being calibrated in Joules, I do have some nagging doubts about the procedure. I might express the first by asking "Are *we* likely to be any better at doing *their* stuff than *they* are at doing *ours*?" The "we" and the "they" are, respectively, economists and ecologists. While I've discussed some of the overlaps between the fields in my opening remarks, some recent forays by ecologists into economics have not been met with favor by many economists. A 1997 effort by Robert Costanza and numerous coauthors was roundly criticized for confusing marginal and average notions, failing to appreciate the limitations of ability to pay on willingness to pay, and as Michael Toman famously remarked, offering "A serious underestimate of infinity." A generation later the ecologist Howard Odum proposed measuring the value of ecosystem services by the energy required to perform them. This proposal betrays, as Partha Dasgupta has noted, an apparent want of familiarity with Paul Samuelson's nonsubstitution theorem. The nonsubstitution theorem demonstrates that reducing values to a common metric reflecting the contribution of any single input is, in general, impossible.

I'm also a little concerned with an attempt to describe the functioning of one complex system—a marine ecosystem—by analogy to another—a general competitive equilibrium—when students of the former have already developed an elaborate description of at least some of its mechanics. I'm referring to the evolutionary paradigm in which the fit survive and replicate themselves. I'll also note in passing that it's always seemed to me that evolutionary arguments in economics founder on the absence of a mechanism of inheritance. There is no, or at best a very poor, analog in economics to the role of genetics in biology.

Having expressed my doubts about Finoff and Tschirhart's use of energy as if it were the objective of a biological system, I should also say that they have certainly not fabricated it from whole cloth. The authors include many citations to biologists who have made similar assumptions, and note especially that it's a staple of the "optimal foraging literature" that describes creatures' feeding habits and the tradeoffs they make between gathering food and risking predation while doing so. Nor, I should add, do Finoff and Tschirhart fall into Odum's error of supposing that values can be represented by equivalent energy *inputs*; in Finoff and Tschirhart, energy is the objective to be maximized, not the fundamental unit of account in which all inputs and outputs are to be measured.[1]

Still, I can't help hearing my mother's voice saying "Eat your vegetables!" What I mean is that a balanced diet requires a mixture of foods; choosing our own diets to maximize solely calories within linear budget constraints would have us subsisting solely on lard, albeit, presumably, not for long before our arteries clogged. In short, and in economic terms, Finoff and Tschirhart ask us to suppose that "biological production functions" exhibit straight-line isoquants whose slopes are determined entirely by relative calorie contents of available food sources. This may be a reasonable approximation, but I guess I'd be more comfortable if I felt I knew the biology a little better.

I have another concern with Finoff and Tschirhart's analysis, although I suspect that it revolves around little more than an expositional suggestion to clarify the notion in their paper. The classic proof of general competitive equilibrium in economics demonstrates that *there exists a set of prices* at which all supplies and demands balance. The limitations of this theorem are well known. It is silent on how these prices are determined. What happens if there is some departure from such prices? My understanding is that the question has never adequately been resolved, but most of the economics profession believes that the intuitive notions that prices go up when demand exceeds supply and decline otherwise provide a workable depiction of the process of reaching equilibrium. Is there a similar process driving convergence to ecological equilibrium in Finoff and Tschirhart's work? "Prices" are determined by energy content, and so it is not clear how these prices would adjust to clear the "markets" for species. Presumably the energy cost of seeking a certain prey decreases in that species abundance, but I'd like to see more explanation of this.

One mechanism for equilibration is apparent: species that acquire more energy through preying on others than they expend in predation or lose by becoming prey themselves thrive. In this respect, population growth is to positive net energy flux as industrial entry is to supernormal profits. Processes of industrial entry may not be wholly adequate for eliminating supernormal profits when barriers exist to entry, however. I'm curious as to whether similar concerns might apply in the biological model.

---

[1] Somewhat ironically, and wholly by coincidence, between the time I presented my oral comments at the workshop and writing them up now I picked up a copy of Robert Nadeau's recent book *The Wealth of Nature*. Nadeau, following Philip Mirowski, develops the thesis that neoclassical economics is modeled on 19th century physics. In Nadeau and Mirowski's view, neoclassical economists did little save relabel the variables in models of physics, and the analogy between utility and energy in their respective disciplines is exact. Without commenting as to the validity of his critique, I'll simply say that Nadeau might find it ironic to see economists now structuring a model of biology in which energy is now the analog to utility.

My remarks thus far have largely focused on the question of whether the net energy flux Finoff and Tschirhart use to motivate their model is the "right" objective. This is a relative matter, though. "Right" for what? I can see several potential purposes:

- Describing population dynamics.
- Calculating and explaining the relative abundance of species.
- Developing real-world policy advice.

It seems that, in order adequately to serve the last of these purposes, the model would have to be fairly closely calibrated to biological data and demonstrate an ability closely to explain and predict them. It is no criticism of a model of so complex a phenomenon to suggest that the model has not yet done this. It's a very, very hard problem!

Thus, I don't think Finoff and Tschirhart's contribution is sufficiently refined as yet to form the basis for concise policy guidance. I might also note in passing that various elements of the problem over and above the fundamental biology make the analysis even more difficult. Consider, for example, fisheries policy: to what combination of political and social factors do regulators respond, and how effective are their regulations? These considerations make the development of policy advice even more complicated.

As another example of policy interactions, Finoff and Tschirhart note that fishermen may earn quasi-rents in that their labor is seasonal. It's difficult, then, to know how to evaluate their earnings and opportunity costs of time. As a personal aside, I grew up in a small fishing town on Puget Sound in Washington State. The area had been settled at the turn of the 19th century by Serbo-Croatian immigrants whose descendents resembled professional basketball player Vlade Divac in appearance, stature, and, in some instances, athletic ability. One guy who was a few years older than me—and whom we all envied greatly—spent his summers fishing in the Gulf of Alaska. This paid him well enough that he drove an expensive sports car. He attended college, on a basketball scholarship, through the other seasons. The rumor around town was that he was also collecting unemployment benefits since he was unable to fish during basketball season but he was, or so he claimed, prepared to quit school and the team if he could find employment. So, the interaction between labor and fishery policies might affect results as well! To be fair, Finoff and Tschirhart demonstrate that their results are not sensitive to wage rate assumptions. Still, any number of interrelated policy interactions might affect the analysis. The collective uncertainties introduced at all the many stages of the analysis might be enough to propagate cumulative errors large enough to preclude precise policy guidance.

If Finoff and Tschirhart's analysis is not (yet) well enough grounded to provide concise policy advice, what are its chief merits? I think they lie in providing a concise and thought-provoking paradigm for thinking about interrelated social and ecological systems. Whether or not a biological approach modeled after economic equilibrium is accurate, there's tremendous value simply in communicating the possibility of approaching problems in this way and providing concrete instances of parallels and differences between biological and social systems.

Another virtue of Finoff and Tschirhart's approach may be that it facilitates "informationally dense," for want of a better term, interpretations of a system's state. Economists often make much of the informational role of prices: they tell us everything we need to know about preferences, costs of production, future prospects, etc. The "energy prices" of Finoff and Tschirhart's model may perform a similar role of describing the state of the biological system. Another analogy comes to mind. Whether or not a particular animal is eaten by another is, of course, a random event, and can't be accurately predicted. Yet on the aggregate level we should be able to say something about general patterns of predation and their consequences for relative abundance. Just as the logistic model of infection generates aggregate regularities from a host of individually stochastic events, the Finoff and Tschirhart paper may usefully reduce complex stochastic phenomena to the compact summary statistics of "prices".

Let me conclude my discussion of Finoff and Tschirhart with one final reservation, however. The paper is concerned with what I might describe as "most-of-the-time" behavior on a path toward a steady-state equilibrium. Our greatest social concern with biological systems often involves rare stochastic events, however. How vulnerable are such systems to climate change? To invasive species? It is, of course, difficult to predict the response to an unpredictable shock, but another useful direction for research might be to consider the "resilience"—to borrow a loaded term from the ecological literature—of such systems.

The paper by James Hammitt and Katarina von Stackelberg takes up some similarly complex issues of ecological and economic interactions using a very different set of tools. I might also note that, because Hammitt and von Stackelberg have only been working on a difficult problem for a limited time, the paper I had to review is still preliminary and incomplete.[2] I will, then, be commenting on their procedures rather than their results.

My first comment is simply to re-emphasize that Hammitt and von Stackelberg are discussing extremely difficult issues. What are the effects of PCB contamination on human health and ecosystem functioning, and how do people form values regarding these effects? If, as Hammitt and von Stackelberg propose, such values are to be elicited by asking stated preference questions, the questions will necessarily be very complex.

The authors are off to an impressive start in formulating the questions. I've never read a paper that discusses, within the span of a few pages, concepts as variesd as "PCB congenors . . . chloronated in the *ortho* . . . *meta* and *para* positions"; " . . . the induction of cytochrome P450 enzymes . . ."and "the McCarthy Scales of Children's Abilities, . . . the Peabody Picture Vocabulary Test-Revised and Buss and Plomin Emotionality Activity Sociability Temperament Survey for Children . . . and the Wechsler Intelligence Scale for Children-Revised (WISC-R)"! This breadth of coverage is both impressive to the reader and challenging for the authors. They will need to knit together the analysis in such a way as to make it cogent to people who are not experts in all fields (who include

[2] I might also note that the project reported at the workshop by David Brookshire was still too recent for there to have been any written material for me to review.

just about everyone except the authors), as well as to reduce these issues to terms that will be comprehensible to their stated preference survey respondents.

While it may always be implicit, perhaps I should mention explicitly before what I say next that "the opinions expressed here are those of the discussant and not necessarily those of the Agency . . . " It seems to me that two questions can be asked of any exercise in valuation, and of stated preference approaches in particular.

1. Are the specific answers generated useful for making policy? And
2. Are we learning more about the validity, reliability, and transferability of the methods employed?

It is difficult to see how one can posit a positive answer to the first without presenting more evidence as to the second.

From this perspective, Hammitt and von Stackelberg are building in interesting and useful tests. By approaching the same phenomenon of PCB contamination from a variety of angles, they are building in cross-checks as to the validity of each. Of particular interest may be their proposal to alternate the order in which they ask questions concerning human health and ecological effects. *In theory* it shouldn't matter if a respondent is asked first about one and then the other, or if the order is reversed. It will be interesting to see if this novel twist on the "embedding" question yields the anticipated result.[3]

It's interesting to see researchers grappling with such challenging questions. One way of thinking about the types of things that Hammitt and von Stackelberg are considering is that they're exploring public attitudes toward experience goods with which people have little or any experience. The severe health consequences of PCB exposure will, for most of us, be encountered once in our lifetimes and at the end of our lives at that. The ecological consequences of PCB are even further from the realm of things with which most people have had any experience.

I'm reminded of something I've heard Dan Bromley say—though I should caution that I can't claim to be quoting exactly, but rather, to the best of my recollection: "If you think prices come from markets, you probably believe milk comes from plastic bottles." I think what he means by this is that the properties we attribute to prices—and some economists assert attributes of foresight and rationality that border on the magical—arise in institutional and cognitive circumstances that have often evolved over long periods of time. What does it mean to be eliciting "prices" respondents profess to be willing to pay absent the trappings of a market? I have no answer to propose, but suspect that we might better inform and refine our attempts at valuation if we could incorporate into our analysis an understanding of what motivates the formation of markets and what we can infer from their absence.

---

[3] I continue to be somewhat surprised that the consistency tests proposed by Peter Diamond in his 1996 *Journal of Environmental Economics and Management* seem to have attracted as little attention as they have.

EPA Valuation of Ecological Benefits: Improving the Science Behind Policy Decisions – A STAR Progress Review Workshop.

Session IV

Juha Siikamäki
Fellow, Resources for the Future

Discussion of two presentations:

"Joint Determination in General Equilibrium Ecology/Economy Model" by David Finnoff and John Tschirhart and

"Contingent Valuation for Ecological and Non-Cancer Effects within an Integrated Human Health and Ecological Risk Assessment Model" by James Hammitt and Katherine von Stackelberg.

"Joint Determination in General Equilibrium Ecology/Economy Model"

This paper by David Finnoff and John Tschirhart is part of their research program, in which the authors have developed a joint ecology/economy general equilibrium framework. This modeling framework suggests concepts to modeling ecology/economy interactions, which makes the research effort particularly challenging and ambitious.

The economic component of the joint equilibrium framework by Finnoff and Tschirhart comprises a standard computable equilibrium model of the economic sector, in this case, the fishing industry. The ecological component (GEEM, general equilibrium ecosystem model) of the framework extends the economic equilibrium model to modeling ecosystems. While the economic model comprises individual agents (consumers and firms), which maximize their objective functions (utility, profit), the ecosystem model comprises different species, which maximize their net energy intake. Ecosystems are organized as hierarchical food webs, which are assumed to transfer energy between different trophic levels via "energy markets," conceptually much the same way as goods and the factors of production are transferred within the economy. Each period, all energy markets are required to clear, bringing the ecosystem to equilibrium.

My discussion highlights the ecological modeling tradition[1] and makes an attempt to place the research by Finnoff and Tschirhart into a larger context. I will discuss different ecological modeling approaches by focusing on their origins.

Most mathematical models in ecology relevant to the Finnoff and Tschirhart paper are *population-level* models. The first such models were introduced well before ecology became an established discipline. Malthus' prediction of the human population growth introduced an exponential growth model in the late 1700s. A few decades later in the 1830s, Verhulst incorporated a carrying capacity constraint in the exponential growth model and thereby formulated the widely used logistic growth model, which has an S-shaped population growth curve. In the 1920s and '30s, physicists Lotka and Volterra developed sophisticated mathematical models of, among other things, species competition and predator-prey interactions. These models, as well as the host-parasite models by Nicholson and Bailey (1935), are still some of the fundamental mathematical models in ecology. The approach taken by Lotka and Volterra influenced economics (for example, Samuelson notes their work in the introduction of his

[1] See, for example, Begon et al. 1996, Edelstein-Keshet 1988, Real et al. 1991.

textbook), and their models of competition were also introduced to economics. May (1976 and elsewhere) demonstrated that simple deterministic models could drive complicated and even chaotic behavior, with completely different outcomes driven by slight differences in initial conditions and population parameters. Current themes in population ecology involve developing complex dynamic models, in particular, meta-population models (Hanski 1999).

Individual-level ecological models relevant to the Finnoff-Tschirhart paper deal with optimal foraging behavior. These models draw directly from economics and explain animals' strategies to exploit resources most efficiently. MacArthur and Pianka (1966) first adapted the economic model to a patch choice problem, proposing that foraging decisions are based on the relative benefits and costs of foraging on alternative patches. A rich consequent literature on foraging behavior has thereafter addressed time spent foraging on each patch, nutritional constraints, learning and memory, risk and stochastic factors, as well as fitness and the genetic base of behavior, and other factors. Central to the foraging studies is the assumed relationship between the behavior of organisms and their net energy intake. Optimal foraging studies often view organism's rate of energy intake as the proxy of evolutionary fitness.

The concept of *ecosystem*, which was introduced by Tansley (1935) and Lindeman (1942), emphasizes that biotic community is not differentiated from its abiotic environment and used the term "ecosystem" to denote the biological community integrated with the abiotic environment. Ecosystem is viewed as the fundamental ecological unit, and organisms within an ecosystem may be grouped into a series of discrete trophic levels. The key processes structuring ecosystems across spatial and temporal scales are tested and discussed, for example, by Holling (1992) and Holling et al. (1995).

I will now proceed to discussing the paper by Finnoff and Tschirhart.

The ecological scales of GEEM and research questions

The suitable model type and its complexity depend on the research question. In this case, the modeling effort seeks to identify prices and quantities of final goods and the factors of production, predator and prey biomass consumption, and species populations in the ecosystem. The ecological questions are, therefore, population-level questions. However, the GEEM is an individual-level model, which is aggregated to the ecosystem level by employing representative organisms/animals (the ecological counterparts of representative consumer/firm). Alternatively, one could combine the economic model with a mainstream dynamic population model from ecology. Multi-species dynamic models are demanding, but using numerical simulation models and software may facilitate complex modeling efforts. The question then becomes which modeling approach is more useful and accurate: the joint ecology/economy equilibrium model or a "mainstream" bioeconomic model (see, e.g., Clark 1990, Sanchirico and Wilen 2001).

Since an altogether new modeling approach is being introduced, it would be valuable to see a comparison of alternative modeling approaches applied to the same problem. Different models could be compared relative to their predictive power. Such a comparison would help determine which types of modeling efforts the GEEM is suitable for, and on the other hand, which modeling may be best carried out by using mainstream bioeconomic models.

Data needs

The data requirements of the GEEM differ from bioeconomic models. Therefore, it would be useful to assess the GEEM also from the perspective of data requirements and quality. Some questions used in assessing the model could be: What are the minimum data requirements for implementing the GEEM and how reliable are these data relative to data used in bioeconomic models? What are the possible gains or losses in modeling accuracy associated with data sources and quality?

Ecosystem equilibrium

The GEEM is an equilibrium model, which clears all energy markets every period. In the long run, the ecosystem directs itself towards the steady state. Ecological systems, however, are often perplexed by non-linearity, complex feedback loops, and multiple or no equilibrium. An application, which would examine how to modify the GEEM to handle these issues, would be welcome.

Spatial scale

The relevant spatial scale may vary among different trophic levels, and depend, on the mobility of different species or other factors. For example, sea urchins, sea otters, and killer whales each operate at different spatial scales. The GEEM may be modified to account for varying spatial scales, perhaps by viewing different meta-populations as separate "species" in the same trophic level. On the other hand, meta-population models in ecology have been developed specifically for handling spatially differentiated populations.

"Contingent Valuation for Ecological and Non-Cancer Effects within an Integrated Human Health and Ecological Risk Assessment Model"

This paper by James Hammitt and Katherine von Stackelberg describes a research project for valuing the ecological and human health effects of PCB contamination. Their research is currently ongoing, with the survey involved nearly ready to be launched. My comments that follow address mostly general issues related to the valuation of ecological and human health risks.

Hammitt and von Stackelberg use a dichotomous choice contingent valuation method for the valuation of both ecological and health endpoints of PCB contamination. The ecological endpoints involve two alternative valuation endpoints: the effects of PCB contamination on a high-profile species (bald eagle) versus its effects on a group of species (species sensitivity distribution). The human health endpoints consist the effects of PCB on developmental outcomes (IQ, reading comprehension). The exposure pathway causing the adverse effects is the ingestion of fish.

Non-market valuation studies typically do not address uncertainties inherent in the evaluated policy outcomes. Several factors contribute to this tendency. First, uncertainties often stem from very complex relationships and scientific phenomena, which are complicated to communicate effectively to survey respondents. Second, the expression of uncertainties as probabilities has been a long-standing challenge in stated preference surveys (Hammitt and Graham 1999). Third, uncertainties in policy outcomes can cause respondents to question the scientific credibility of the scenarios presented to them.

Hammitt and von Stackelberg address the uncertainty of ecological outcomes by using the species sensitivity distribution (SSD) approach to describe the distribution of reproductive effects of PCB contamination for all species. The ecological basis of the SSD approach is appealing, but the involved graphs are cognitively challenging. It will be interesting to see how well using the SSD works in the valuation context. The survey also uses graphs with colored dots for intuitively easy illustrations of the risk probabilities.

The survey will help estimate the value per statistical life (VSL) for children, which is an important research question for which practically no information currently exists. Children are especially sensitive to the effects of pollution and estimating VSL for children would therefore be an important contribution and useful in policy evaluations.

Willingness to pay for both ecological and human health risk reductions will be determined by respondents' risks perceptions, which, in turn, will reflect information available to the respondents both in the survey and prior to it. Therefore, it would be interesting if the survey could collect information on the actual risk perceptions of the respondents. Quantitative measures of the perceived risks may be hard to attain, but the survey could collect data on at least the extent of ecological and human health effects respondents consider in answering the valuation questions.

References

Begon, M., J.L. Harper, and C. R. Towsend, (1996). *Ecology: Individual, Populations, and Communities,* Blackwell Science, Third Edition, p. 1068.

Clark, C. W. (1990), Mathematical Bioeconomics: the Optimal Management of Renewable Resources, Second Edition, John Wiley & Sons.

Edelstein-Keshet, L. (1998). *Mathematical Models in Biology,* McGraw Hill, p. 586.

Hanski, I., (1999). *Metapopulation Ecology*, Oxford University Press, p. 313.

Hammitt, J.K. and J.D. Graham, (1999). Willingness to Pay for Health Protection: Inadequate Sensitivity to Probability? *Journal of Risk and Uncertainty* 18(1): 33-62.

Holling, C.S., (1992). Cross-Scale Morphology, Geometry and Dynamics of Ecosystems. *Ecological Monographs.* 62(4):447-502.

Holling, C.S., D.W. Schindler, B. W. Walker, and J. Roughgarden, (1995). Biodiversity in the Functioning of Ecosystems: An Ecological Synthesis. In: Perrings, C. K-G Mäler, C. Folke, C. S. Holling, B-O. Jansson, *Biodiversity Loss, Economic and Ecological Issues,* Cambridge University Press.

Lindemann, R. L., (1942). The Trophic-Dynamic Aspect of Ecology, *Ecology* 23:399-418.

Lotka, A.J., (1925). *Elements of Physical Biology.* Baltimore: Williams and Wilkins.

MacArthur, R. H. and E. R. Pianka, (1966). On Optimal Use of a Patchy Environment, *The American Naturalist* 100: 603-09.

May, R. M., (1976). Simple Mathematical Models with Very Complicated Dynamics, *Nature*, 269, 471-477.

Nicholson, A. J. and Bailey, V. A., (1935). The Balance of Animal Populations, Part 1, Proceedings of Zoological Society of London, 3:551-598.

Real, L. A. and J. H. Brown, editors, (1991). Foundations of Ecology, Ecological Society of America.

Sanchirico, J. N., and Wilen J. E. Bioeconomics of Spatial Exploitation in a Patchy Environment, *Journal of Environmental Economics and Management,* 37: 129-150

Tansley, A. G., (1935). The Use and Abuse of Vegetational Concepts and Terms, *Ecology* 16: 284-307.

Volterra, V., (1926). Fluctuations in Abundance of a Species Considered Mathematically, *Nature* 118:558-60.

Summary of the Q&A Discussion Following Session IV

Amy Ando (University of Illinois at Urbana-Champaign)
Directing her comment to David Brookshire, Dr. Ando said, "Yesterday, Nancy Bockstael made the astute observation that individual decisions, in your case water use—people watering their bluegrass—*don't* tend to feedback directly to them. It seems to me that the *main* method of feedback in your case will be policy—changes in water prices or rules that you can't have bluegrass or at least can't water it. Are you planning on having policy be endogenous in your study?"

Turning to John Tschirhart and David Finnoff and saying that her comment related to a few of the points made by the discussants, Dr. Ando said, "Let me make a quick analogy to economics. It may be profit-maximizing for a farmer to adopt a new cost-saving technology, but if all the farmers adopt the cost-saving technology, the supply curve shifts down and the price falls. I think you had *at least two* such micro but then macro feedback [options] and I can't tell from a 25-minute talk whether you're accounting for them. One, as David mentions, is energy prices. If a seal lion avoids being eaten, that's good for the sea lion—the population rises—but that lowers the energy cost (energy price) of eating a sea lion, so the killer whales may move more to prey upon sea lions. The second one I was thinking about—again, both of your discussants alluded to this, is fitness. Why on earth did we reintroduce wolves into vast parts of the continental U.S.? One argument was that it actually benefits prey populations and improves their fitness. So, if a sea lion avoids being preyed upon, that's good for the sea lion but may be *bad* for the population, because maybe it was a crummy, unfit sea lion that ought to have been eaten anyways. And, do we really want to get rid of all the killer whales? One argument against that might be that it would reduce the fitness of the two prey populations. That may be a hard thing to have data for, but I'm wondering if you can address those kinds of issues."

David Brookshire (University of New Mexico)
Dr. Brookshire first explained that he didn't have a paper prepared for the workshop because his funding came in just a couple of months ago. He then responded to the question by saying, "Nancy's point of view is very interesting. Actually, I see it a little differently than she does. I think at the individual level we don't get feedback on our decisions. Actually, it's not even on our radar—let me give you an example: If you take a 10-minute shower thirty times in Albuquerque using a 2.5-gallon-per-minute shower head (that's a water saver), as a commodity charge that would cost you $1.09. This is spare change in the parking lot." Referring to the decision process involved in pricing water in the West, he went on to say that this level of individual water use is "*not* on our radar, so to speak. However, *collectively*, it *is* on our radar. And this is where you have your stakeholder groups, and again, for instance, if I may use my hometown of Albuquerque, we're very conscious of the fact (and most people actually know this, believe it or not) that we're mining ground water at a rate of approximately 70,000 acre feet per year and that we'll have a short fall in the year 2035. We are *compounding daily* the problem with the collective implications. So, on the one hand, at the individual level

we don't get the signals that we as economists would like people to be seeing. Actually, we're doing some work on experimental estimation of what will happen in terms of urban demand at higher price levels, using both a lab and the water bills for every household in Albuquerque for the last seven years. . . . So, we'll have some idea how people would respond *if* the prices were higher, but if you look at the literature, you don't see that anywhere—you see the traditional administrative cost prices."

Addressing Dr. Ando's question more directly, Dr. Brookshire continued, "In terms of the policy being endogenous, I don't know. I don't know exactly how we're going to do some of this. We have an upcoming meeting with the San Pedro Partnership. To some extent, we have to work with our local folks. How they want us to bring forth the Harvard study and other kinds of things remains to be seen at this point. It's a possibility—it's a good thought—but that's all I can leave you with at this point."

David Finnoff (University of Wyoming)
Dr. Finnoff responded to Dr. Ando by saying, "By the example that you used, let's say we were to cull killer whales. That would lower the predation of the sea lions, and with less predation the population would increase," which would result in increased intraspecies competition among sea lions for *their* food supply. He concluded by saying, "So as the population goes up, the price rises and demand will eventually go down, so you'll have a population growth, but that will then be limited by this intraspecies competition. It's the way that we treat our ecosystem exchanges (or "transfers," as we call them) that allows these threads to be captured."

John Tschirhart (University of Wyoming)
Dr. Tschirhart stated, "We don't make any welfare judgments about what's good or bad with respect to the ecosystem, whether it's good to have this many more sea lions or something like that, other than how it might affect the economy. In fact, we start off with calibrating the ecosystem without any humans whatsoever and call that the natural, steady state. Then we introduce the economy—the economy is not self standing; the economy cannot survive without the ecosystem, because in this case you need the food, whereas the ecosystem does very well without humans." (scattered laughter)

Dan Phaneuf (North Carolina State University)
Posing his question to David Finnoff and John Tschirhart, Dr. Phaneuf said, "The economic general equilibrium model is apparently aspatial, correct?—it assumes that there's perfect integration of markets across space and it abstracts away from the notion that there might be differences across landscape. I thought I'd mention that . . . the ecosystem general equilibrium model is also aspatial in the way you've thought about it thus far, and I think that that's a necessary condition for what you're looking at. I'm wondering what you *lose* from going in that direction. In the economic general equilibrium model we have a good sense of what we'd lose, and we're usually willing to assume that there's the kind of arbitrage that sort of makes prices the same across space. Is that going to be a reasonable assumption in what you guys are looking at, and if not, what are we losing because of that?"

David Finnoff
Dr. Finnoff responded, "Well, we have a little of space, in the sense that we have two legs of the food web in different regions, but *within* those regions, we model" those with no concept of space. In a project I'm working on with Kerry (Smith) right now we are adding space, and so migration" between regions .

Dan Phaneuf
Dr. Phaneuf stated that he saw similar problems between Finnoff and Tschirhart's work and Smith's study in dealing with the space issue. He characterized Finnoff and Tschirhart's work as "using more careful structural modeling that abstracts more from space."

David Finnoff
Dr. Finnoff added, that this relates to the question regarding "whether we're trying to run two kinds of modeling frameworks in a parallel fashion to answer the same kind of question." He said it always comes down to looking at what a potential model "brings to the table that a standard macro population dynamic model doesn't, and vice versa."

John Tschirhart
Dr. Tschirhart clarified, "Basically, you could have killer whales feeding in two different areas, and which area are they going to go to?—They're going to go to where the prices are lower, and when they move from one area to another, they're going to cause those prices to increase and then there's a tendency to move back to the first place." So, there is interaction through price with regards to space.

Nancy Bockstael (University of Maryland)
Offering a follow-up comment on Amy Ando and David Brookshire's exchange, Dr. Bockstael stated, "Actually the system I was talking about yesterday is one in which there *isn't* that strong public feedback. It's where residential development is putting a lot of pressure along the East Coast—water quality, stream ecology, and such—but there isn't any *sense* of that and it's not affecting the housing market *except* to the extent that it *induces* policy responses in some *feeble* effort to reconfigure how the land use changes."

Dr. Bockstael continued, "Concerning your point about policy being endogenous, it seems to me that in *that* context policy *is* endogenous, but there's a long lag. It is such a long lag that it almost doesn't pay to view it as endogenous *except* to the extent that all of the ecologists want to spew out these scenarios over 50 years." She went on to state that these extended projections are senseless exercises because "the structure is going to change in the system so much because of the induced policy changes" that we can't anticipate all the effects and ramifications. She concluded by saying that this is a big difference between the ecologists and economists, who "understand that there will *indeed* be induced policy changes but who really aren't sure what form they would take."

Amy Ando
Dr. Ando commented to David Brookshire: "Considering your idea that people have a collective sense of "Yes, we're drawing down the water"—in a public choice model, that feeds into a policy change. So, I think that these are not entirely different things."

Nancy Bockstael
Addressing John Tschirhart, Dr. Bockstael stated, "It seems to me in my encounters with ecologists that there's a lot of resistance to belief in the equilibrium. I may be wrong, but that's the way I feel. Loosely speaking, when we're thinking about equilibrium . . . we're thinking about it in two ways, really: There's sort of a *market* equilibrium—prices adjust to equate supply and demand . . . but then there's this *steady state* equilibrium in a dynamic system. That's the more interesting part, I think, about the equilibrium in your model—that you're *thinking* in terms of steady state. My sense is that ecologists would say, "Well, we never get there, so why even talk about it?" But shocks aren't infrequent—they're very frequent, and they're environmental shocks. I wonder if you've encountered that criticism and whether there's a way to think about this issue in a way that would be more pleasing to ecologists in terms of introducing random shocks so that you don't have this steady state equilibrium that you characterize in the system."

John Tschirhart
Dr. Tschirhart answered, "Yes, we definitely have gone into that. They don't talk about general equilibrium, of course—they talk about steady states, and they have gone away from the steady state type idea in more recent times. But, we have another model, for example, in which we have just plants. Modeling plants without animals is okay because that's where it all starts. What we do, very simply, is we have temperature as the random variable, so the system is constantly being jostled from heading toward one steady state to another. That seems somewhat satisfying, so we *are* trying to bring that into account."

Stephen Swallow (University of Rhode Island)
Also addressing David Finnoff and John Tschirhart, Dr. Swallow commented, "When I looked at your paper in the Journal of Biological Theory a while ago, I had some questions about capturing the *intra*specific competition for prey and I wondered whether you were capturing *inter*specific data. As an analogy, when you have a lot of firms, they are all competing for the same labor pool, whereas in the ecology model you showed us today it appeared that the consumers of prey were competing "within their own industry" for that prey, but not necessarily between the two species for the same prey. As you go to looking at a larger number of species, I imagine that an extra level of detail would enter in." He closed by asking whether the researchers had "any insights as to whether that's actually going to be a significant problem in your next modeling step and, if it is, how you might handle it."

John Tschirhart
Dr. Tschirhart replied, "That's a really good observation—we've thought about doing it both ways. The issue would be, for instance, if you have, as we do in our expanded model," a predator preying not just on one but on two species. He stated that this raises the issue of deciding whether it's one market—in which the predator is paying one price for the two different species—or two markets. Dr. Tschirhart clarified that "in economics, it would be just one market—one price for both." He added, "We didn't do that because it just seemed to work better in the simulations to have separate markets between each pair of species, but it's a good question." He acknowledged, though, that it would be reasonable to make it one price because the price is actually measured "per kilogram of fish flesh," thereby eliminating any species size differential that would influence species-specific prices. Dr. Tschirhart closed by saying that they are continuing to look at both options and haven't determined yet which is preferable. He added that they hadn't yet talked to ecologists about the details of this issue because ecologists "are so unused to seeing this whole methodology that getting down to those kinds of details just hasn't happened yet."

Kerry Smith (North Carolina State University)
Dr. Smith commented, "We didn't get much of a look at the utility function on the economic part of the model and this is sort of a detailed question: Is the value derived from recognition separable or non-separable from the quantity and type of species of fish? In other words, what I'm looking for is a feedback effect, such that the rate of leisure choice associated with looking is influenced by the availability of these species to look at." He said when you put that feedback back in, "you get a couple of different loops in the model that connect the economic structure with the biological structure."

David Finnoff
Dr. Finnoff responded, "No, it's not like that right now. . . . Essentially, this was our test model . . . One thing I'd like to say, though, is that our leisure choice is essentially regulator determined in this model."

Will Wheeler (U.S. EPA/NCER)
Dr. Wheeler said he didn't have a question but wanted to clarify something for the audience, and he commented, "It's part of the STAR Grant policy that all grantees come in once a year to present their work and we have violated that policy. That's why when we have a conference on ecovaluation, we have all our ecovalution grantees come in. That's why, although David's grant was just awarded this year, we still had to make him come in so we don't violate our policy quite so bad as we have. Actually, the other two grantees work began only last year, so that's why we're seeing work in progress—we're still trying to tweak everything. We appreciate everyone's work.

Bob Reilly (Virginia Commonwealth University)
Dr. Reilly stated, "I'm still a little bit troubled with these energy prices in the general equilibrium model. It seems to me that the way things are at the moment these prices are just market-clearing prices affecting differences in excess demand. In point of fact, really, these energies are functional relationships. Some of them are easily movable, possibly, and others move as a result of density interactions in the species. It's nothing like moving the market-clearing prices in the economic market. It's hard for me to believe that an ecologist is going to sign off on this kind of a view of moving energy prices when they are very well aware what it takes to handle and absorb this energy price is very different from the movement of an energy price when in fact you have to worry about spatial issues and search costs and a lot of things that appear to be central in this problem. . . . Those relationships are difficult to nail down and the literature is very poor on how does energy cost vary as a result of density effects. As far as I know, there's not a lot of good development literature there. . . .

David Finnoff
Dr. Finnoff answered by saying, "I definitely agree. One thing in our model is that our respiration function is a physiological function that really governs the transfer of energy into heat production and whatnot. So, a lot of what you're talking about takes place within our respiration function itself. What we think is unique about this energy price rate is that the system together helps determine outcomes—and not just a functional relationship for one species to another, but there's something that's endogenous to the interactions of all these individuals. That's really what we add to the table here, because there are input-output kinds of models in ecology. But, we think that this system-wide interaction is important and that's what these prices are allowing us to bring to the table."

David Brookshire
Dr. Brookshire said, "I can't let this issue on policies go. . . .This is like saying, "let the market do it. What market? What does it look like?"—these kinds of things. We use the phrase "heterogeneous preferences" in economics. That takes on *real* meaning when we look at water issues in the West—line everybody up and you'll get 2x number of ideas. So, when we talk about policies, we're really talking about *chipping* at the market, and Nancy (Bockstael) alluded to that." He used an example of putting in low-flow toilets only to discover that everyone then double-flushes and water consumption goes up—or installing low-flow shower heads, and then everybody takes longer showers. Dr. Brookshire went on to say that "we haven't really come up with a set of systematic policies that account for the human behavior side of this issue. We would like to see prices raised, which is a popular and unpopular thing to say, depending on who you speak with. Our typical policies are short-term: we ration; we jawbone through conservation; we don't raise prices, even though we should—the reason I gave you that commodity chart is to give you a clue as to just how cheap it really is. So, it's not clear what to do in the San Pedro area. In fact, it is *very clear* that if you go to the San Pedro area and you ask, "What should be the water policy?" you will get *multiple* answers, and that's why it's so difficult and why the San Pedro Partnership exists."

Dr. Brookshire said that they are looking for “some guidance from this group” (the San Pedro Partnership) because they “need some anchor so that we’re not discredited for “inventing” things, if you will—we’re going to have to get some buy-in. But to think that there’s going to be *a* water policy for the San Pedro region is mythical” and he said this is true for the West, in general.

In closing, Dr. Brookshire commented, “The *one* area that we are making progress in is what we all know as “water banking”—the institution of re-allocating water on a spatial and temporal basis, where we don’t actually have to trade the property rights and so don’t run into adjudication problems. We are making progress in getting *better use* of what we have through these institutions, and various states are interested. That’s one of the *few* kind of global policies that everybody seems to be *at least* willing to talk about.”

END OF SESSION IV Q&A