Theme: Application Fields and Integrated Coastal Zone Management
Sub-Theme: Environmental Conservation
Kind of Presentation: Oral

BIODIVERSITY, FOCAL SPECIES AND ISLAND BIOGEOGRAPHY ON THE CENTRAL COAST OF BRITISH COLUMBIA, CANADA: A GIS APPROACH

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Geographic Information Systems (GIS) and Remote Sensing (RS) technologies are extremely useful tools in conservation planning (Poiani et al. 2000). Modelling of species distribution and abundance using GIS and RS applications are valuable for delineating areas of conservation concern, and often are used to identify and predict regions of biodiversity importance (Prasad et al. 1998, Debinski et al. 1999, Lenton et al. 2000). The use of these applications in biodiversity assessment and modelling within a coastal environment is however, not fully explored and presents a unique challenge for analysis. Species in island archipelagos may move between islands and use the entire archipelago system, which requires the integration of land and ocean characteristics to adequately represent all elements of a species habitat. The configuration of islands (or the spatial layout of the islands) must also be included in analysis to account for factors that may affect island-to-island travel. GIS and RS enable us to efficiently combine all these influential factors and model the relationships between coastal physical characteristics and species distribution and abundance. The predictive capability of GIS also allows us to determine areas of critical species habitat in unsampled areas, providing vital information for conservation planning.

The British Columbia (BC) Central and North Pacific Coast (NPC) in Canada offers the opportunity to examine the use of GIS in coastal species modelling and conservation planning. Our study region encompasses the island archipelago between the northern tip of Vancouver Island and Prince Rupert, BC (55• 37'N, 129• 48'W), and covers approximately 29 700 km^2, of which 19 300 km^2 is land (Figure 1). The area is bounded by the Coast Mountains to the east and the Pacific Ocean to the west. Coastal temperate rainforest dominates, forming part of the most extensive habitat of this type left in the world (MacDonald and Cook 1996). Climate is temperate and wet; most areas receive upwards of 350 cm of annual precipitation.

There are few human settlements consisting primarily of First Nations people. Human disturbance and development is minimal, resulting in a nearly pristine landscape. However, mainland logging has occurred and is proposed for areas throughout the study region. Oil and gas exploration also is expected to commence in the near future. The study region, combined with southeastern Alaska, supports the highest endemic species concentration for the temperate rainforest region of Pacific North America (Cook and MacDonald 2001). This region is a unique and diverse landscape and is of immediate conservation concern as biodiversity and focal species research has not been fully conducted in the area.

The nearly pristine nature of our study area allows us to examine the effects of natural fragmentation on species distribution and abundance and to explore island biogeography theory. According to the theory of island biogeography, we expect greater biodiversity on larger islands that are less isolated, particularly for poor dispersers such as terrestrial mammals, to whom water channels pose a significant barrier to movement (versus highly vagile animals such as birds or marine mammals). Although few in number, other biogeographic studies focused on the NPC, have found island isolation to be a significant factor in determining species presence and diversity (Craig 1990, Conroy et al. 1999, Nagorsen and Keddie 2000). None of these studies however, have examined island biogeography theory in a spatial context. Island area, isolation, shape and configuration may interact to affect species diversity and should be examined within a spatial framework. Our study area is unique as it explores these spatial interactions, using the GIS environment.

In addition to spatial factors, island biodiversity is affected by physical characteristics of an island's landscape. Island attributes such as elevation, slope, aspect, topography, vegetation type and human development can alter the amount of available habitat for species. Islands with large spatial areas may appear to support high diversity, but may consist of primarily unsuitable habitat. High slope and high elevation mountainous terrain can be unproductive habitat, as can areas under human development or alteration. Plant assemblages and vegetation type can affect species presence through resource availability. Characteristics of water channels between islands may influence species movement through the landscape; tides, sea floor depth, water temperature and current strength may hinder travel between islands.

The presence of a particular species also may affect biodiversity. Focal species (i.e. species that represent an ecosystem) play an important role in ecosystem-based conservation by indicating system health (indicator), affecting ecosystem structure and/or function (keystone), protecting a multitude of other species by virtue of their large home range (umbrella), or through public recognition (flagship) (Simberloff 1998). Research has identified salmon (*Oncorhynchus* spp.), bear (*Ursus arctos*), and wolf (*Canis lupus*) as focal species for our study region (Darimont and Paquet 2001). Spawning pink and chum salmon comprise a significant portion of diet for bear and wolf as well as many other mammal species. Salmon are critical to the functioning of the coastal ecosystem and are very important in nutrient cycling (Darimont *pers. comm*. 2003). Bear and wolf can indirectly affect system biodiversity through prey population control (Terbough et al. 1999), which is particularly apparent in resident wolf populations whose main prey species are black-tailed deer (*Odocoileus hemionus*). If wolves were removed from the system, escalating deer populations could result in the exclusion of deer competitors vying for the same resources (Darimont and Paquet 2001). Likewise, the exclusion of deer competitors may alter species composition and richness, and overall diversity. Predator species such as bear, wolf, cougar (*Felis concolor*) and wolverine (*Gulo gulo)* also indirectly affect diversity through competition for similar resources and the possibility of competitive exclusion.

The purpose of the present paper is to examine the effects of island biogeography, physical island characteristics, and focal species presence on island biodiversity with the use of GIS. We predict that larger, less isolated islands that are more productive and less disturbed will support greater species diversity. Moreover, we anticipate that island-level topographic features will limit mammalian diversity. We also expect that average tidal displacement, current speed and sea depth of the intervening matrix may limit island colonization, resulting in detectable differences in endemic species diversity. Predictive models will be built in GIS using presence/absence data (indicating high biodiversity). Such models may be extrapolated to the entire region to isolate centres of high biodiversity for management and conservation planning, which are imminent due to human development pressure in the region.

Methods

Data for analysis were taken from a variety of sources including previous research, field collection and observation, and from existing or derived digital databases. At the time of analysis, several potentially important independent variables were not ready for inclusion. Ocean characteristic data, such as tide cycles, current speed and direction, sea floor depth and surface temperature, are to be included in future analyses, as is solar insolation. Anthropogenic disturbance is presently of minimal impact and was excluded, but may be influential on mammalian diversity as development increases. Hence, this paper explores the use of GIS in modelling biodiversity of our coastal study area and reports results solely for mammalian diversity, using independent variables that were sufficiently developed at the time of this analysis.

Diversity (or richness) of mammalian species was integrated using surveys reported by Craig (1990) and augmented with field observations from surveys conducted between 1999 and 2002 (Darimont and Paquet 2003). Data was available for 22 islands within the study area. Species presence was defined by scat, tracks, markings or direct observation. The dataset was split into high or low diversity to create a dichotomous response variable for use in logistic regression analysis and to allow formation of a predictive GIS surface. Islands were considered to have either high biodiversity (>=12 mammal species and assigned a value of 1), or low biodiversity (<12 species and assigned a value of

0). We selected the biodiversity threshold based on the median number of species and acknowledge this is arbitrary. Mammal diversity was georeferenced to corresponding islands on a digital map of the study area, created from a 50m resolution Digital Elevation Model (DEM) in ArcView3.2.

Independent variables that were included in analysis are listed in Table 1. Island area and shape index were calculated from the study area digital map derived from the DEM. Shape index (SI) was calculated according to the formula: SI = [{0.25(perimeter)}/ •(area)) where 0.25 accounts for square pixel shape. Island distance to mainland, and island distance to the nearest island greater than 75km^2 variables, were taken from Darimont and Paquet (2003) and where data did not exist, were directly measured from the digital study area layer. Maximum and minimum curvature measures were used to represent the interaction of elevation, slope and aspect and were calculated directly in IDRISI32[1].

Salmon presence data for pink and chum species, was derived from line shape files provided by the British Columbia Fisheries Department Inventory database (FISS). Pink and chum estuaries were truncated to 500m inland from the mouth of the river as salmon have not been observed to spawn at greater distances inland (Darimont *pers comm*. 2003). Islands were then classified according to the presence of pink and chum salmon; if salmon streams were present on the island, a value of 1 was assigned, if no streams existed, a value of 0 was assigned. Wolf presence data was collected on transects in spring, summer, and fall between 1999 and 2002 (Darimont and Paquet 2003), and was determined by scat occurrence, track presence, and observation. Predator diversity included brown and black bear, cougar, wolverine, and wolf species, and was extracted from the diversity dataset as was the deer, black bear and brown bear presence data.

Island data were extracted from each spatial layer using a module extension in ArcView3.2. Correlation analyses were run on all variables; those with an r^2 value greater than or equal to 0.7 were considered correlated. Logistic regression and Akeike's Information Criterion (AIC) were used to eliminate the need for a significance cut-off value, as traditional hypothesis testing techniques require a definition of a p-value to determine acceptance or rejection of a null hypothesis. Selection of a p-value is often arbitrary (0.05 or 0.01 is often used) and may not reflect biological significance of the phenomena being tested (Burnham and Anderson 1998). AIC however, provides a measure of the degree of truth each model represents and selects the best approximating model according to the goodness of fit (log likelihood or '2LL'), and model complexity (number of parametres or 'k'). AIC also corrects the models for sample size and ranks each model according to the probability that a specific model best represents the process of interest, within the group of potential models (Burnham and Anderson 1998). Thirty-two potential models were compiled based on prior hypotheses and various investigatory variables.

Preliminary Results

Significant correlations ($p = 0.000$) were found to exist between 8 sets of independent variables. Predator diversity was correlated positively with black bear ($r^2 = 0.781$) and brown bear presence ($r^2 = 0.722$). Distance to mainland was positively correlated with distance to islands >75 km^2 ($r^2 = 0.940$) and negatively with wolf and deer presence ($r^2 = -0.718$, $r^2 = -0.751$ respectively). Maximum and minimum curvature were negatively correlated ($r^2 = -0.999$). Chum salmon presence was positively correlated with pink salmon and wolf presence ($r^2 = 0.896$, $r^2 = 0.770$ respectively). Correlated variables were not included together in any individual model.

Results for the AIC analysis are shown in Table 2 and the top five individual logistic regression models in Table 3. Five top models were selected as together they explained 72% of the variability. Island distance to mainland was the best-fit model with a probability of 24.5%. The second rank model consisting of island area and distance to mainland variables, had a probability of 18%. A probability of 11% was returned for the third ranked model, which included distance to mainland, area, and shape index variables. The fourth rank model had a probability of 9.6% and included area and "distance to islands greater than 75km^2" variables. This model however, was very similar to the second ranked

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[1] IDRISI help notes on the curvature algorithm indicate that it is based on that from G.J. Pellegrini's 1995 document, "Terrain Shape Classification of Digital Elevation Models using Eigenvectors and Fourier Transforms, UMI Dissertation Services". For further information on the IDRISI curvature calculation, please refer to the CURVATURE help notes in the IDRISI32 program.

model and was excluded from further analysis as the variable “distance to islands greater than 75km^2“ was highly correlated to the “distance to mainland” variable. The fifth rank model returned a probability of 9.0%, and included distance to mainland and pink salmon presence. For all best-fit models, distance to mainland had a weak negative relationship with presence of high mammal diversity. Shape index and pink salmon presence were positively related to high mammal diversity.

Discussion

The results from this pilot study indicate that the greatest influence on island mammalian diversity in our study area is distance to the mainland. From a biogeographic perspective, this is expected. Island biogeography theory as described by MacArthur and Wilson (1967), states that the equilibrium of species richness (or the number of species) on an island is related to immigration and extinction rates. For species that are poor dispersers, immigration rates are expected to be greater for islands closer to a population source than islands further away. In the same manner, islands that are closer to a source population are expected to have more resilience to species extinction rates. Higher immigration rates and moderated extinction rates will result in greater numbers of species on islands that are closer to a population source. The relationship between mammal diversity and distance to the mainland for this archipelago system, reflects the relatively poor dispersal abilities of the mammals included in our diversity counts. A biogeographic study conducted in SE Alaska on the Alexander Archipelago, directly north of our study area, found isolation to be the primary factor affecting species richness (Conroy et al. 1999). Island isolation was also indicative of Mountain Goat (*Oreamnos americanus*) presence on 13 islands distributed along the NPC (Nagorsen and Keddie 2000). Patterns of mammalian species richness along the NPC may be related to recent deglaciation and as such are highly dependent on species colonization (Conroy et al. 1999). Island isolation therefore, would be expected to be an important predictor of species diversity in our study area.

It was expected that larger islands would support higher species numbers because of more available resources. This expectation was supported by a small, yet positive relationship between these two variables. The positive relationship between shape index and high diversity in the third model did not support the area hypothesis: higher shape index values indicate islands with more convoluted coastlines and less area according to the perimeter-to-area relationship used in the shape index calculation. More spherical islands with smaller perimeters would maximize island area. However, it is possible that more convoluted shorelines offer more points of initial contact and colonization of islands.

The positive relationship between pink salmon presence and high mammal diversity was expected. The coastal ecosystem is highly dependent on spawning salmon as they provide a valuable food source for carnivores and are a keystone species for the system (Darimont and Paquet 2001). The presence of salmon in the coastal system is integral to ecosystem function through nutrient cycling. Salmon carcasses are an extremely important source of nitrogen and phosphorous, providing essential nutrients for phytoplankton and green algae growth in coastal freshwater lakes and estuaries (Reimchen 2002). Nutrients released from salmon remains also contribute to vegetation growth (Darimont and Paquet 2001) providing resources for herbivores and subsequently, prey for carnivores. It is also expected that salmon abundance is related to mammal diversity, however, this still remains to be investigated.

Several potential sources of error within the datasets and methods of analysis may have affected our model results. Although independent variables were included in models to avoid multicollinearity, the selection of a correlation value of 0.7 as a cutoff, is somewhat arbitrary in nature. Model compilation using a correlation value cutoff substantially less than 0.7, may yield different results. The division of species diversity into high and low diversity may also alter the resulting models and we would suggest altering the threshold to examine other hypotheses. Inherent error in the DEM and digital spatial layers may also skew results and should be accounted for in future analyses. Furthermore, inclusion of ocean and anthropogenic characteristics as well as more complex island configuration metrics in analysis may generate different results.

Due to the small sample size of islands with diversity values, our final models were not verified to allow inclusion of all data in model compilation. Verification of GIS models to be used for conservation planning is essential and should be conducted to highlight any potential error within the models.

Future Initiatives

These preliminary results are encouraging and reveal the potential and usefulness of GIS application in coastal ecosystem research. Inclusion of coastal attributes such as ocean floor depth, tidal cycles, current strength and direction, and water temperature, will reflect possible constraints on species movement between islands and can be derived from spatial imagery. More detailed island configuration metrics such as island density and more complex isolation measures will be produced in GIS. Measures of vegetation heterogeneity will be derived from DEM and LANDSAT imagery using a moving window analysis to obtain average complexity values for each island. Furthermore, focal species predictive modelling will be undertaken and used in conjunction with the diversity models to isolate areas of biological importance. Verification of the model created in this study as well as future models, is essential before use in any conservation management plan. Receiver Operating Characteristic (ROC) curves will be used for verification purposes, using a subset of data that did not contribute to model development.

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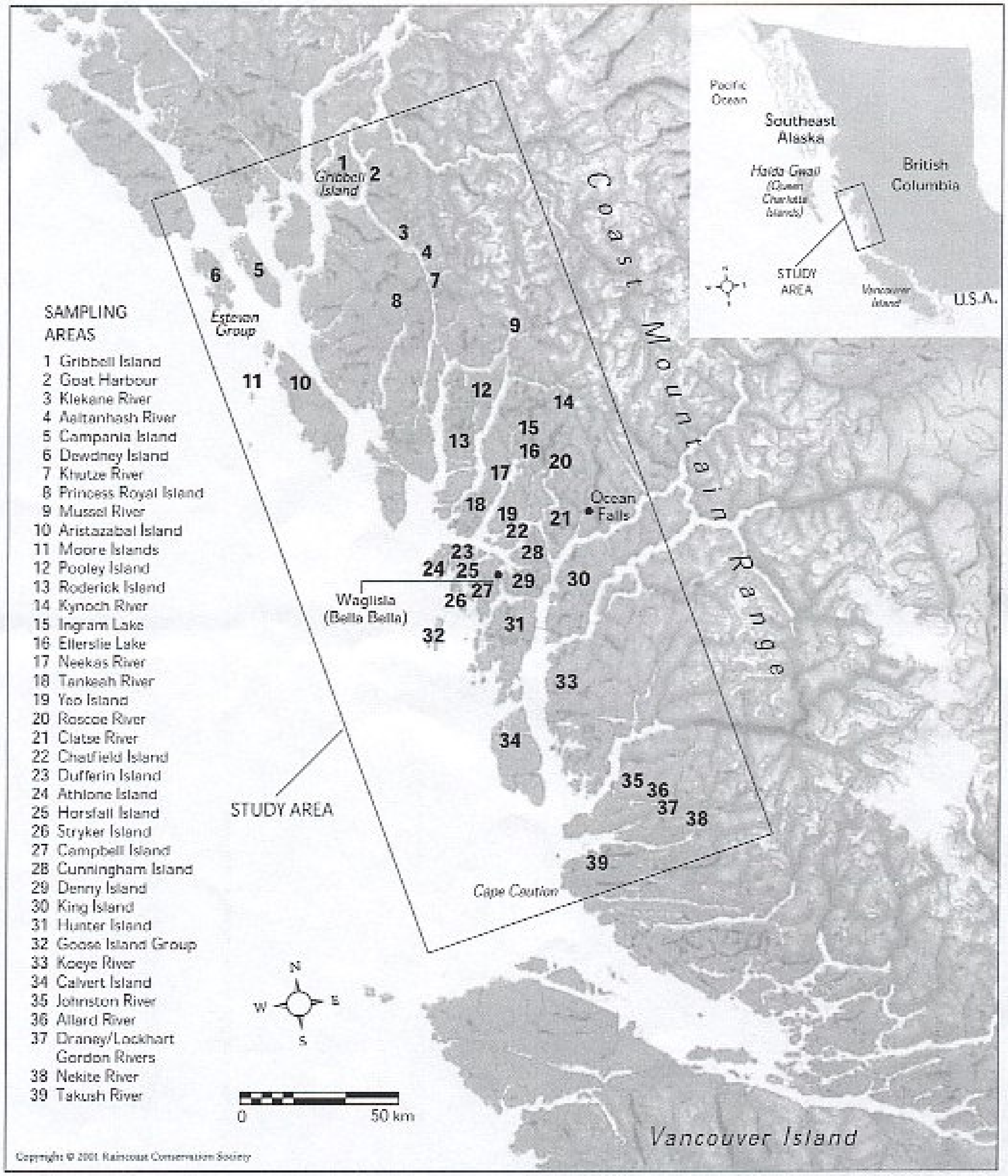

Figure 1: Study area: Pacific coast of British Columbia, Canada (Darimont and Paquet 2001).

Table 1: Dependent and independent variables used in logistic regression and AIC analysis.

Variable	Source
Dependent	
Mammalian Island Diversity	Craig (1990), (Darimont *pers comm.* 2003)
Independent	
Island Area	DEM
Island Shape Index	DEM
Island Distance to Mainland	Darimont and Paquet (2003), DEM
Island Distance to Closest Island >75 km^2	Darimont and Paquet (2003), DEM
Maximum Curvature	DEM
Minimum Curvature	DEM
Chum Salmon Presence	FISS
Pink Salmon Presence	FISS
Wolf Presence	Darimont and Paquet (2003)
Predator Diversity	Mammalian Island Diversity database
Deer Presence	Mammalian Island Diversity database
Black Bear Presence	Mammalian Island Diversity database
Brown Bear Presence	Mammalian Island Diversity database

Table 2: AIC ranking of potential models with log likelihood (2LL), complexity (k), sample size (n), and weight of evidence (wi) values.

Rank	Model	Model Variables	2LL	k	n	wi
1	11	distance to mainland	17.134	2	22	0.244826607
2	17	area, distance to mainland	15.754	3	22	0.17956733
3	21	area, shape, distance to mainland	14.735	4	22	0.109952696
4	18	area, distance to 75island	17.005	3	22	0.09606742
5	24	distance to mainland, pink	17.134	3	22	0.090066675
6	1	area, shape, distance to mainland, maxcurve, chum	11.455	6	22	0.076711393
7	19	area, chum, distance to 75island	16.916	4	22	0.036949431
8	20	area, pink, distance to 75island	16.964	4	22	0.036073201
9	10	distance to 75island	21.128	2	22	0.033233229
10	2	area, shape, distance to mainland, maxcurve, pink	14.334	6	22	0.018184148
11	32	preddiv	22.616	2	22	0.015792738
12	3	area, shape, distance to mainland, maxcurve, chum, brown bear, black bear	10.994	8	22	0.013073016
13	7	area, shape, distance to 75island, maxcurve, chum	15.328	6	22	0.011062381
14	6	area, shape, distance to 75island, maxcurve, pink	16.078	6	22	0.007603056
15	27	area, brown bear	23.123	3	22	0.004508887
16	4	area, shape, distance to mainland, maxcurve, pink, brown bear, black bear	13.525	8	22	0.003687874
17	30	shape, maxcurv	23.735	3	22	0.003320284
18	14	pink	25.773	2	22	0.003257794
19	25	area, preddiv, wolf pres	22.512	4	22	0.002251395
20	12	maxcurve	26.85	2	22	0.001901324
21	16	area, pink	25.043	3	22	0.001726421
22	23	maxcurve, pink	25.205	3	22	0.001592094
23	8	area	27.222	2	22	0.001578619
24	13	chum	27.513	2	22	0.001364858
25	29	maxcurve, wolf pres	25.994	3	22	0.001073098
26	22	maxcurve, chum	26.108	3	22	0.001013642
27	26	area, wolf pres	26.251	3	22	0.000943697
28	15	area, chum	26.285	3	22	0.00092779
29	9	shape	29.207	2	22	0.000585113
30	31	shape, chum	27.208	3	22	0.000584821
31	5	area, shape, distance to 75island, maxcurve, pink, brown bear, black bear, wolf presence, deer presence	14.248	10	22	0.000347688
32	28	area*distance to mainland	29.664	3	22	0.000171281

Table 3: Equations for the top five models from AIC analysis.

Model Rank	Equation
1	(High Diversity) = 3.317 – 0.001(DISTMAIN)
2	(High Diversity) = 2.482 – 0.001(DISTMAIN) + 0.000(AREA)
3	(High Diversity) = 1.188 – 0.002(DISTMAIN) +0.591 (SHAPE) +0.000(AREA)
4	(High Diversity) = 0.894 – 0.002(DIST75) +0.000(AREA)
5	(High Diversity) = 3.298 – 0.001(DISTMAIN) + 0.17(PINK PRESENCE)