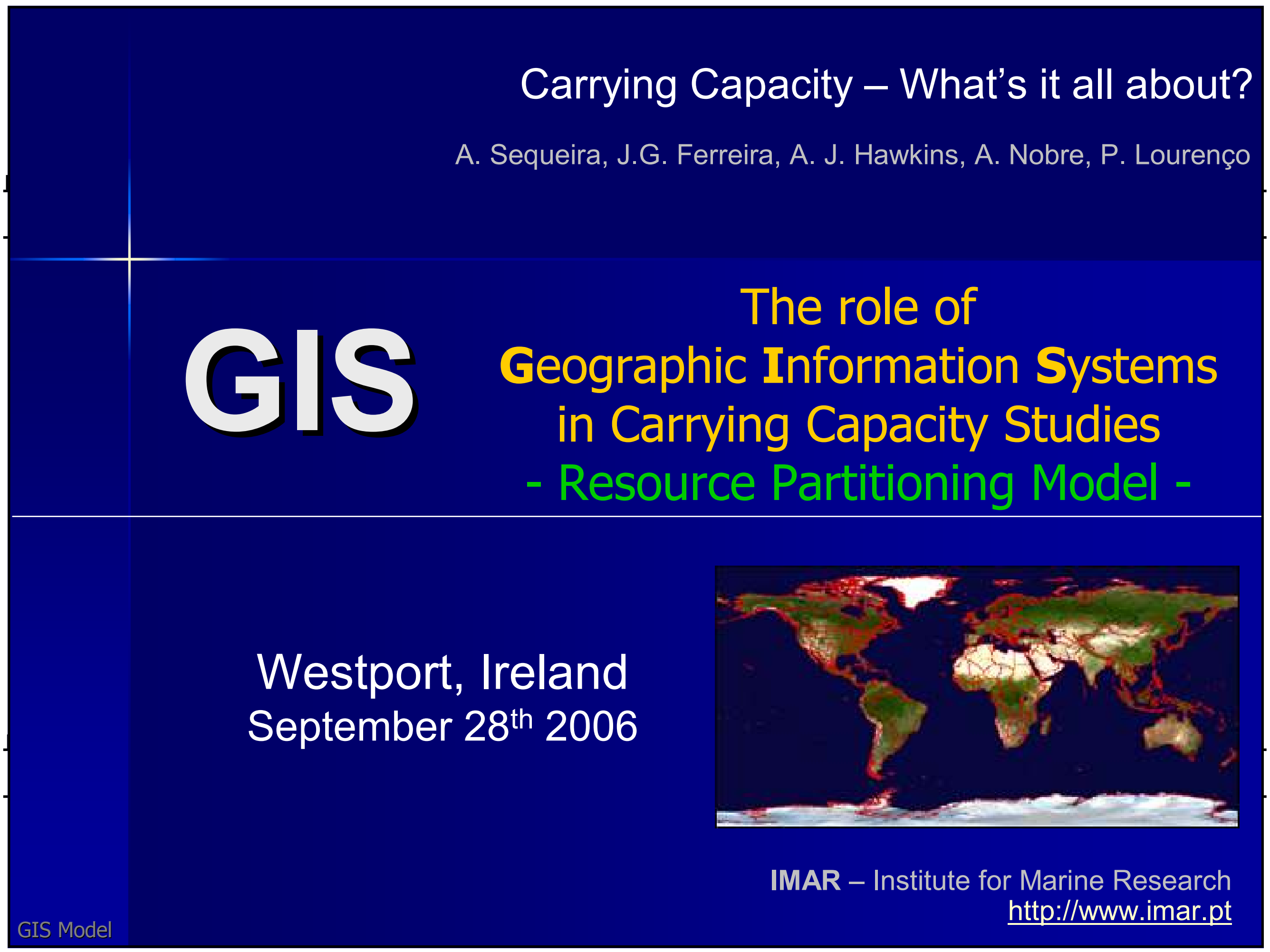
Carrying Capacity – What's it all about?
A. Sequeira, J.G. Ferreira, A. J. Hawkins, A. Nobre, P. Lourenço
GIS
The role of
Geographic Information Systems
in Carrying Capacity Studies
- Resource Partitioning Model -
Westport, Ireland
September 28th 2006
IMAR – Institute for Marine Research
http://www.imar.pt
GIS Model

Notes:

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Wild species - Resource Partitioning Model

TOPICS

GIS Model

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Wild species - Resource Partitioning Model

Rational
- Carrying capacity

- **Physical Carrying Capacity - the total area of marine farms that can be accommodated in the available physical space**
- **Production Carrying Capacity - the stocking density of bivalves at which harvests are maximized**
- **Social Carrying Capacity - the level of farm development that causes unacceptable social impacts**
- **Ecological Carrying Capacity - the stocking or farm density which causes unacceptable ecological impacts**

(Inglis et al, 2000)

GIS Model

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Wild species - Resource Partitioning Model

Key objectives
Resource Partitioning Model

1. Determine baseline food requirements for maintaining benthic biodiversity in a natural system;

2. Improve accuracy of carrying capacity modelling of cultivated species by appropriately partitioning the food resource (phytoplankton and POM) between wild and cultured species;

3. Establish an upper threshold for shellfish aquaculture development scenarios in order to assure the maintenance of wild populations;

GIS Model

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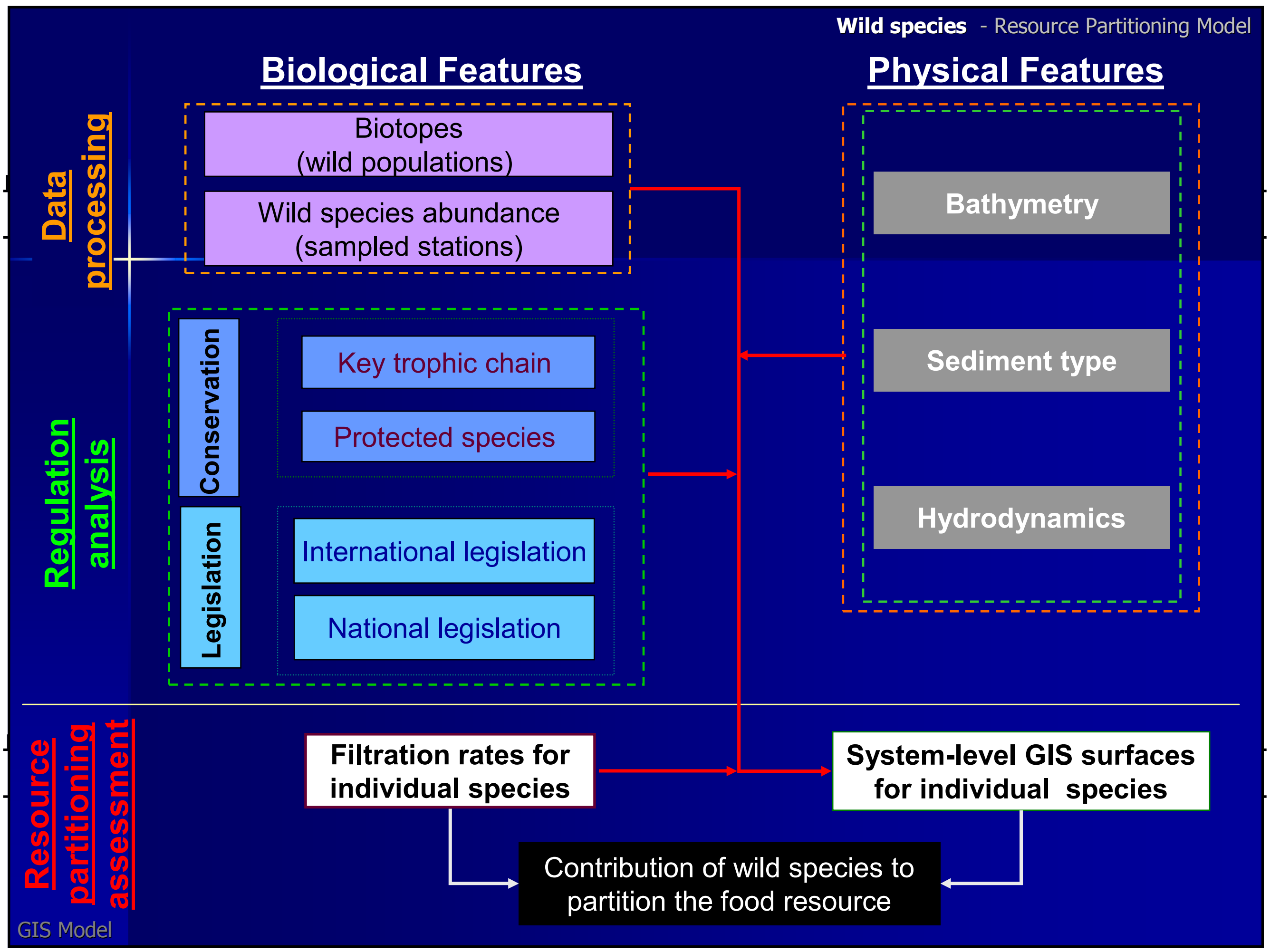
Wild species - Resource Partitioning Model
Biological Features
Physical Features
Data processing
Biotopes (wild populations)
Wild species abundance (sampled stations)
Bathymetry
Sediment type
Hydrodynamics
Regulation analysis
Conservation
Key trophic chain
Protected species
Legislation
International legislation
National legislation
Resource partitioning assessment
Filtration rates for individual species
System-level GIS surfaces for individual species
Contribution of wild species to partition the food resource
GIS Model

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Wild species - Resource Partitioning Model

General Approach

Data processing

- **Spatial distribution of the ecosystem features**
  - Ecosystem biotopes / habitats;
  - Sediment types;
  - Bathymetry.
- **Interpolation of wild species data**
  - Stations with quantitative data on wild species abundance;
  - IDW (Inverse Distance Weight): Interpolation method assuming that each station has a local influence that diminishes with distance;
  - For each species the interpolation area shall correspond to the area containing the typical type of sediment where the species are found.
- **Production of results**
  - GIS statistical analysis is used to determine the abundance of each wild shellfish species in any part of the ecosystem.

GIS Model

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Wild species - Resource Partitioning Model

General Approach
Regulation analysis

- Identify key species within the ecosystem trophic chain:
  - Species in danger of extinction;
  - Species with conservation interest (autochtonous and not easily found elsewhere);
  - Identify the possibility of intra or interspecific competition occurence with the increasing number of species cultured.

GIS Model

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Wild species - Resource Partitioning Model

General Approach

<u>Resource partitioning assessment</u>

- Volume cleared per day by wild species:

$$\sum_{i=1}^{n} (\text{Species } i \times \text{ Clearance rate } i)$$

- Number of days to filter the lough:

$$\frac{\text{Ecosystem Volume}}{\text{Volume cleared per day}}$$

GIS Model

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Wild species - Resource Partitioning Model

General Approach
Resource partitioning assessment

- Baseline food requirements:

Phytoplankton biomass cleared by wild species — $V_{cleared}$ x Chl *a*

Particulate organic mass cleared by wild species — $V_{cleared}$ x POM

- Food removal from the ecosystem:

$[\text{Chl } a - \Sigma(\alpha_i \text{PB})]$ & $[\text{POM} - \Sigma(\gamma_i \, POM_F)]$

α_i, γ_i - fraction of phytoplankton biomass and POM, respectively that species *i* actually remove from the ecosystem

GIS Model

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Wild species - Resource Partitioning Model
A. Sequeira, J.G. Ferreira, A. J. Hawkins, A. Nobre, P. Lourenço
Loch Creran: Model Results
GIS Model

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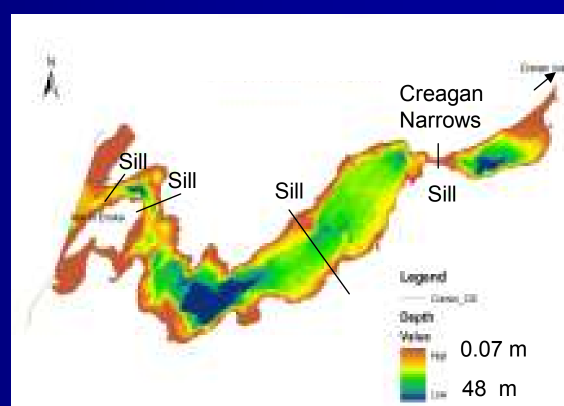
Wild species - Resource Partitioning Model

Loch Creran - Data processing

Physical characteristiscs	Loch Creran
Volume ($10^6 m^3$)	240
Total area (km^2)	15
Maximum depth (m)	48
Catchment area (km^2)	164
Temperature range (ºC)	6 - 15
Mean salinity	30 - 33
Flushing time (days)	6

Loch Creran



Black et al, 1999

GIS Model

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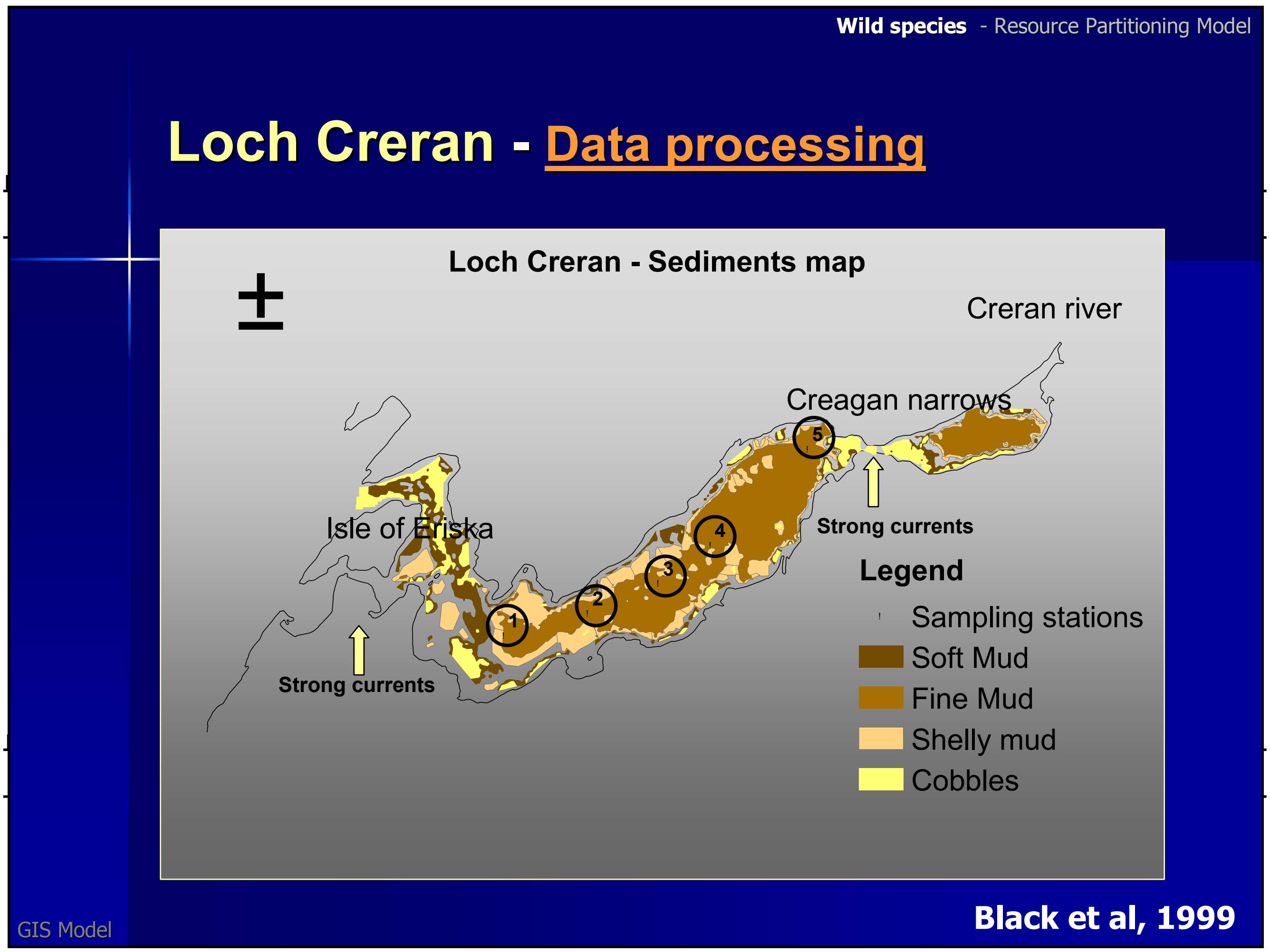
Wild species - Resource Partitioning Model
Loch Creran - Data processing
Loch Creran - Sediments map
Creran river
Creagan narrows
Isle of Eriska
Strong currents
Strong currents
1
2
3
4
5
Legend
Sampling stations
Soft Mud
Fine Mud
Shelly mud
Cobbles
Black et al, 1999
GIS Model

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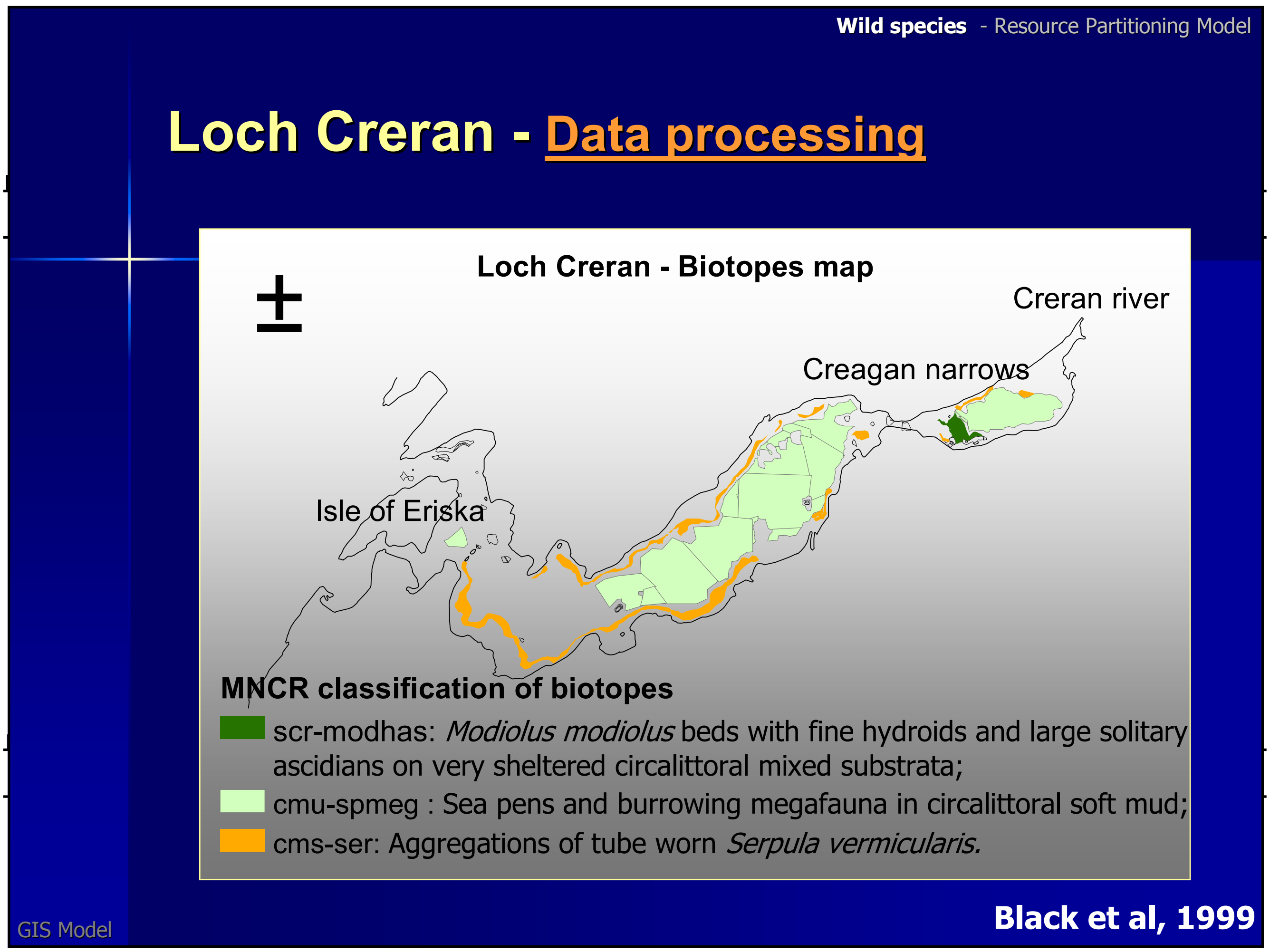
Wild species - Resource Partitioning Model
Loch Creran - Data processing
Loch Creran - Biotopes map
Creran river
Creagan narrows
Isle of Eriska
MNCR classification of biotopes
scr-modhas: *Modiolus modiolus* beds with fine hydroids and large solitary ascidians on very sheltered circalittoral mixed substrata;
cmu-spmeg : Sea pens and burrowing megafauna in circalittoral soft mud;
cms-ser: Aggregations of tube worn *Serpula vermicularis.*
Black et al, 1999
GIS Model

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Wild species - Resource Partitioning Model

Loch Creran - Data processing

Species \ Stations	Depth (m)	Sediment type
Abra sp.	-	-
Abra alba	0 – 70	Muddy substrate
Abra nitida	0 – C. depths	Muddy sand and gravel
Aequipecten opercularis	-	-
Circomphalus casina		Coarse sand and shell gravel
Corbula gibba	-	Muddy sand and gravel
Dosinia exoleta	0 – 100	Muddy or shell gravel
Gari fervenses	-	-
Hiatella artica	0 – 50	Soft rock and shells
Mya truncata	0 – 70	Mixed sand, sandy mud or gravel substrata
Myrtea spinifera	-	-
Mysella bidentata	-	Muddy sand or fine gravel
Mysia undata	-	-
Modiolus modiolus	0 – 280	Soft sediments or attached hard substrata
Nucula nitidosa	Bottom	Fine sand, sandy mud and silt
Parvicardium scabrum	-	-
Phaxas pellucidus	to 100 m	Fine mixed sand
Thyasira flexuosa	-	Muddy sand or fine gravel

GIS Model

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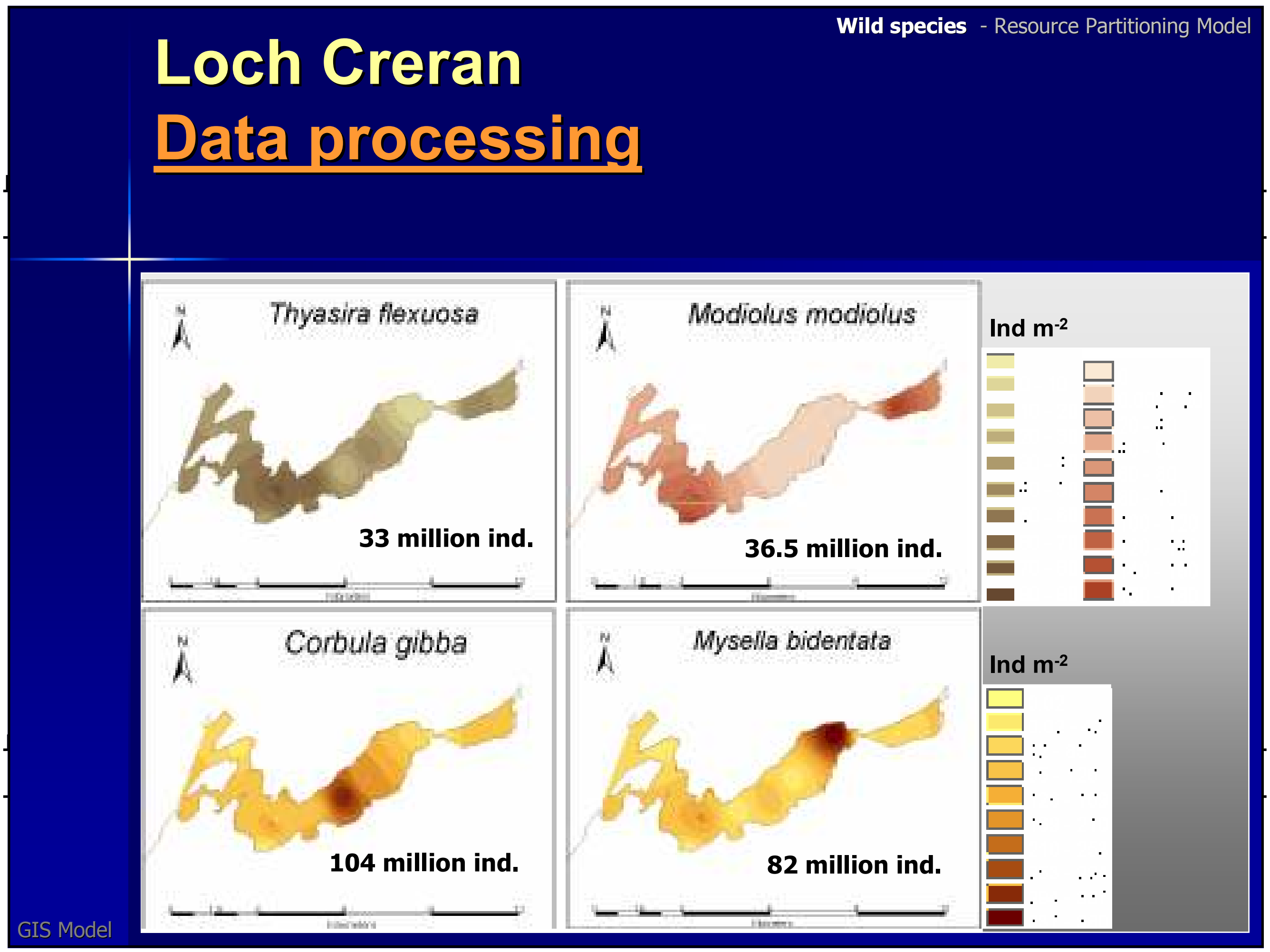
Wild species - Resource Partitioning Model
Loch Creran
Data processing
Thyasira flexuosa
33 million ind.
Modiolus modiolus
36.5 million ind.
Corbula gibba
104 million ind.
Mysella bidentata
82 million ind.
Ind m-2
Ind m-2
GIS Model

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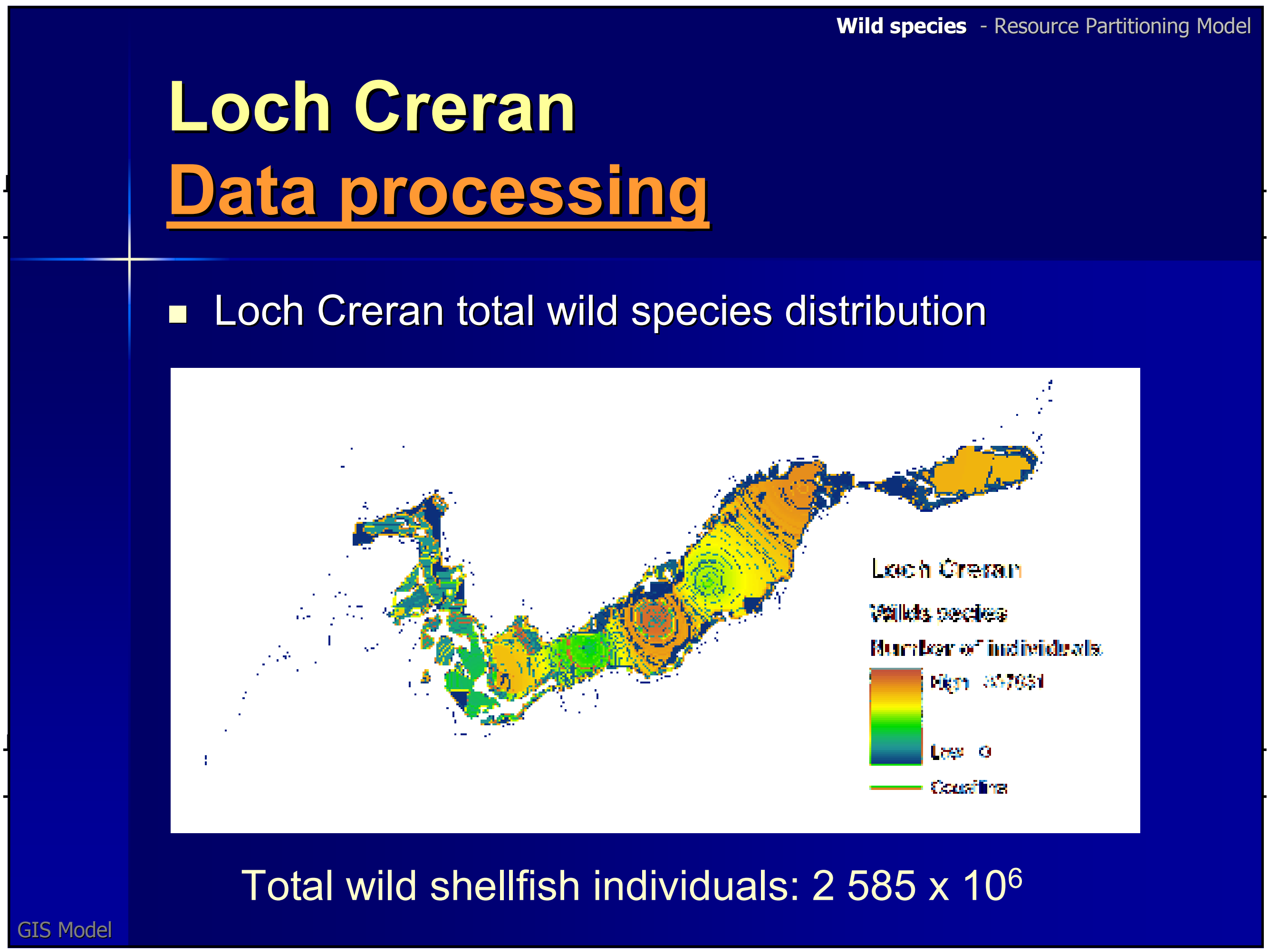
Wild species - Resource Partitioning Model
Loch Creran
Data processing
Loch Creran total wild species distribution
Loch Creran
Total wild shellfish individuals: 2 585 x 10^6
GIS Model

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Wild species - Resource Partitioning Model

Loch Creran
Regulation analysis

Marine biological interest in Loch Creran:

- Tidal rapids
- Biogenic reefs of
  - *Modiolus modiolus*
  - *Serpula vermicularis*

→ Habitats Directive (SAC)

Serpula vermicularis **reef associated with fauna in Loch Creran from Black et al, 1999**

GIS Model

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Loch Creran

Resource partitioning assessment

Wild species filtration rate

Wild species	Filtration rate ($L\ ind^{-1}\ h^{-1}$)	Condition
*Hiatella arctica**	0.0055	5 ºC
	0.0341	15 ºC
*Modiolus modiolus***	$F = 0.929\ w^{0.74}$	W = dry weight (g)
	1.5	$18\ g_{fw} \rightarrow \sim 2\ g_{dw}$
	2.6	$39.8\ g_{fw} \rightarrow \sim 4\ g_{dw}$
Other species	1.5	Mean filtration

* Winter (1969) in Jörgensen, S. E., Handbook of ecological parameters and ecotoxicology, 1991
** Willet *et al*, 1999

GIS Model

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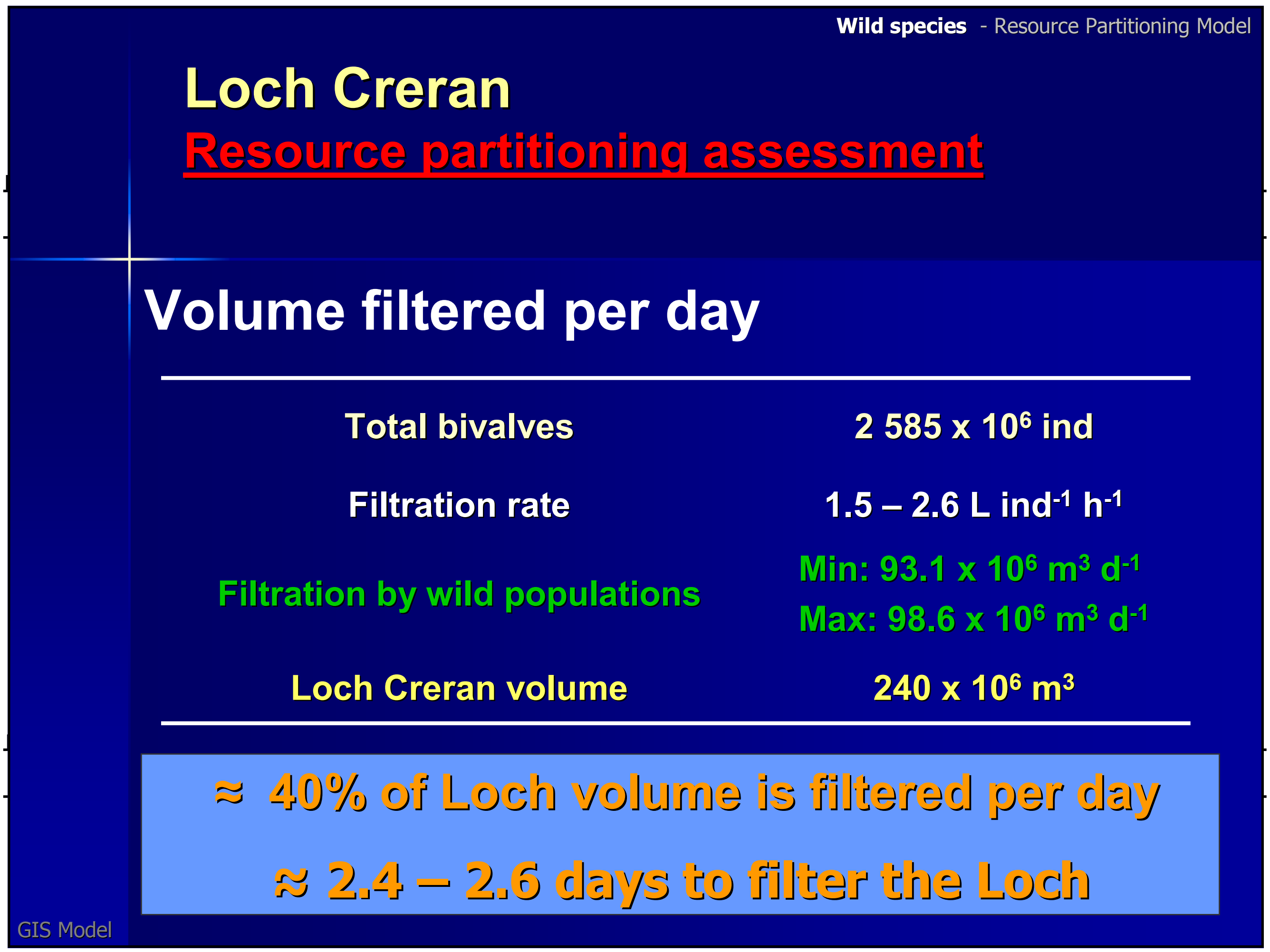
Wild species - Resource Partitioning Model
Loch Creran
Resource partitioning assessment
Volume filtered per day
Total bivalves
2 585 x 10⁶ ind
Filtration rate
1.5 – 2.6 L ind⁻¹ h⁻¹
Filtration by wild populations
Min: 93.1 x 10⁶ m³ d⁻¹
Max: 98.6 x 10⁶ m³ d⁻¹
Loch Creran volume
240 x 10⁶ m³
≈ 40% of Loch volume is filtered per day
≈ 2.4 – 2.6 days to filter the Loch
GIS Model

Notes: ______________________ Notes: ______________________

Wild species - Resource Partitioning Model

Loch Creran

Resource partitioning assessment

Baseline food requirements

Filtration by wild populations	Min: 93.1×10^6 m^3 d^{-1} Max: 98.6×10^6 m^3 d^{-1}
Loch Creran volume	240×10^6 m^3
Chl *a* concentration*	1 µg L^{-1}
Total chl *a* in Loch Creran	240 kg
Chl *a* cleared by wild species	93.1 – 98.6 kg chl *a* d^{-1}

* Mean value, from KEYZONES project data - 2005

GIS Model

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Loch Creran

Resource partitioning assessment

Food removal by wild species

$$[\text{Chl } a - \Sigma(\alpha_i \text{PB})]$$

For a removal efficiency of 95%

	Oysters	Mussels
α_i	0.893	1.0

- Wild species would remove about:
  - 88 to 94 kg chl *a* d^{-1} → 0.37 to 0.40 μg L^{-1} d^{-1}

GIS Model

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Wild species - Resource Partitioning Model

Loch Creran

Resource partitioning assessment

Shellfish production values

Shellfish cultivated species	Production (ton y^{-1})	Number of Individuals (x 10^{-6})	Filtration rate* (L ind^{-1} d^{-1})	Food cleared (kg chl *a* d^{-1})	Food removed (kg chl *a* d^{-1})
Mytilus edulis (Blue mussel)	500	25	16	1	1
Crassostrea gigas (Pacific oyster)	100	1	250	0.63	0.56

* Average calculated value from values available in Jörgensen et al, 1991

Mean wet weight at harvest was considered 20 and 100 g for mussels and oysters, respectively - from culture practise in the Eastern Scheldt (KEYZONES project)

GIS Model

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Wild species - Resource Partitioning Model

Loch Creran

Resource partitioning assessment

Food availability estimation (approach)

- Average concentration of chl *a* = 240 kg

CONSIDERING:

- **Sources**: doublings (phytoplankton biomass duplicates each 1.5 days)
  - 240 x (0.67 x 365) ~ 59 ton y^{-1}
- **Sinks**: wild and cultured species consumption
  - Wild: ~ 36.5 ton y^{-1}
  - Cultured: ~ 570 kg y^{-1}

SOURCES – SINKS ~ 22 ton chl *a* y^{-1} ← **Unknown Processes**

GIS Model

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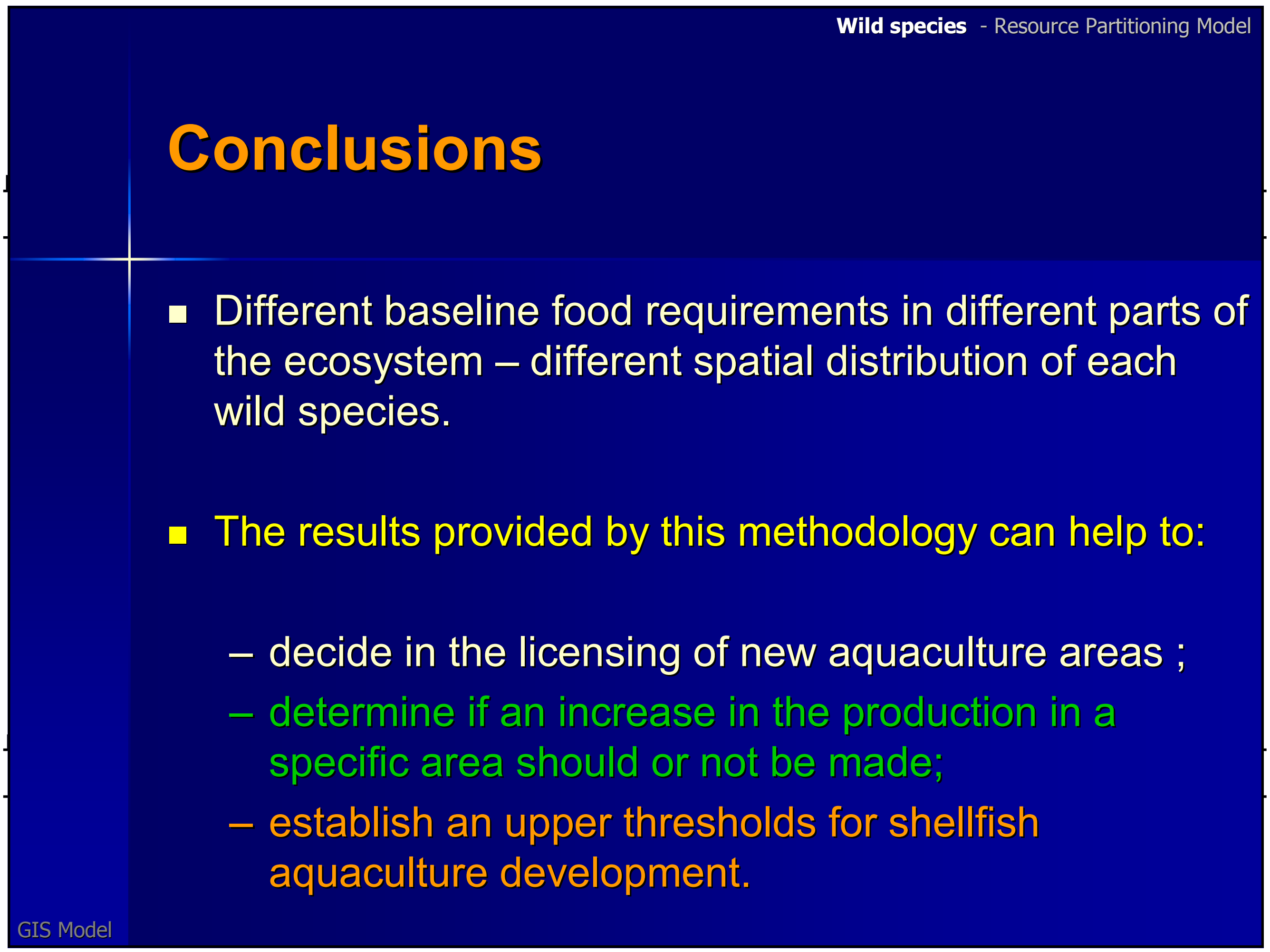
Wild species - Resource Partitioning Model
Conclusions
Different baseline food requirements in different parts of the ecosystem – different spatial distribution of each wild species.
The results provided by this methodology can help to:
– decide in the licensing of new aquaculture areas ;
– determine if an increase in the production in a specific area should or not be made;
– establish an upper thresholds for shellfish aquaculture development.
GIS Model

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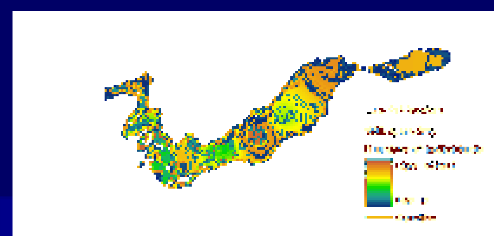
Wild species - Resource Partitioning Model

Model Improvements:



- **Clearance rates specific for the species in analysis**
  - Rates used here were based on the *Modiolus modiolus* filtration. Clearance rates will vary according to species, body size and season.
- **Other wild species**
  - Consider other filter feeders that are nor shellfish (e.g. red tube worn).
- **Map of sediments and biotopes**
  - A good map of the type of sediments and biotopes is important to improve the interpolation surfaces.
- **Increase number of sampling stations**
  - Species density is a highy variable parameter. Results shown here are useful to give a rough idea of the type of results one can obtain.

GIS Model

http://www.ecowin.org

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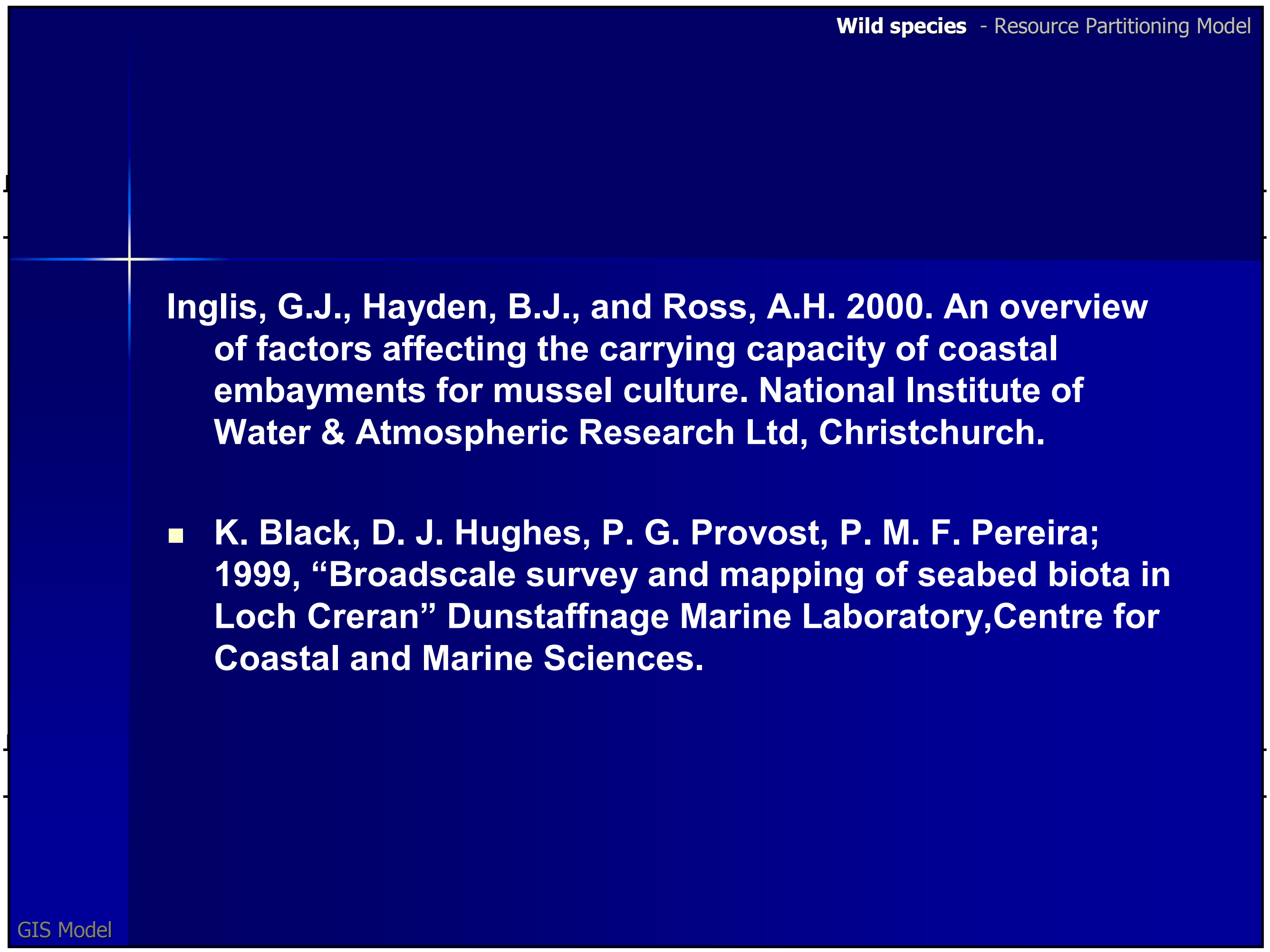
Wild species - Resource Partitioning Model
Inglis, G.J., Hayden, B.J., and Ross, A.H. 2000. An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. National Institute of Water & Atmospheric Research Ltd, Christchurch.
K. Black, D. J. Hughes, P. G. Provost, P. M. F. Pereira; 1999, "Broadscale survey and mapping of seabed biota in Loch Creran" Dunstaffnage Marine Laboratory,Centre for Coastal and Marine Sciences.
GIS Model

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