Evaluating how food webs and the fisheries they support are affected by fishing closures in temperate Western Australia

IPFC & ASFB 2009 Conference

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Motivation

Rationale:

· Explore the ecosystem impacts of fishing

Goal:

· Evaluate how food webs and the fisheries they support are likely to be influenced by fishing closures

· Investigate how changes in abundance of key fished species (e.g. rock lobster, snapper, dhufish) are likely to influence other species

Applications:

· Dynamics of target species

· Commercial *vs* Recreational fishing

· Climate variability scenarios

· Provide useful ecosystem indicators

Ecopath model : 2006

30°

- **Boundaries of the model:**

  Marine Park to 30m depth

  Area = 823 km²

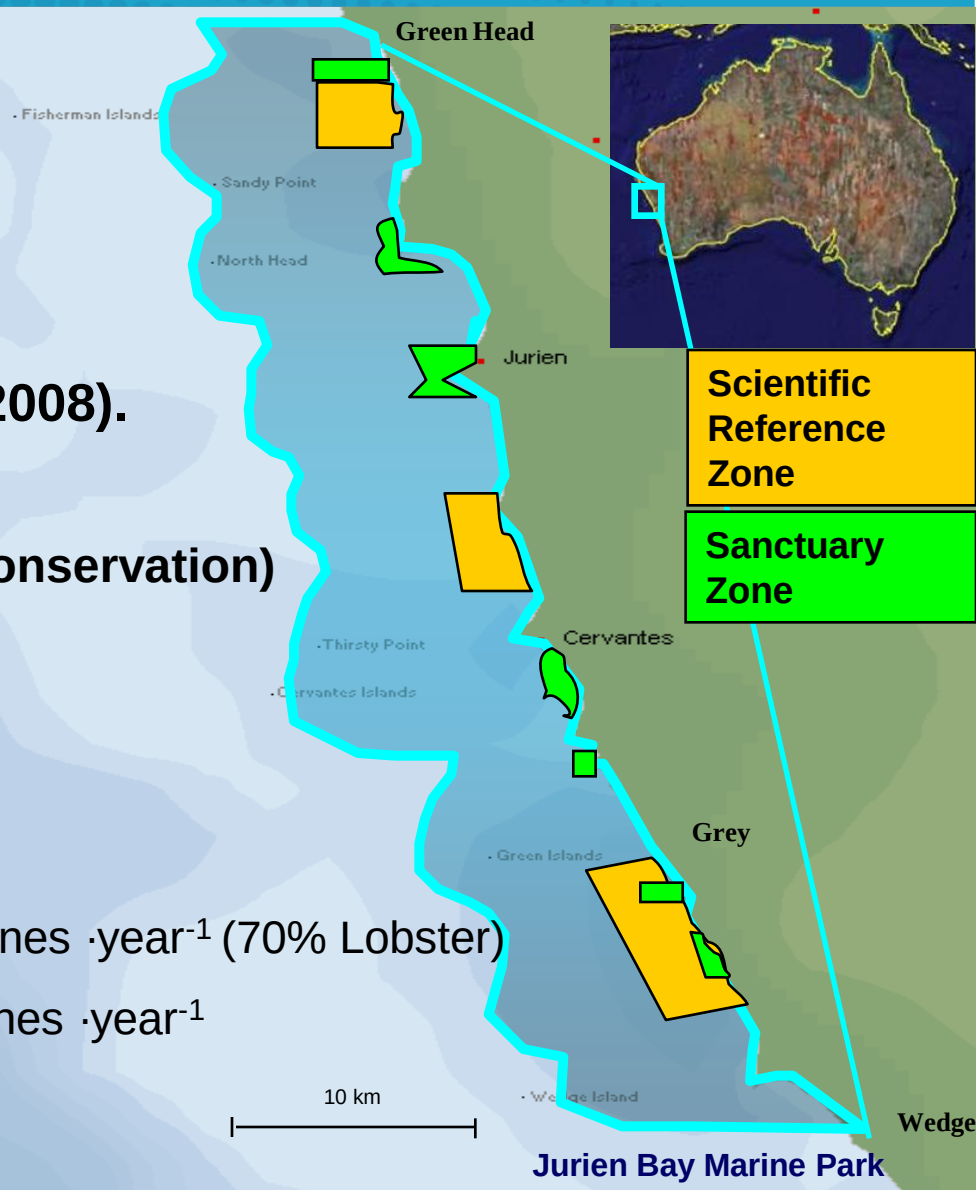
- **Period: Average year 2006 (2003-2008).**

Management Zones

(WA Department of Environment and Conservation)

- **80 groups (> 200 species)**

- **Fishing gears**
  - 8 commercial ~480 tonnes ·year^{-1} (70% Lobster)
  - 6 recreational ~ 38 tonnes ·year^{-1}



31°

Functional groups

- **Fish = 24**
- **Special interest = 10**
- **Invertebrates = 19**
- **Primary producers = 11**
- **Zooplankton = 4**
- **Non-Fish = 5**
- **Non-Living = 7**

Iconic/special interest

Pink snapper

Dhufish

Baldchin grouper

Breaksea cod

Foxfish

King wrasse

4 stages of rock lobster

Ecopath & Ecosim core equations:

1) Mass-balance (within groups):

$$B_i \cdot (P/B)_i = Y_i + \sum_{j=1}^{n} B_j \cdot (Q/B)_j \cdot DC_{ji} + E_i + BA_i + B_i (P/B)_i \cdot (1 - EE_i)$$

Production = Yield + Predation + Biomass Acc. + Migration

2) Conservation of energy (between groups):

$$B \cdot (Q/B) = B \cdot (P/B) + (1 - GS) \cdot Q - (1 - TM) \cdot P + B \cdot (Q/B) \cdot GS$$

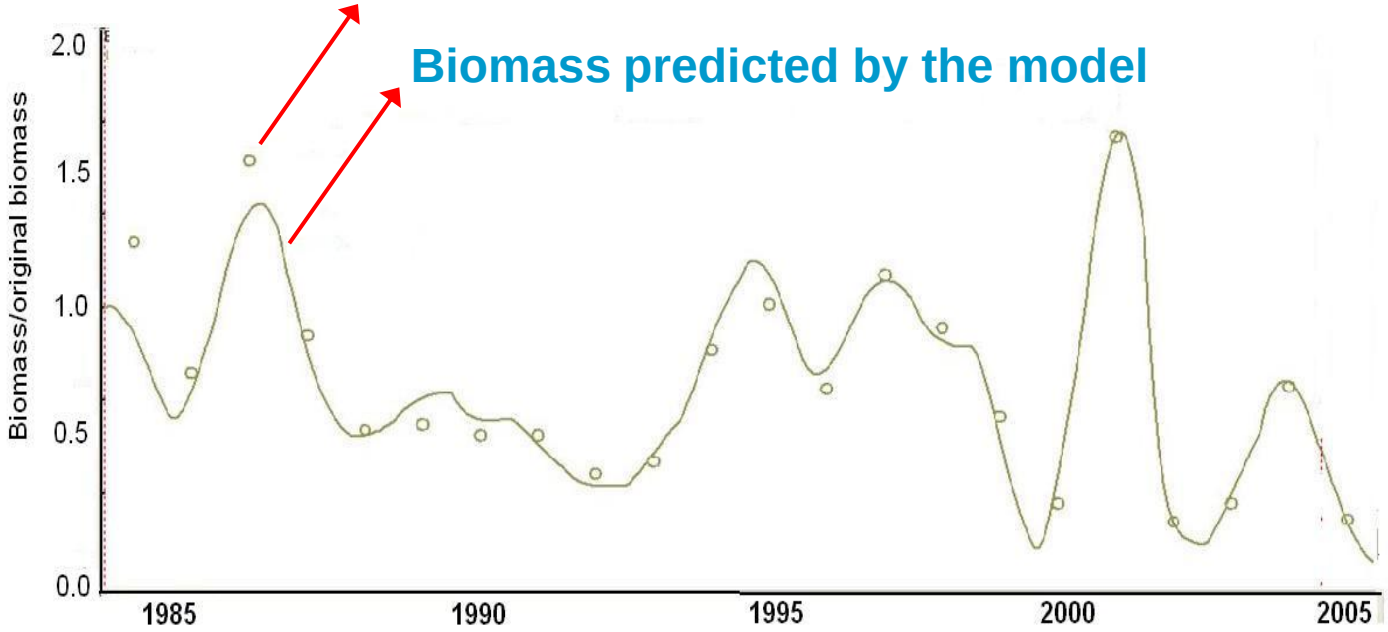
Consumption = Production + Respiration+ Unassimilated food

3) Biomass dynamics:

$$\frac{dB_i}{dt} = g_i \sum_j C_{ji} - \sum_j C_{ij} + I_i - (M_i + F_i + e_i) B_i$$

D Biomass = Growth + Immigration – Predation - Mortality

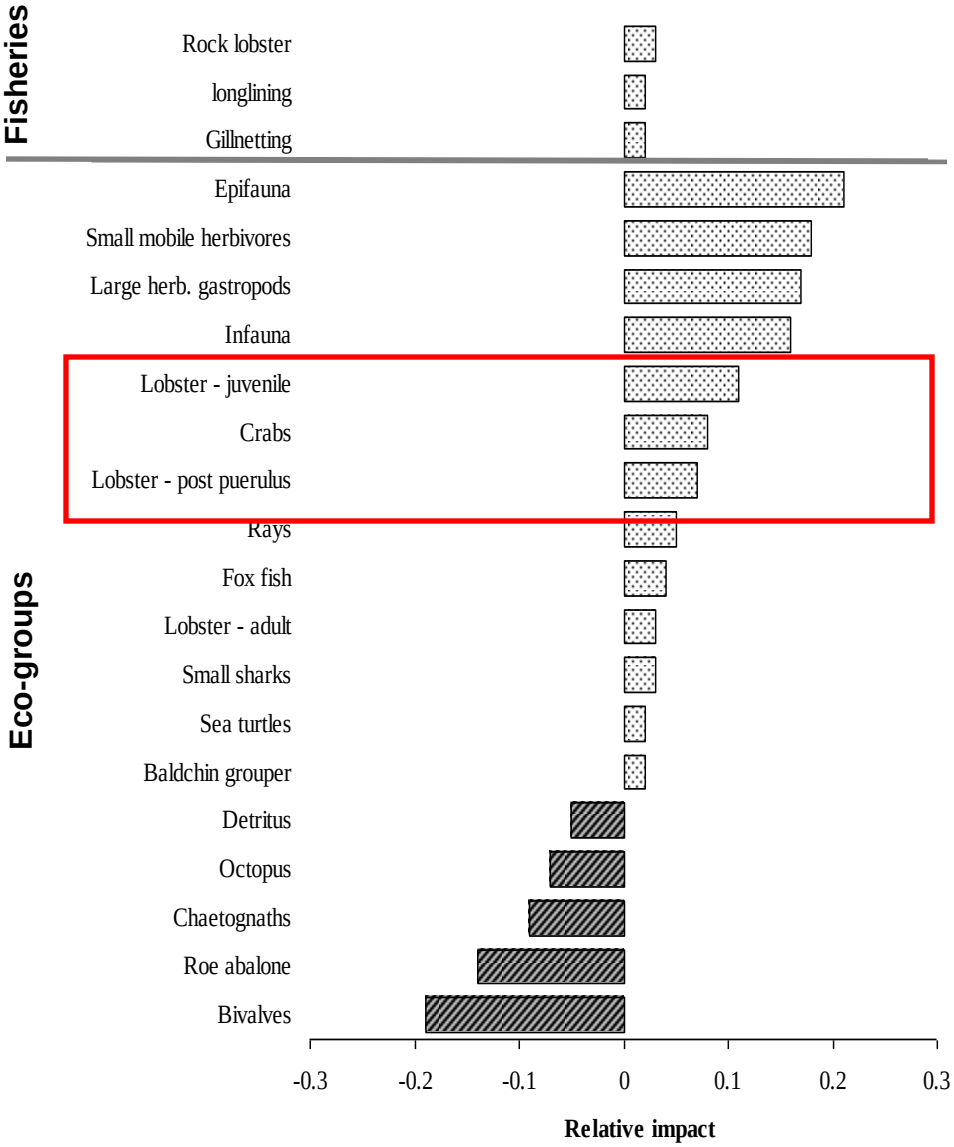
Model Calibration: Wester Rock Lobster
(data from Department of Fisheries, WA)



Panulirus cygnus

- Model captures general variability
- Model can reproduce known history

Results: trophic role of *Ecklonia* (kelp)

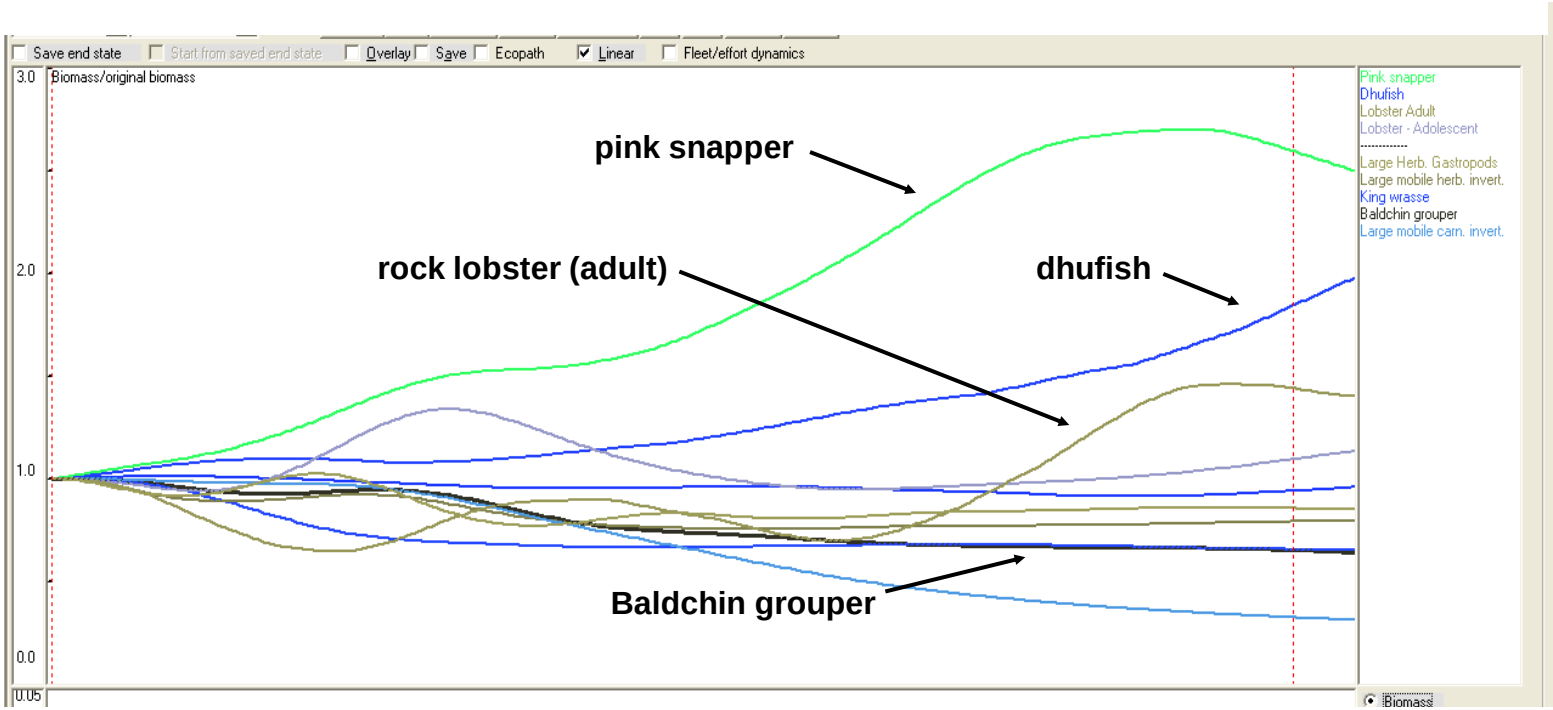


Ecklonia sp (kelp)

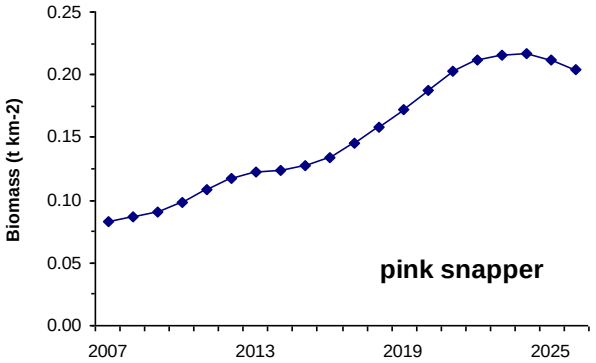
- *Ecklonia*, seagrasses and macroalgal assemblages are the major sources of habitat and food for marine invertebrates and fish.

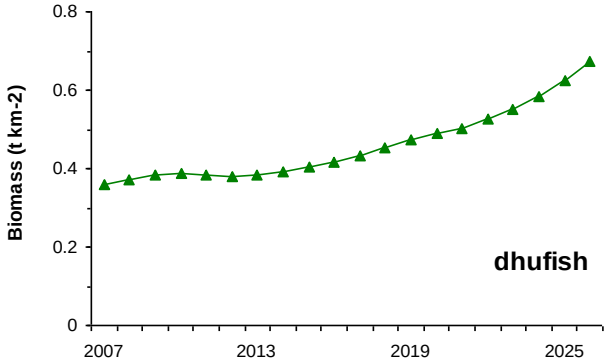
- *Ecklonia* provided substrata for food (epiphytes and epifauna) and shelter from predators.

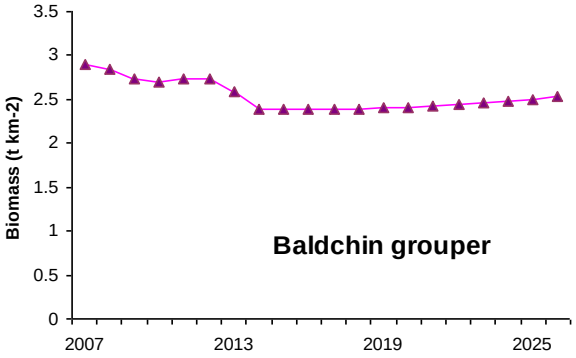
Ecosim scenario: Reduction of F by 50% over 20 years (2.5% year^{-1}) of dhufish and pink snapper

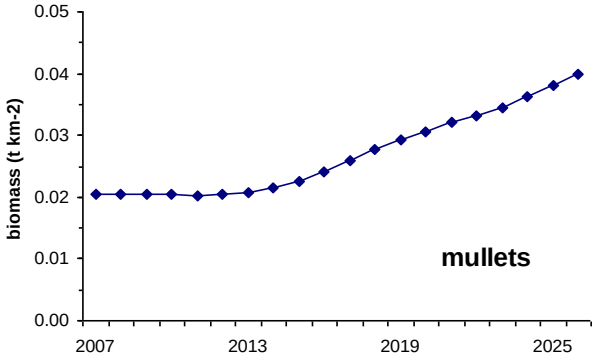


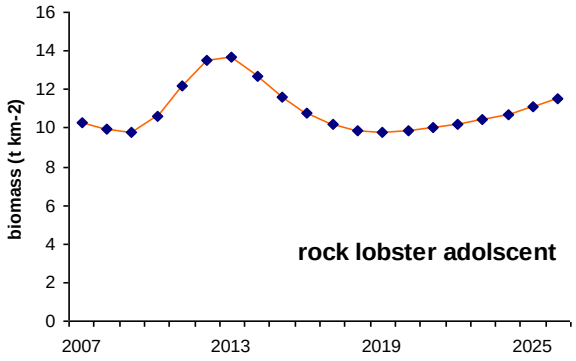
Ecosim scenario: Reduction of F by 50% over 20 years (2.5% year^{-1}) of dhufish and pink snapper

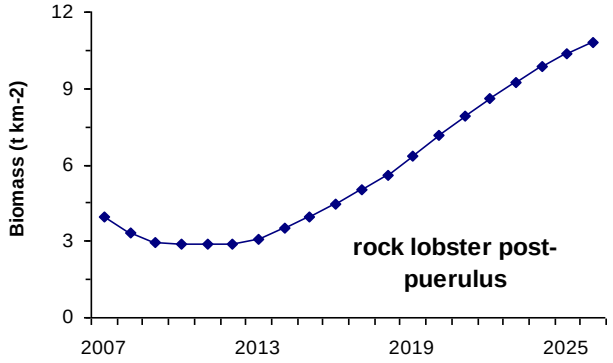




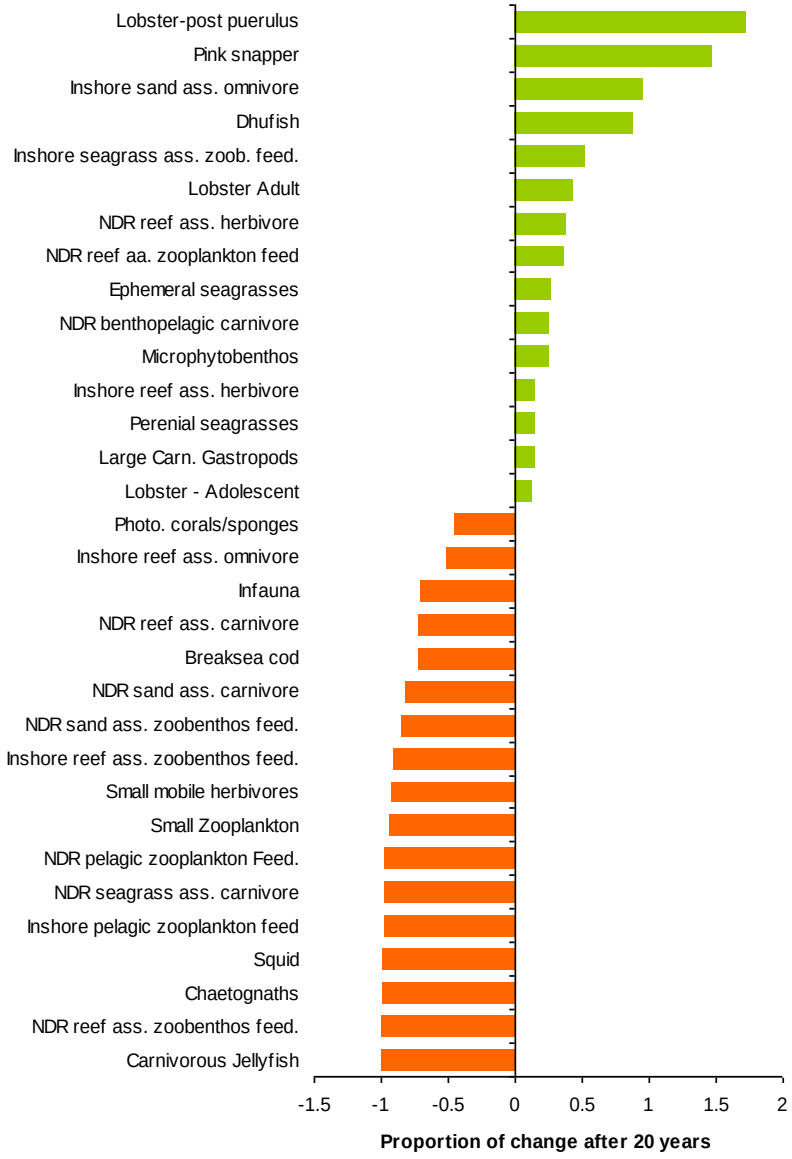




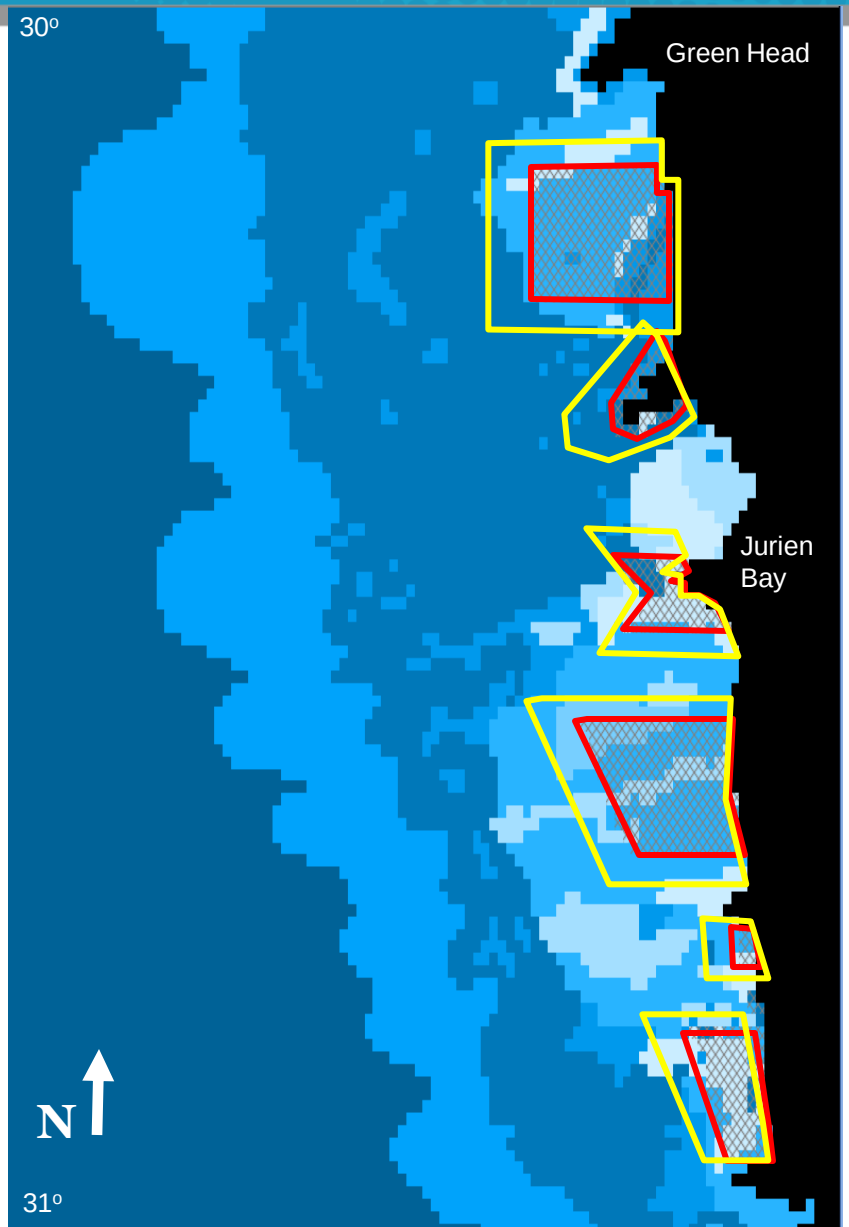




Ecosim scenario: Reduction of F by 50% over 20 years (2.5% year^{-1}) of dhufish and pink snapper



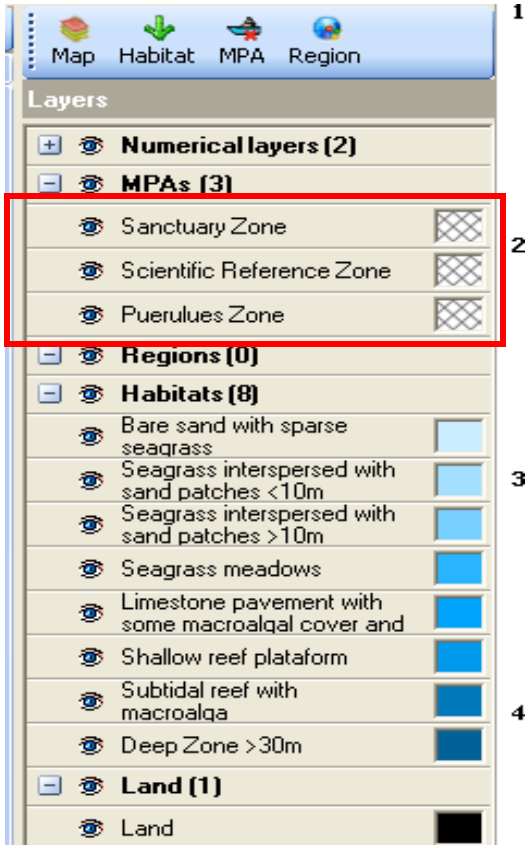
Ecospace: Spatial modelling of Jurien Bay



Scenario 1: ~10% of the park

Scenario 2: No fishing closures

Scenario 3: Fishing closures up to 30%



Ecopath models are like cubism art….abstract, ambiguous, with random angles, but (probably/possibly) realistic.

Picasso, 1913

Thank you

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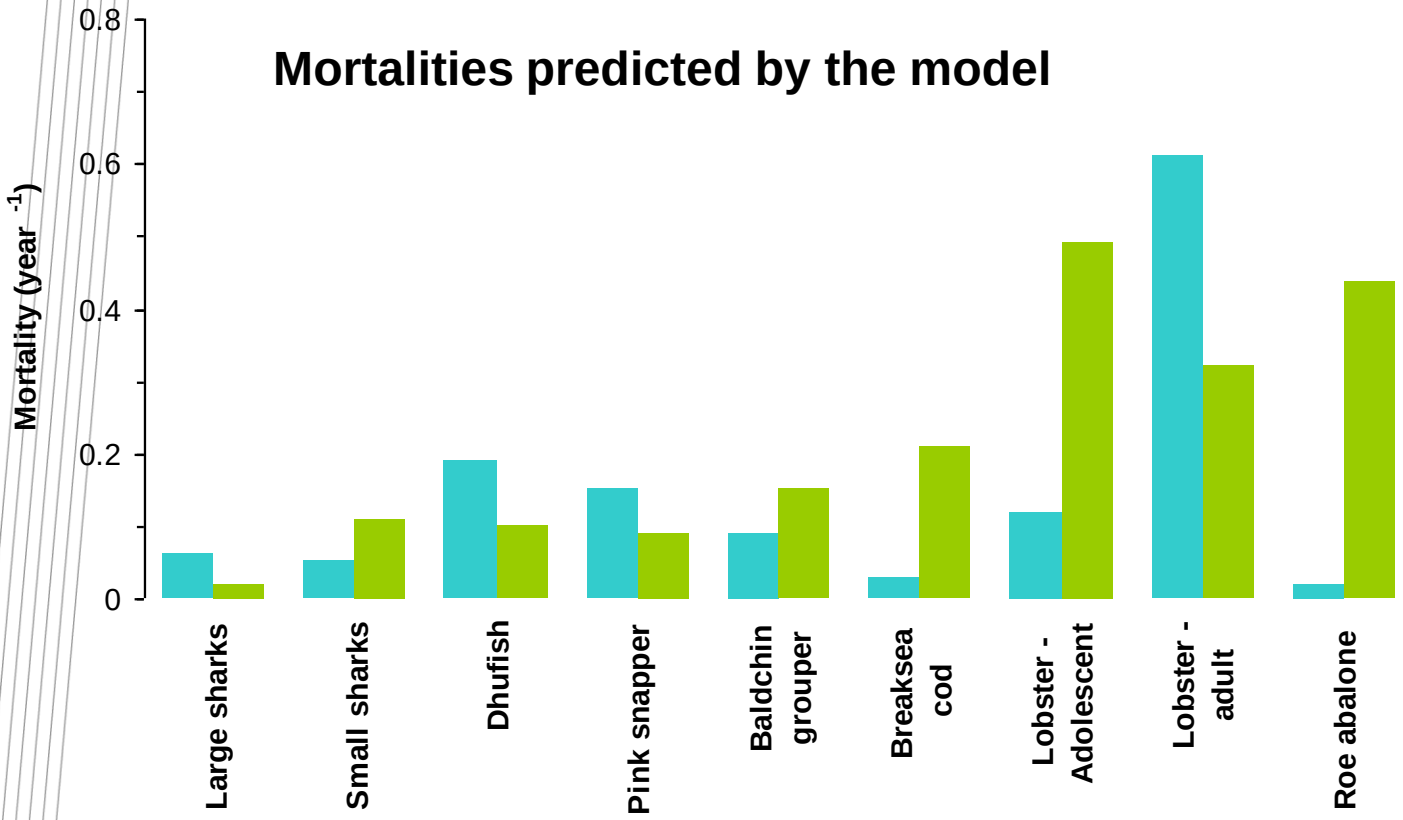
Scenario: Reduction of F by 50% (2.5% year^{-1}) of dhufish, pink snapper & baldchin grouper

Western Rock Lobster

Panulirus cygnus

Model's Performance: Mortalities

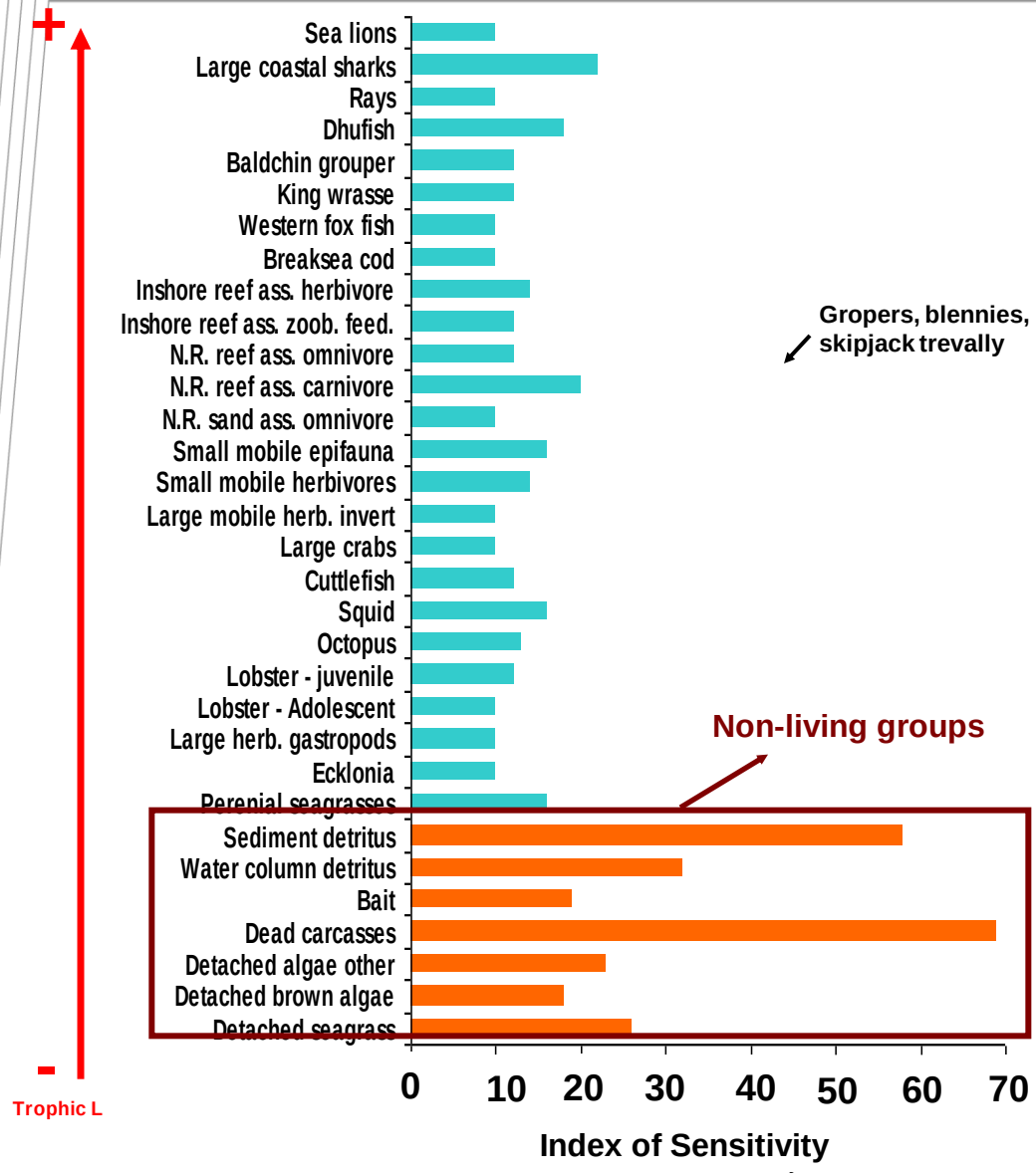


Production = Fishery yield + Natural Mortality

$$P/B = Z = F + M_2$$

$$F = C/B$$

Sensitivity Analysis - (change biomass of each living group)



- Index of Sensitivity = the number of groups affected (± 30%) by 50% of biomass for each group.
- The Ecopath model is relatively insensitive to parameter values for most living groups (only 34 groups produced Index sensitivity >10).
- Changes in parameters of Dead carcasses and sediment detritus exert the greatest influence (living groups) in the system.
- The importance/sensitivity of the model to sediment detritus emphasises the ultimate desirability of developing Atlantis type model.

Ecosystem attributes of Jurien Bay

- Jurien Bay is a relatively complex ecosystem.

- Medium/High productive system. More energy produced than respired within the system (*Primary Production/Respiration = 1.23*).

- Dynamic system. There is a low-medium level of biomass accumulation (*Primary Production/ Biomass= 1.68*).

- Low rates of cycling (*proportion of flows originated from detritus ~ 10%*)

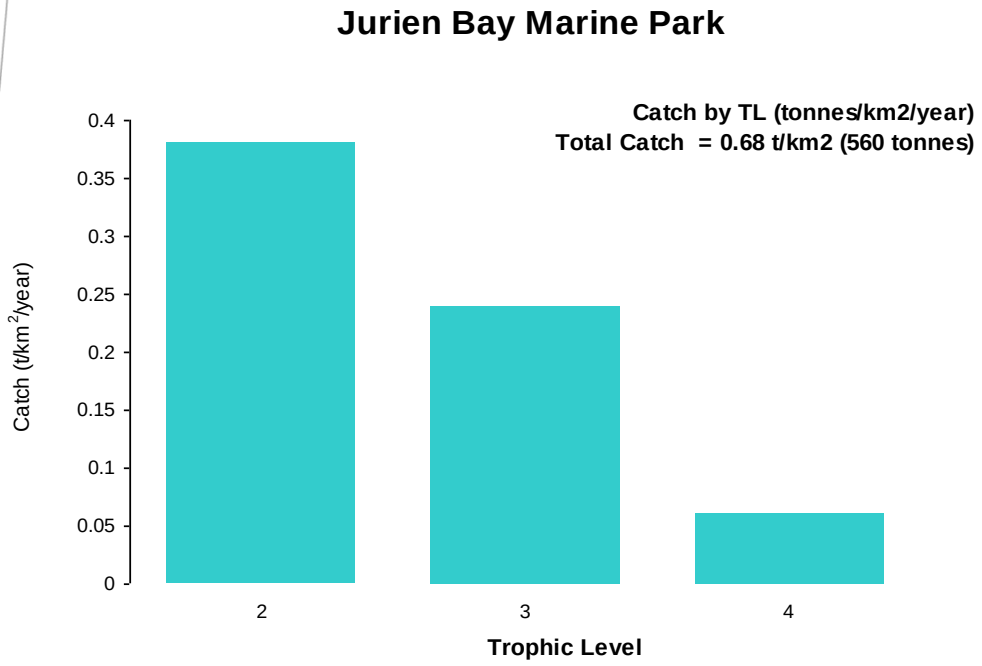
- Ecosystem dominated by the benthic community (*Ratio of biomass benthic/pelagic groups = 1.27).*

- Ecosystem function related to *Bottom-up control*, but wasp-waist predator-prey and top-down interactions were identified.

- This ecosystem could be considered in an Intermediate-Low development stage, dominated by lower trophic levels. (*overall network analysis results*).

Trophic structure and fisheries

- Mean trophic level of the catch = *2.96*
- Gross Efficiency (Catch/Primary Production) = *0.00041*
- Total Catch = *0.68 t/km²* (560 tonnes taken within the park in 2005, where almost 90% was removed by commercial fishing)



Some of these attributes could be used as 'indicators' to identify overfishing in the future.

Outline: Results from Ecosim

Ecosim

- Scenario evaluation:

  Workshop November, 2007: Participants + Steering group

Scenario	Species	Fishing effort (%) year^{-1} Commercial (C)	Recreational (R)	Duration (years)	Rationale
1	**Lobster**	**↓ 2.5**	**↓2.5**	**20**	**Ecological role**
2	**Lobster**	**↑2.5**	**↑2.5**	**20**	**Ecological role**
3	**Pink snapper**	**↑15**	**↑15**	**20**	**Ecological role**
4	**Pink snapper**	**↓ 2.5**	**↓2.5**	**20**	**Ecological role**
5	**All**	**↓ 2.5**	**↓2.5**	**20**	**Impact of fisheries and closure areas**
6	**All**	**Close**	**↓2.5**	**20**	**Impact of fisheries and closure areas**

Run info | Group info | Stage | Vulnerabilities | Mediation | Forcing functions | Apply FF | Run Ecosim | Equilibrium

(Individual grou | Lobster Adult | F value | F = 0 | Reset F's | Values | Time series | Hide | Plot | Tracer

Save end state | Start from saved end state | Overlay | Save | Ecopath | Linear | Fleet/effort dynamics

Biomass/original biomass

Role of western rock lobster

Lobster adult

its prey have high productivity and short life cycles (i.e. coralline algae and crustaceans) in the system.

mortality of the western rock lobster is unlikely to produce important trophic cascade effects

↑ Lobster ~ 30%

↓ Biomass prey up to 20%

Low impact on other groups

Lobster Adult

Small coastal sharks
Small Gastropods
NDR seagrass ass. carnivor
Inshore reef ass. omnivore
Inshore reef ass. zoobentho
Infauna
NDR sand ass. carnivore
Chaetognaths
Small mobile herbivores
Photo. corals/sponges
Dhufish
Inshore ass. carnivore
Squid
Rays
Inshore seagrass ass. omniv
Inshore seagrass ass. zoob.
Detached seagrass

1.5 1.0 0.5 0.0

Scenario 1: Reduction of lobster fishing mortality from 0.6 to 0.3 in 20 years

Fishing mortality in 2006 (F=0.62)

Fishing mortality in 2026 (F=0.3)

1.20 0.90 0.60 0.30 0.00

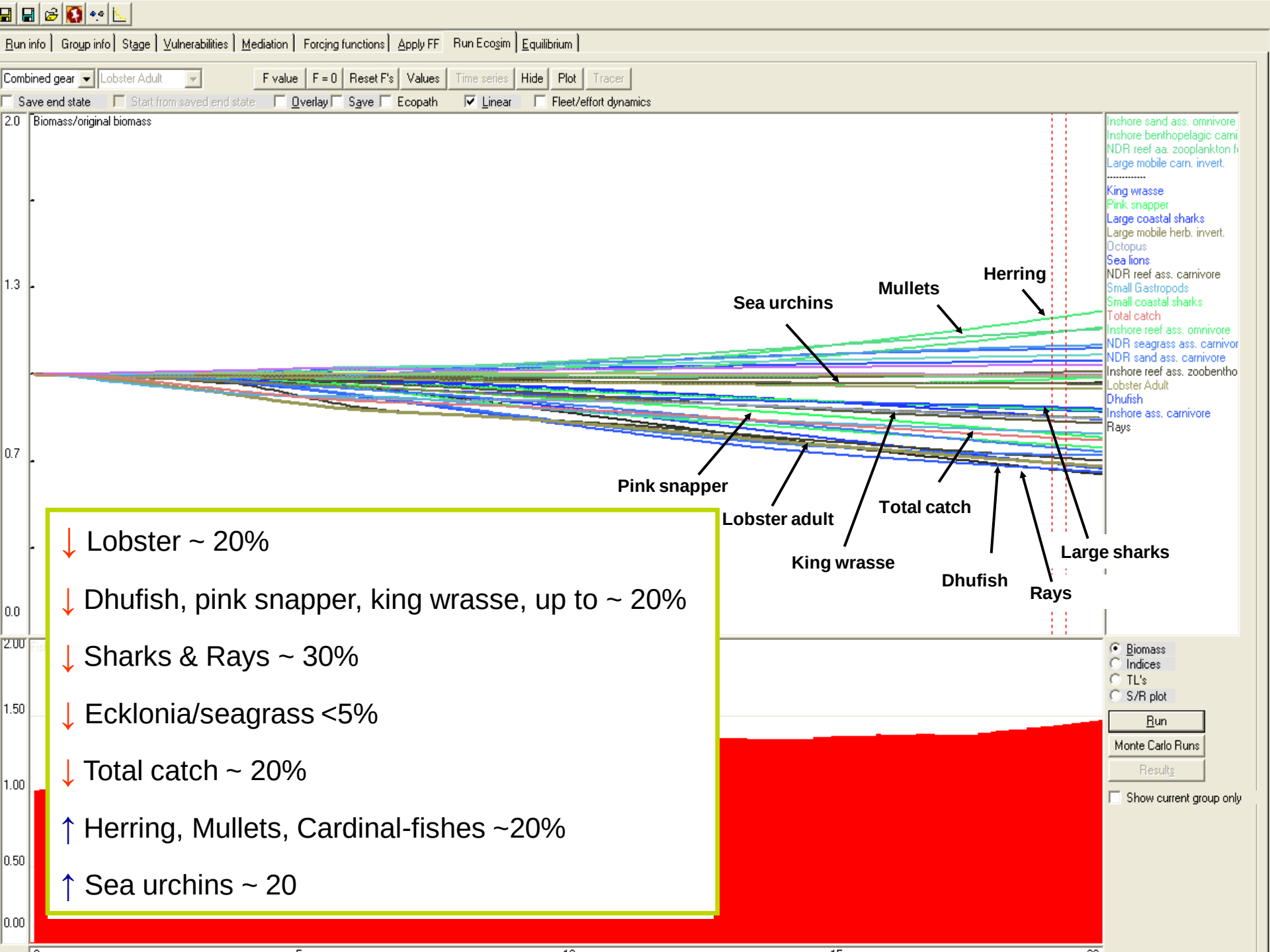
0 5 10 15 20

Years

Biomass | Indices | TL's | S/R plot

Run | Monte Carlo Runs | Results

Show current group only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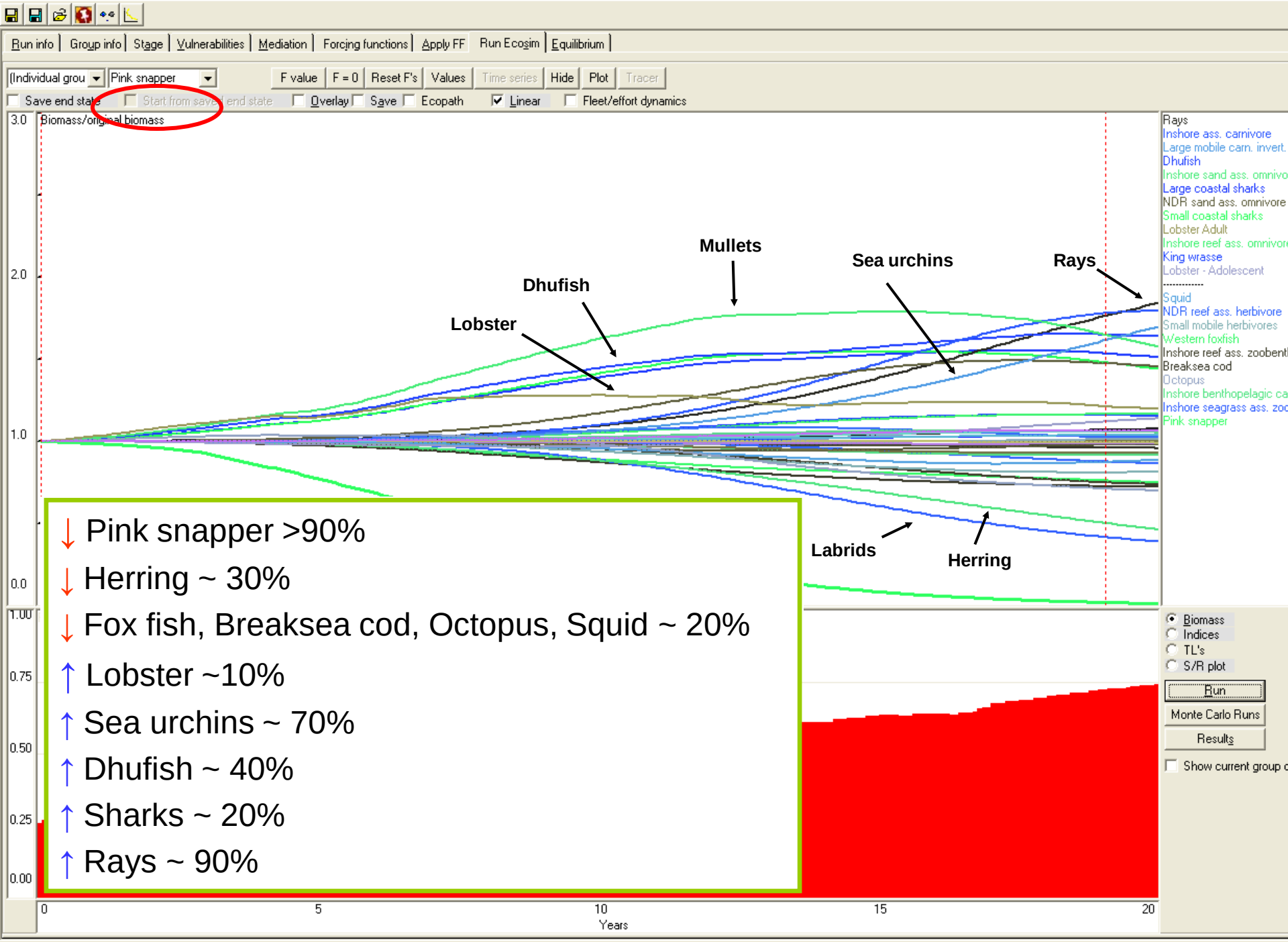
Combined gear
Lobster Adult
F value | F = 0 | Reset F's | Values | Time series | Hide | Plot | Tracer
Save end state
Start from saved end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
2.0
1.3
0.7
0.0
Inshore sand ass. omnivore
Inshore benthopelagic carni
NDR reef aa. zooplankton f
Large mobile carn. invert.
King wrasse
Pink snapper
Large coastal sharks
Large mobile herb. invert.
Octopus
Sea lions
NDR reef ass. carnivore
Small Gastropods
Small coastal sharks
Total catch
Inshore reef ass. omnivore
NDR seagrass ass. carnivor
NDR sand ass. carnivore
Inshore reef ass. zoobentho
Lobster Adult
Dhufish
Inshore ass. carnivore
Rays
Herring
Mullets
Sea urchins
Pink snapper
Lobster adult
King wrasse
Total catch
Dhufish
Rays
Large sharks
↓ Lobster ~ 20%
↓ Dhufish, pink snapper, king wrasse, up to ~ 20%
↓ Sharks & Rays ~ 30%
↓ Ecklonia/seagrass <5%
↓ Total catch ~ 20%
↑ Herring, Mullets, Cardinal-fishes ~20%
↑ Sea urchins ~ 20
2.00
1.50
1.00
0.50
0.00
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only



↓ Pink snapper >90%

↓ Herring ~ 30%

↓ Fox fish, Breaksea cod, Octopus, Squid ~ 20%

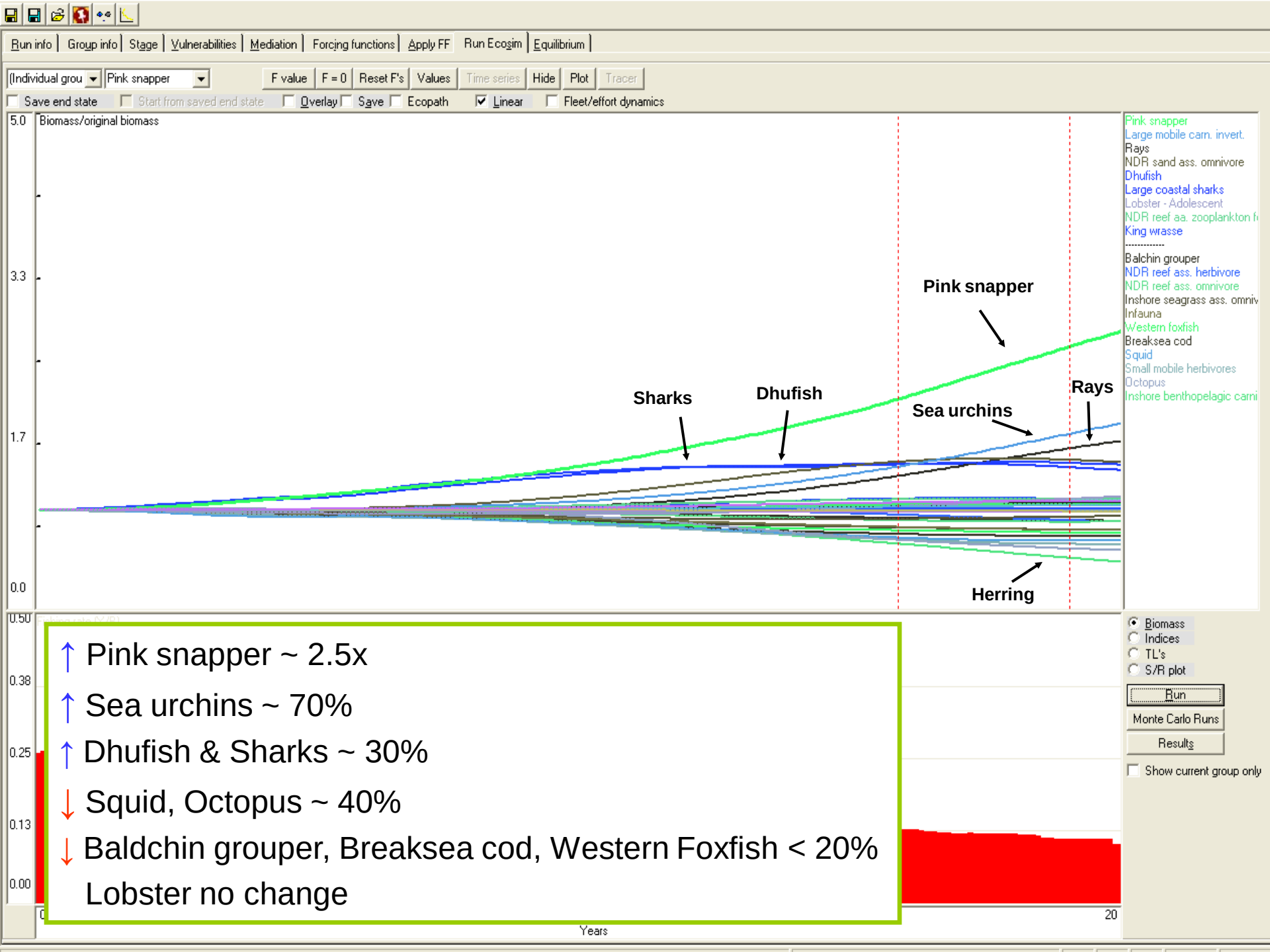
↑ Lobster ~10%

↑ Sea urchins ~ 70%

↑ Dhufish ~ 40%

↑ Sharks ~ 20%

↑ Rays ~ 90%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Biomass/original biomass
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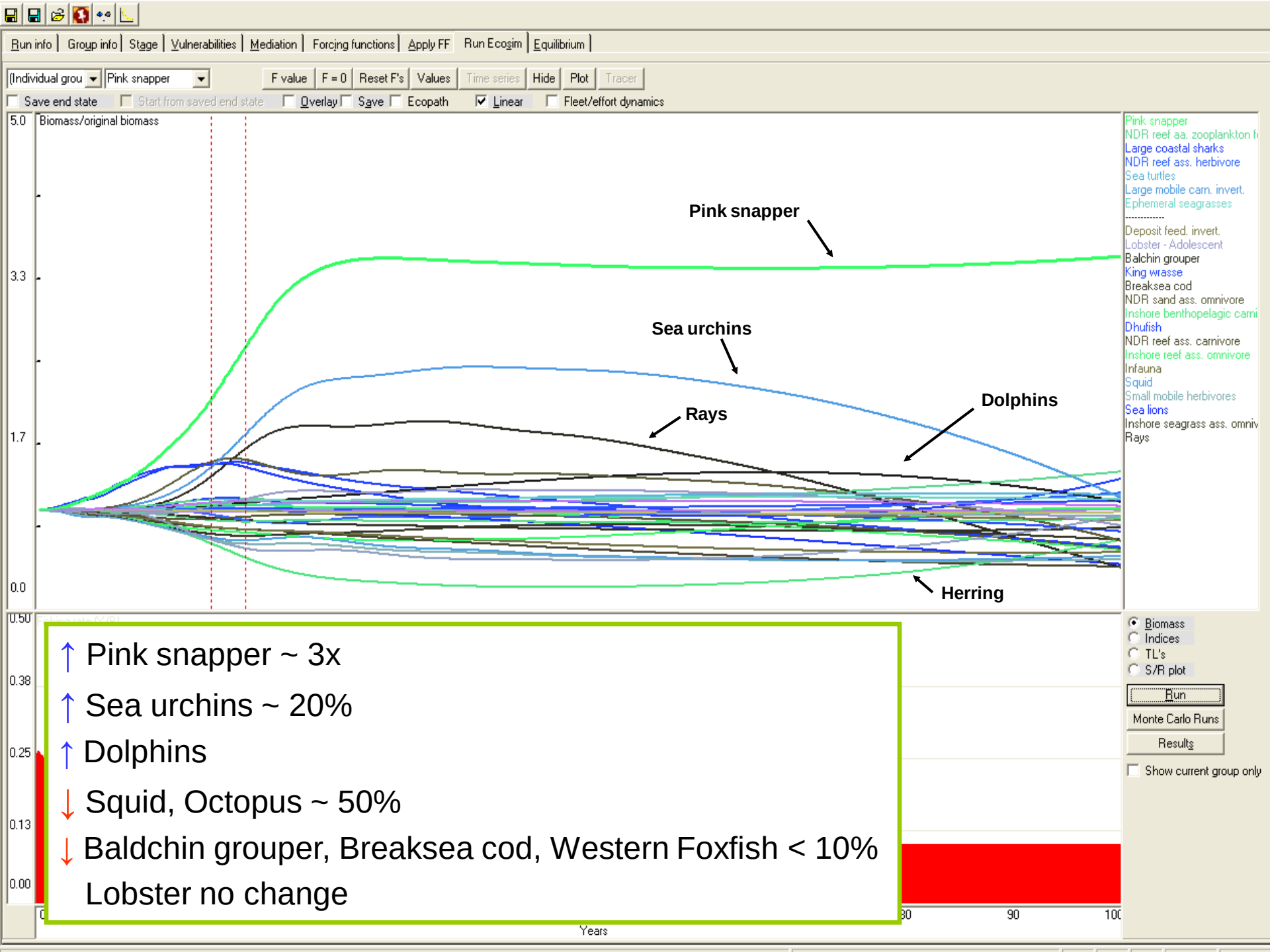
Pink snapper
Sharks
Dhufish
Sea urchins
Rays
Herring
Pink snapper
Large mobile carn. invert.
Rays
NDR sand ass. omnivore
Dhufish
Large coastal sharks
Lobster - Adolescent
King wrasse
Balchin grouper
NDR reef ass. herbivore
NDR reef ass. omnivore
Inshore seagrass ass. omniv
Infauna
Western foxfish
Breaksea cod
Squid
Small mobile herbivores
Octopus
Inshore benthopelagic carni
0.50
0.38
0.25
0.13
0.00
↑ Pink snapper ~ 2.5x
↑ Sea urchins ~ 70%
↑ Dhufish & Sharks ~ 30%
↓ Squid, Octopus ~ 40%
↓ Baldchin grouper, Breaksea cod, Western Foxfish < 20%
Lobster no change
20
Years
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only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Ecopath
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Fleet/effort dynamics
Biomass/original biomass
5.0
3.3
1.7
0.0
Pink snapper
Sea urchins
Rays
Dolphins
Herring
Pink snapper
Large coastal sharks
Sea turtles
Large mobile carn. invert.
Ephemeral seagrasses
Deposit feed. invert.
Lobster - Adolescent
Balchin grouper
King wrasse
Breaksea cod
NDR sand ass. omnivore
Dhufish
NDR reef ass. carnivore
Infauna
Squid
Small mobile herbivores
Sea lions
Rays
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0.25
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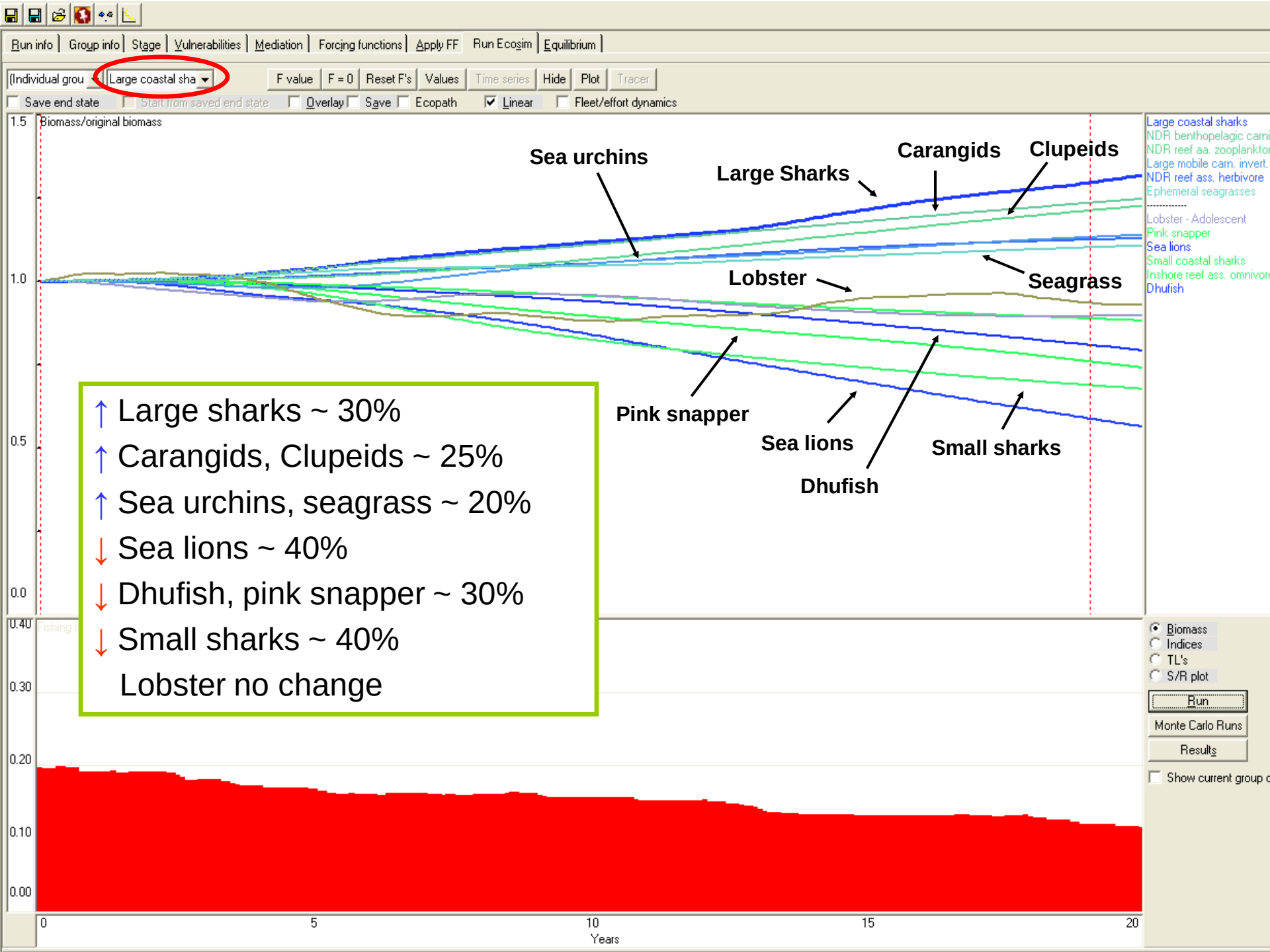
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only
90
Years
↑ Pink snapper ~ 3x
↑ Sea urchins ~ 20%
↑ Dolphins
↓ Squid, Octopus ~ 50%
↓ Baldchin grouper, Breaksea cod, Western Foxfish < 10%
Lobster no change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Start from saved end state
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Fleet/effort dynamics
Biomass/original biomass
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Sea urchins
Large Sharks
Carangids
Clupeids
Lobster
Seagrass
Pink snapper
Sea lions
Small sharks
Dhufish
Large coastal sharks
NDR benthopelagic carni
NDR reef aa. zooplankton
Large mobile carn. invert.
NDR reef ass. herbivore
Ephemeral seagrasses
Lobster - Adolescent
Pink snapper
Sea lions
Small coastal sharks
Inshore reef ass. omnivore
Dhufish
↑ Large sharks ~ 30%
↑ Carangids, Clupeids ~ 25%
↑ Sea urchins, seagrass ~ 20%
↓ Sea lions ~ 40%
↓ Dhufish, pink snapper ~ 30%
↓ Small sharks ~ 40%
Lobster no change
0.40
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0.20
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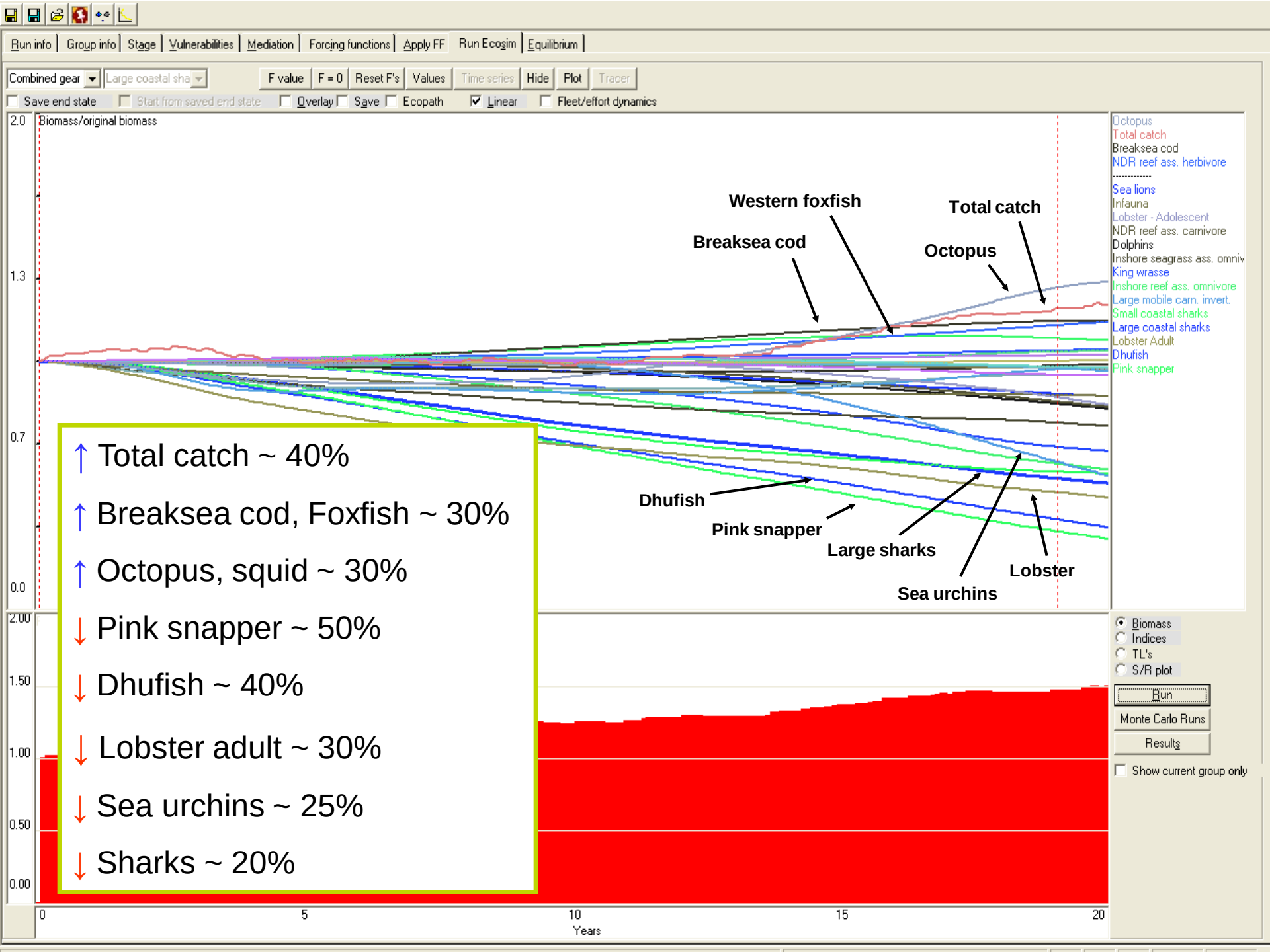
Years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Biomass/original biomass
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Western foxfish
Total catch
Breaksea cod
Octopus
Dhufish
Pink snapper
Large sharks
Lobster
Sea urchins
Octopus
Total catch
Breaksea cod
NDR reef ass. herbivore
Sea lions
Infauna
Lobster - Adolescent
NDR reef ass. carnivore
Dolphins
Inshore seagrass ass. omniv
King wrasse
Inshore reef ass. omnivore
Large mobile carn. invert.
Small coastal sharks
Large coastal sharks
Lobster Adult
Dhufish
Pink snapper
↑ Total catch ~ 40%
↑ Breaksea cod, Foxfish ~ 30%
↑ Octopus, squid ~ 30%
↓ Pink snapper ~ 50%
↓ Dhufish ~ 40%
↓ Lobster adult ~ 30%
↓ Sea urchins ~ 25%
↓ Sharks ~ 20%
2.00
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1.00
0.50
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Biomass
Indices
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S/R plot
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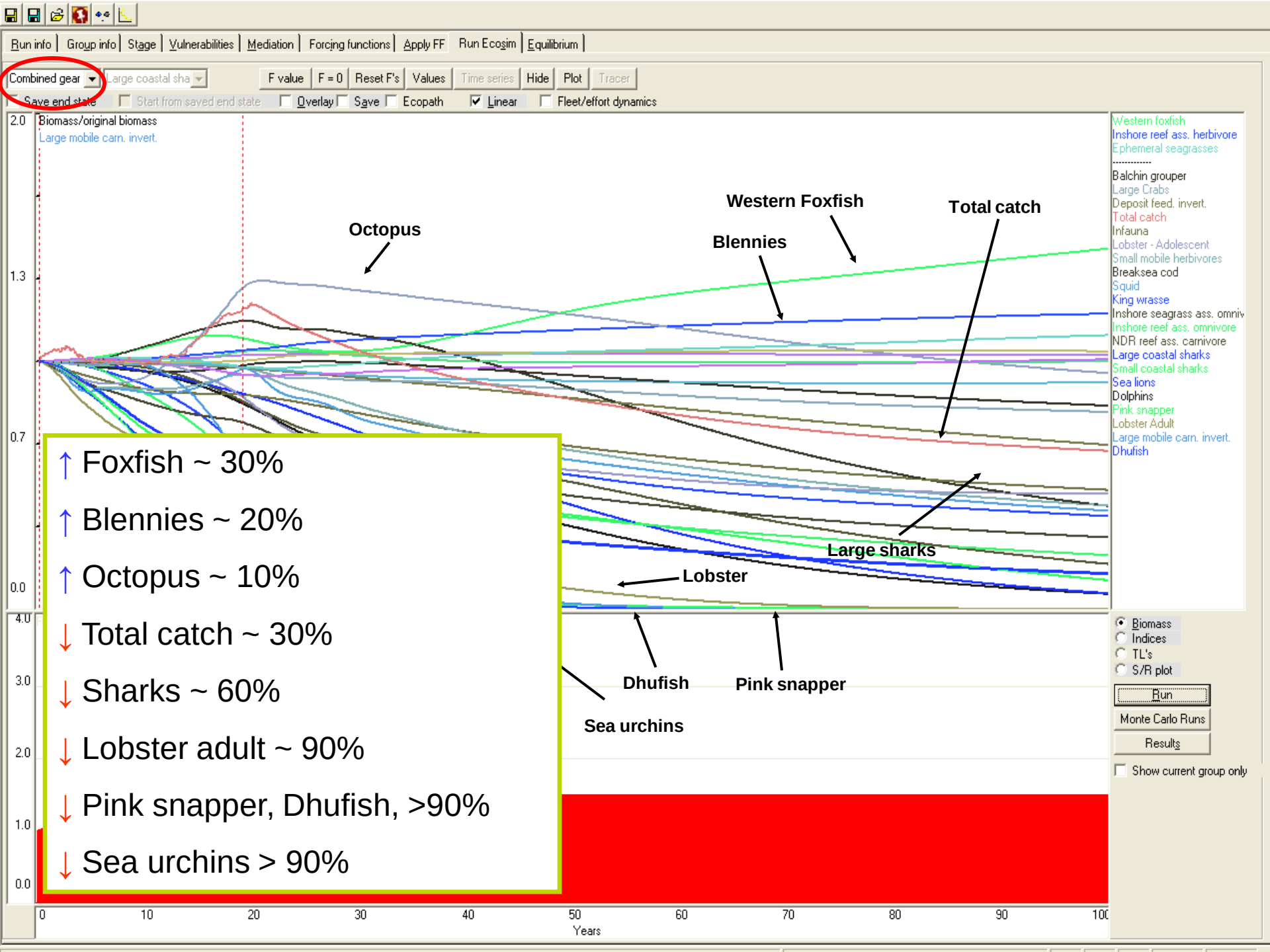
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Biomass/original biomass
Large mobile carn. invert.
2.0
1.3
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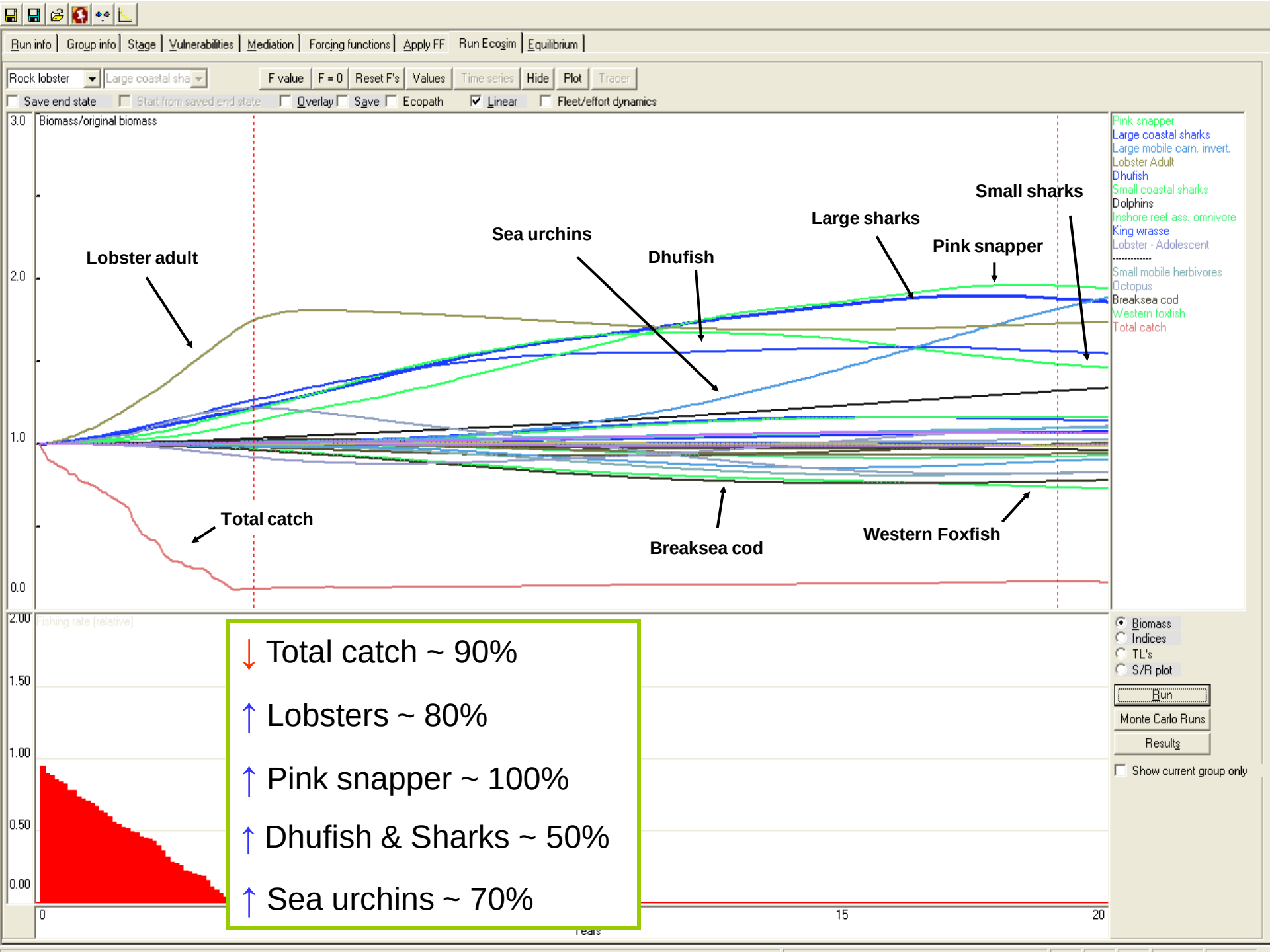
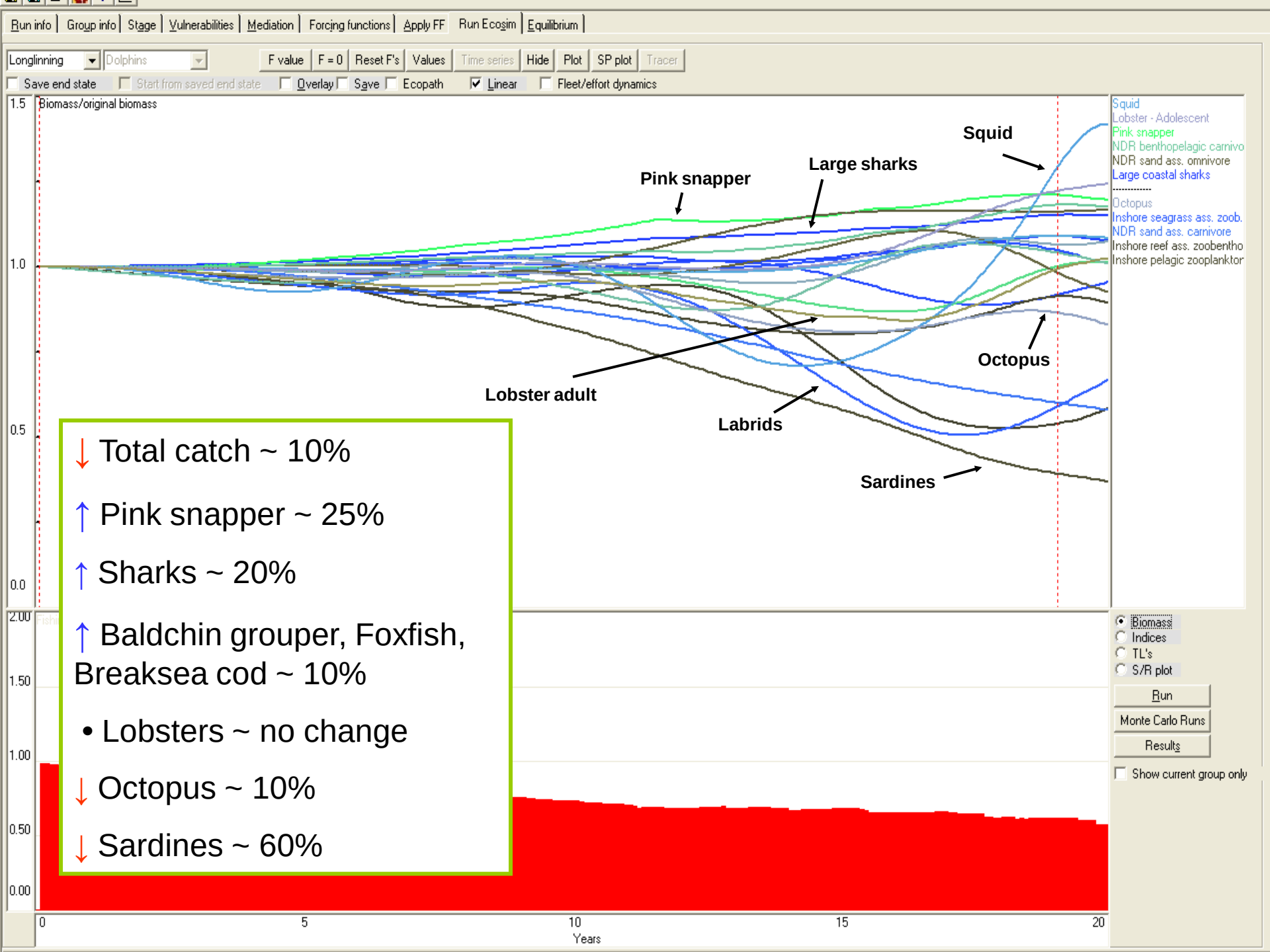
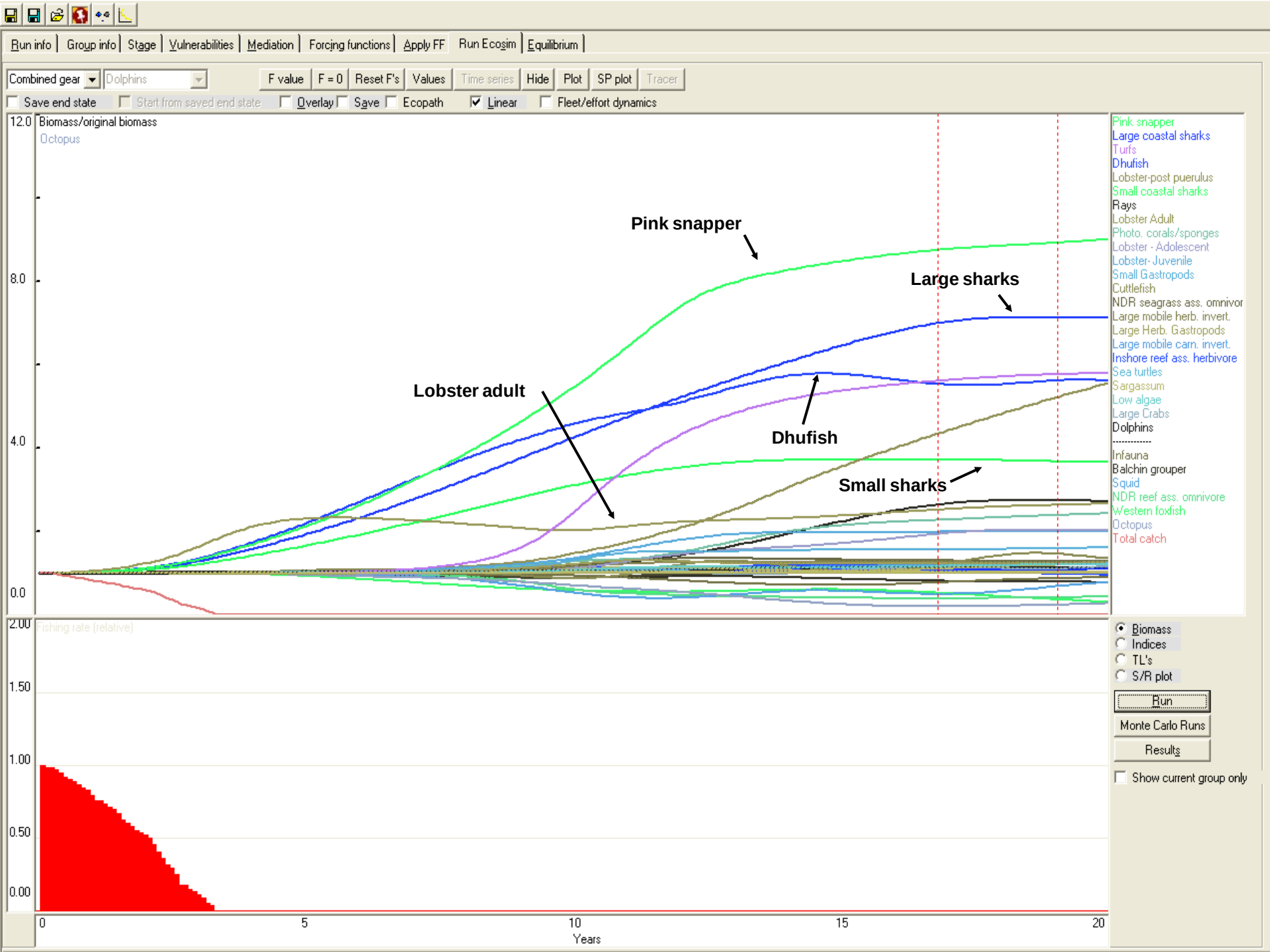
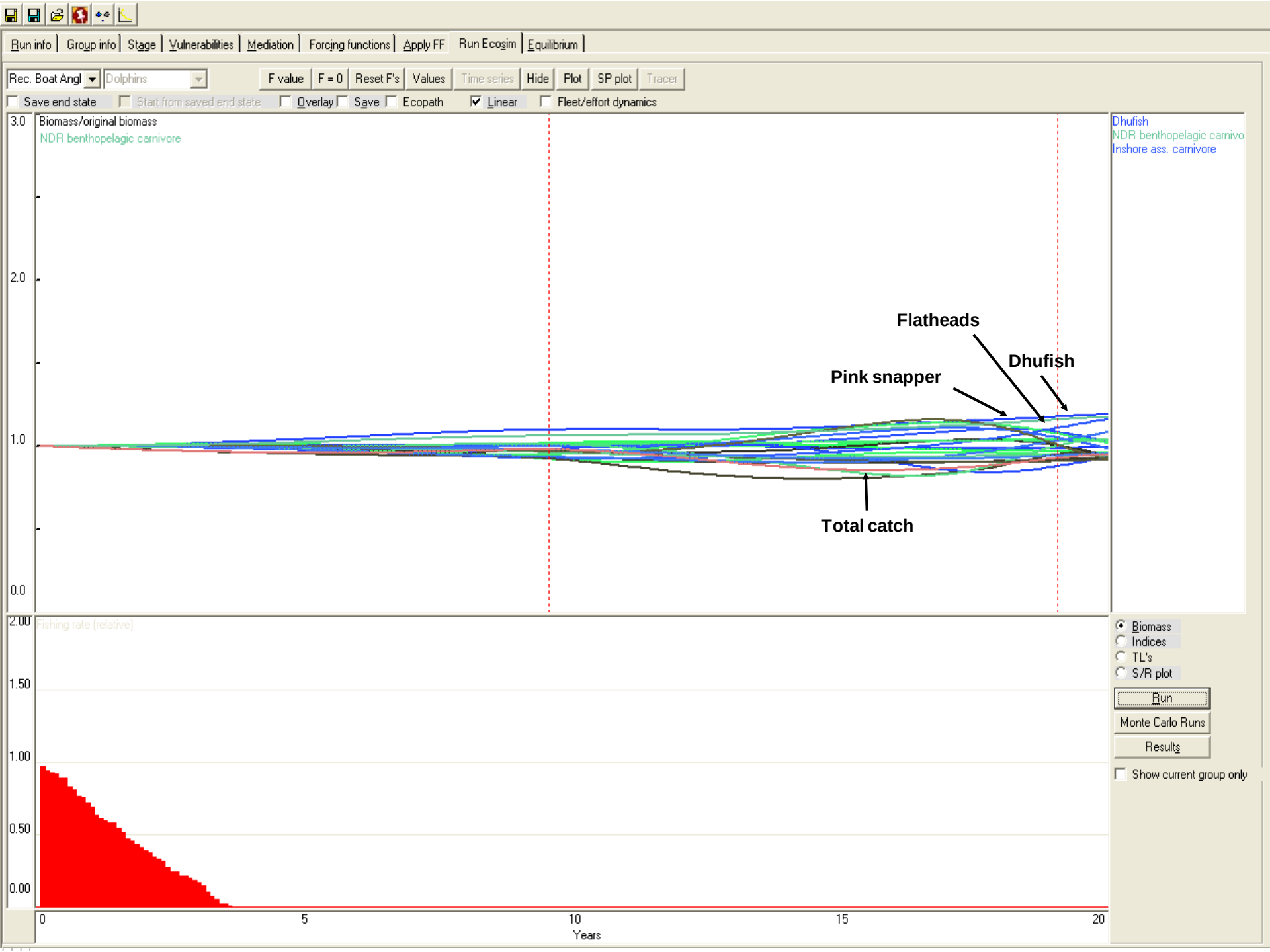
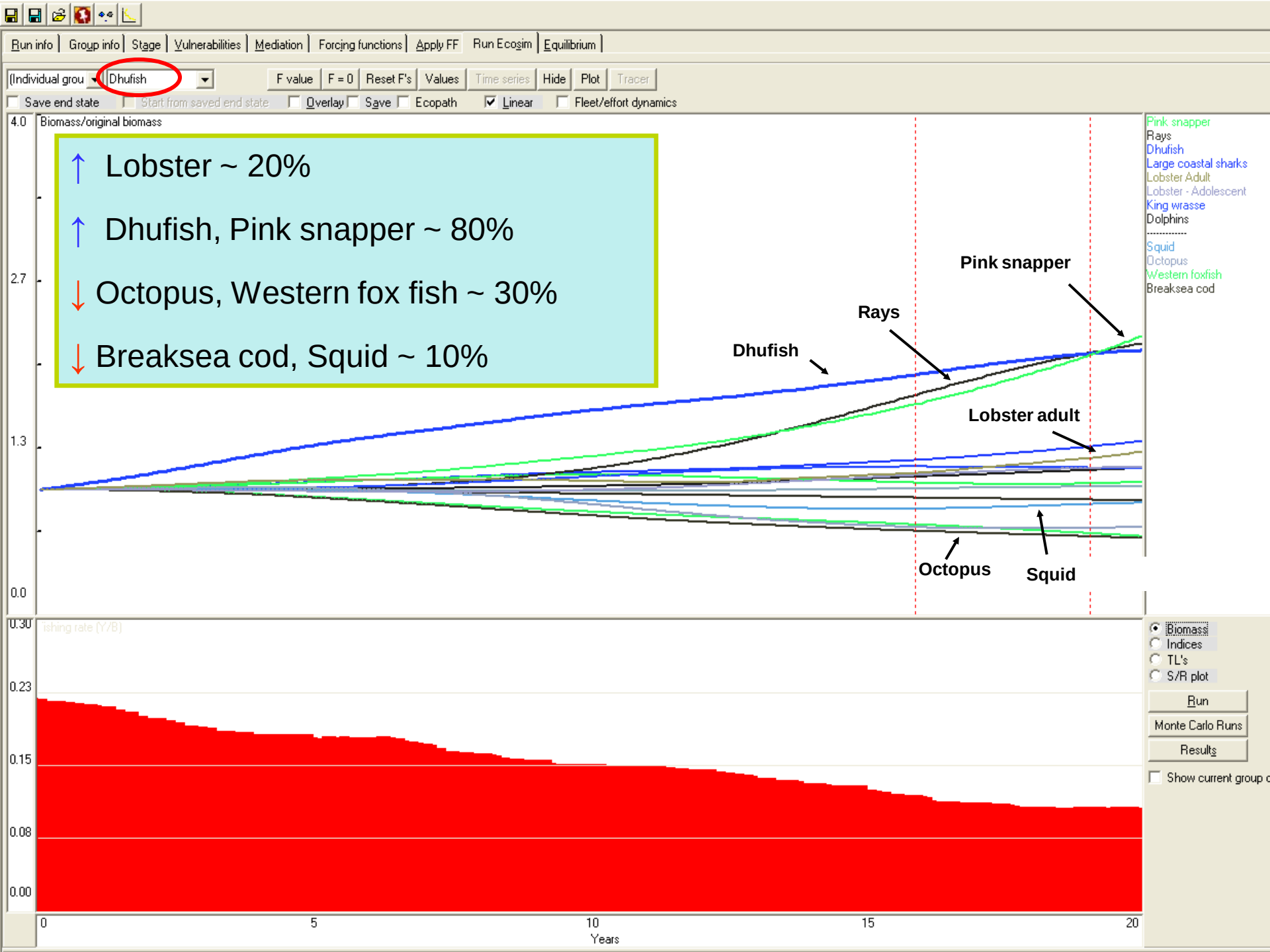
0.0
Octopus
Western Foxfish
Blennies
Total catch
Large sharks
Lobster
Dhufish
Pink snapper
Sea urchins
↑ Foxfish ~ 30%
↑ Blennies ~ 20%
↑ Octopus ~ 10%
↓ Total catch ~ 30%
↓ Sharks ~ 60%
↓ Lobster adult ~ 90%
↓ Pink snapper, Dhufish, >90%
↓ Sea urchins > 90%
Western foxfish
Inshore reef ass. herbivore
Ephemeral seagrasses
Balchin grouper
Large Crabs
Deposit feed. invert.
Total catch
Infauna
Lobster - Adolescent
Small mobile herbivores
Breaksea cod
Squid
King wrasse
Inshore seagrass ass. omniv
Inshore reef ass. omnivore
NDR reef ass. carnivore
Large coastal sharks
Small coastal sharks
Sea lions
Dolphins
Pink snapper
Lobster Adult
Large mobile carn. invert.
Dhufish
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only
4.0
3.0
2.0
1.0
0.0
0
10
20
30
40
50
60
70
80
90
100
Years

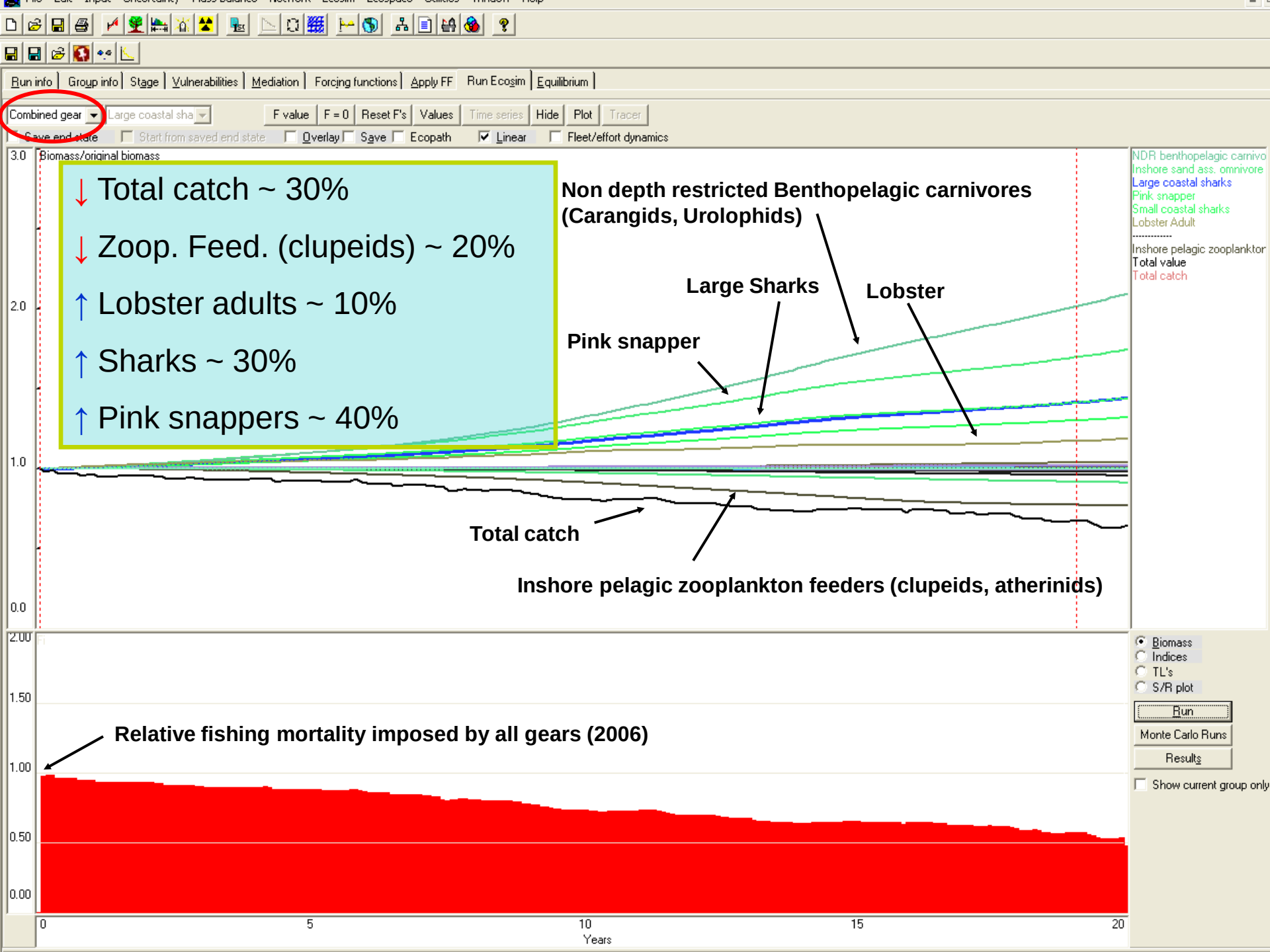

Run info
Group info
Stage
Vulnerabilities
Mediation
Forcing functions
Apply FF
Run Ecosim
Equilibrium
Rock lobster
Large coastal sha
F value
F = 0
Reset F's
Values
Time series
Hide
Plot
Tracer
Save end state
Start from saved end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
3.0
2.0
1.0
0.0
Lobster adult
Sea urchins
Dhufish
Large sharks
Small sharks
Pink snapper
Total catch
Breaksea cod
Western Foxfish
Pink snapper
Large coastal sharks
Large mobile carn. invert.
Lobster Adult
Dhufish
Small coastal sharks
Dolphins
Inshore reef ass. omnivore
King wrasse
Lobster - Adolescent
Small mobile herbivores
Octopus
Breaksea cod
Western foxfish
Total catch
Fishing rate (relative)
2.00
1.50
1.00
0.50
0.00
0
15
20
Years
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only
↓ Total catch ~ 90%
↑ Lobsters ~ 80%
↑ Pink snapper ~ 100%
↑ Dhufish & Sharks ~ 50%
↑ Sea urchins ~ 70%

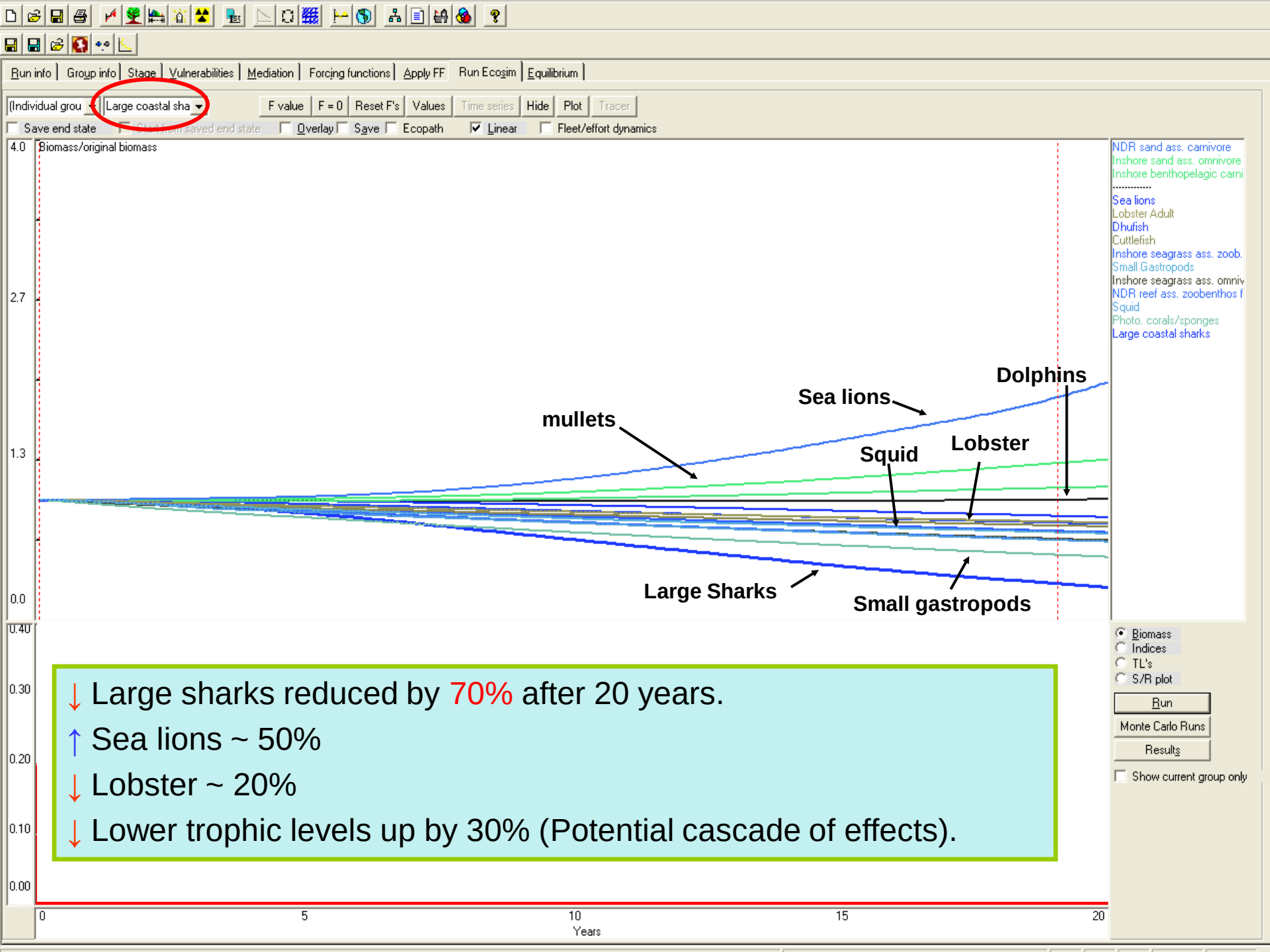

Run info
Group info
Stage
Vulnerabilities
Mediation
Forcing functions
Apply FF
Run Ecosim
Equilibrium
Longlinning
Dolphins
F value
F = 0
Reset F's
Values
Time series
Hide
Plot
SP plot
Tracer
Save end state
Start from saved end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
1.5
1.0
0.5
0.0
Squid
Pink snapper
Large sharks
Lobster adult
Octopus
Labrids
Sardines
Squid
Lobster - Adolescent
Pink snapper
NDR benthopelagic carnivo
NDR sand ass. omnivore
Large coastal sharks
Octopus
Inshore seagrass ass. zoob.
NDR sand ass. carnivore
Inshore reef ass. zoobentho
Inshore pelagic zooplanktor
↓ Total catch ~ 10%
↑ Pink snapper ~ 25%
↑ Sharks ~ 20%
↑ Baldchin grouper, Foxfish, Breaksea cod ~ 10%
• Lobsters ~ no change
↓ Octopus ~ 10%
↓ Sardines ~ 60%
2.00
1.50
1.00
0.50
0.00
0
5
10
15
20
Years
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only


Run info
Group info
Stage
Vulnerabilities
Mediation
Forcing functions
Apply FF
Run Ecosim
Equilibrium
Combined gear
Dolphins
F value
F = 0
Reset F's
Values
Time series
Hide
Plot
SP plot
Tracer
Save end state
Start from saved end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
Octopus
12.0
8.0
4.0
0.0
Pink snapper
Large sharks
Lobster adult
Dhufish
Small sharks
Pink snapper
Large coastal sharks
Turfs
Dhufish
Lobster-post puerulus
Small coastal sharks
Rays
Lobster Adult
Photo. corals/sponges
Lobster - Adolescent
Lobster- Juvenile
Small Gastropods
Cuttlefish
NDR seagrass ass. omnivor
Large mobile herb. invert.
Large Herb. Gastropods
Large mobile carn. invert.
Inshore reef ass. herbivore
Sea turtles
Sargassum
Low algae
Large Crabs
Dolphins
Infauna
Balchin grouper
Squid
NDR reef ass. omnivore
Western foxfish
Octopus
Total catch
Fishing rate (relative)
2.00
1.50
1.00
0.50
0.00
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only
0
5
10
15
20
Years


Run info
Group info
Stage
Vulnerabilities
Mediation
Forcing functions
Apply FF
Run Ecosim
Equilibrium
Rec. Boat Angl
Dolphins
F value
F = 0
Reset F's
Values
Time series
Hide
Plot
SP plot
Tracer
Save end state
Start from saved end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
NDR benthopelagic carnivore
3.0
2.0
1.0
0.0
Flatheads
Dhufish
Pink snapper
Total catch
Dhufish
NDR benthopelagic carnivo
Inshore ass. carnivore
Fishing rate (relative)
2.00
1.50
1.00
0.50
0.00
0
5
10
15
20
Years
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only


Run info
Group info
Stage
Vulnerabilities
Mediation
Forcing functions
Apply FF
Run Ecosim
Equilibrium
(Individual grou
Dhufish
F value
F = 0
Reset F's
Values
Time series
Hide
Plot
Tracer
Save end state
Start from saved end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
4.0
2.7
1.3
0.0
↑ Lobster ~ 20%
↑ Dhufish, Pink snapper ~ 80%
↓ Octopus, Western fox fish ~ 30%
↓ Breaksea cod, Squid ~ 10%
Pink snapper
Rays
Dhufish
Lobster adult
Octopus
Squid
Pink snapper
Rays
Dhufish
Large coastal sharks
Lobster Adult
Lobster - Adolescent
King wrasse
Dolphins
Squid
Octopus
Western foxfish
Breaksea cod
0.30
0.23
0.15
0.08
0.00
0
5
10
15
20
Years
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group


Run info
Group info
Stage
Vulnerabilities
Mediation
Forcing functions
Apply FF
Run Ecosim
Equilibrium
Combined gear
Large coastal sha
F value
F = 0
Reset F's
Values
Time series
Hide
Plot
Tracer
Save end state
Start from saved end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
3.0
2.0
1.0
0.0
↓ Total catch ~ 30%
↓ Zoop. Feed. (clupeids) ~ 20%
↑ Lobster adults ~ 10%
↑ Sharks ~ 30%
↑ Pink snappers ~ 40%
Non depth restricted Benthopelagic carnivores (Carangids, Urolophids)
Large Sharks
Lobster
Pink snapper
Total catch
Inshore pelagic zooplankton feeders (clupeids, atherinids)
NDR benthopelagic carnivo
Inshore sand ass. omnivore
Large coastal sharks
Pink snapper
Small coastal sharks
Lobster Adult
Inshore pelagic zooplanktor
Total value
Total catch
2.00
1.50
1.00
0.50
0.00
Relative fishing mortality imposed by all gears (2006)
0
5
10
15
20
Years
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only


Run info
Group info
Stage
Vulnerabilities
Mediation
Forcing functions
Apply FF
Run Ecosim
Equilibrium
(Individual grou
Large coastal sha
F value
F = 0
Reset F's
Values
Time series
Hide
Plot
Tracer
Save end state
Overlay
Save
Ecopath
Linear
Fleet/effort dynamics
Biomass/original biomass
4.0
2.7
1.3
0.0
NDR sand ass. carnivore
Inshore sand ass. omnivore
Inshore benthopelagic carni
Sea lions
Lobster Adult
Dhufish
Cuttlefish
Inshore seagrass ass. zoob.
Small Gastropods
Inshore seagrass ass. omniv
NDR reef ass. zoobenthos f
Squid
Photo. corals/sponges
Large coastal sharks
Dolphins
Sea lions
mullets
Squid
Lobster
Large Sharks
Small gastropods
0.40
0.30
0.20
0.10
0.00
0
5
10
15
20
Years
Biomass
Indices
TL's
S/R plot
Run
Monte Carlo Runs
Results
Show current group only
↓ Large sharks reduced by 70% after 20 years.
↑ Sea lions ~ 50%
↓ Lobster ~ 20%
↓ Lower trophic levels up by 30% (Potential cascade of effects).

Jurien Bay trophic structure

Energy flow in Jurien Bay