Variability of marine ecosystems, constraints and indeterminism

Christian Mullon, P. Freon, P. Cury, L. Shannon, C. Roy

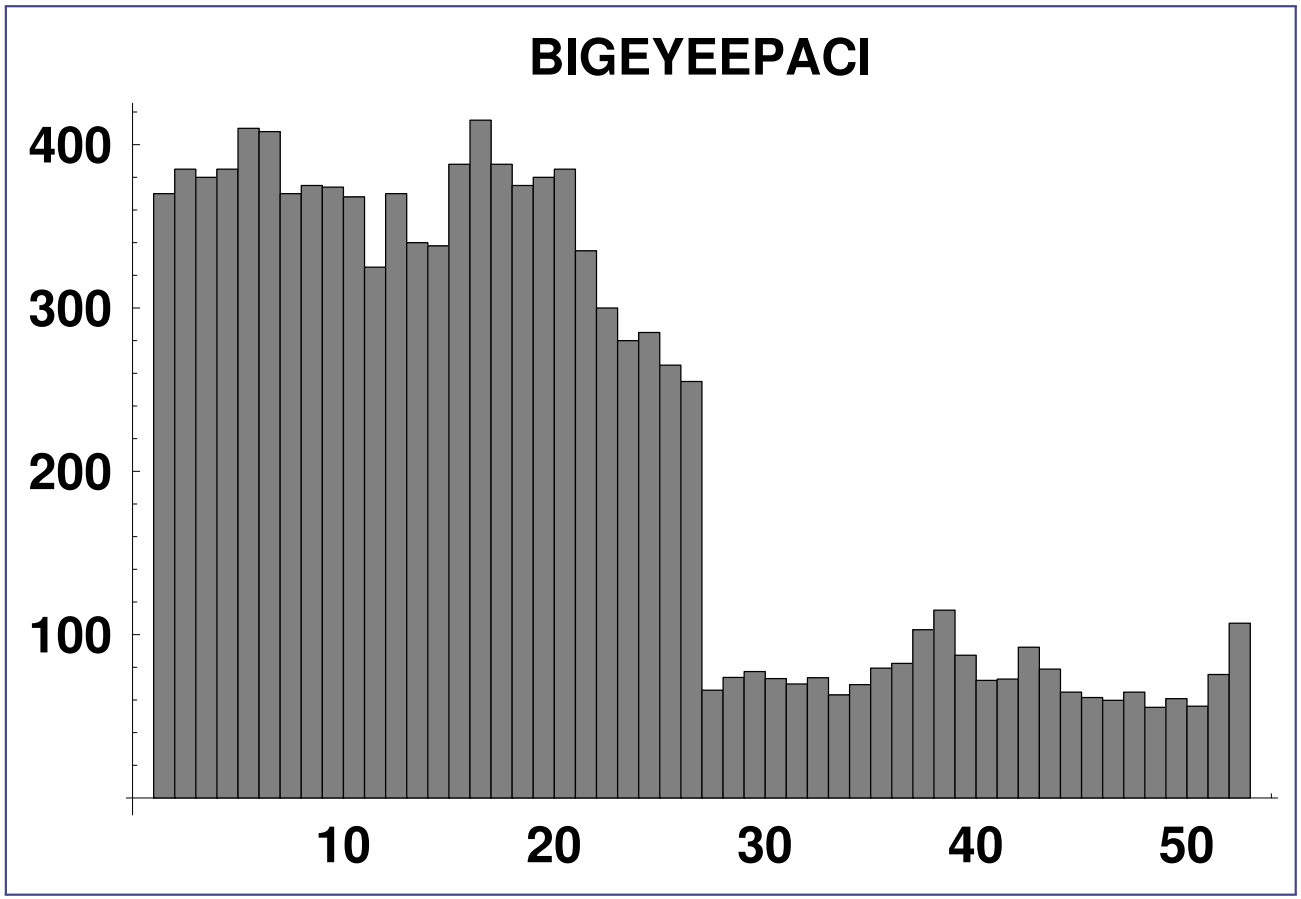
Christian.Mullon@ird.fr

ECO-UP

CRH

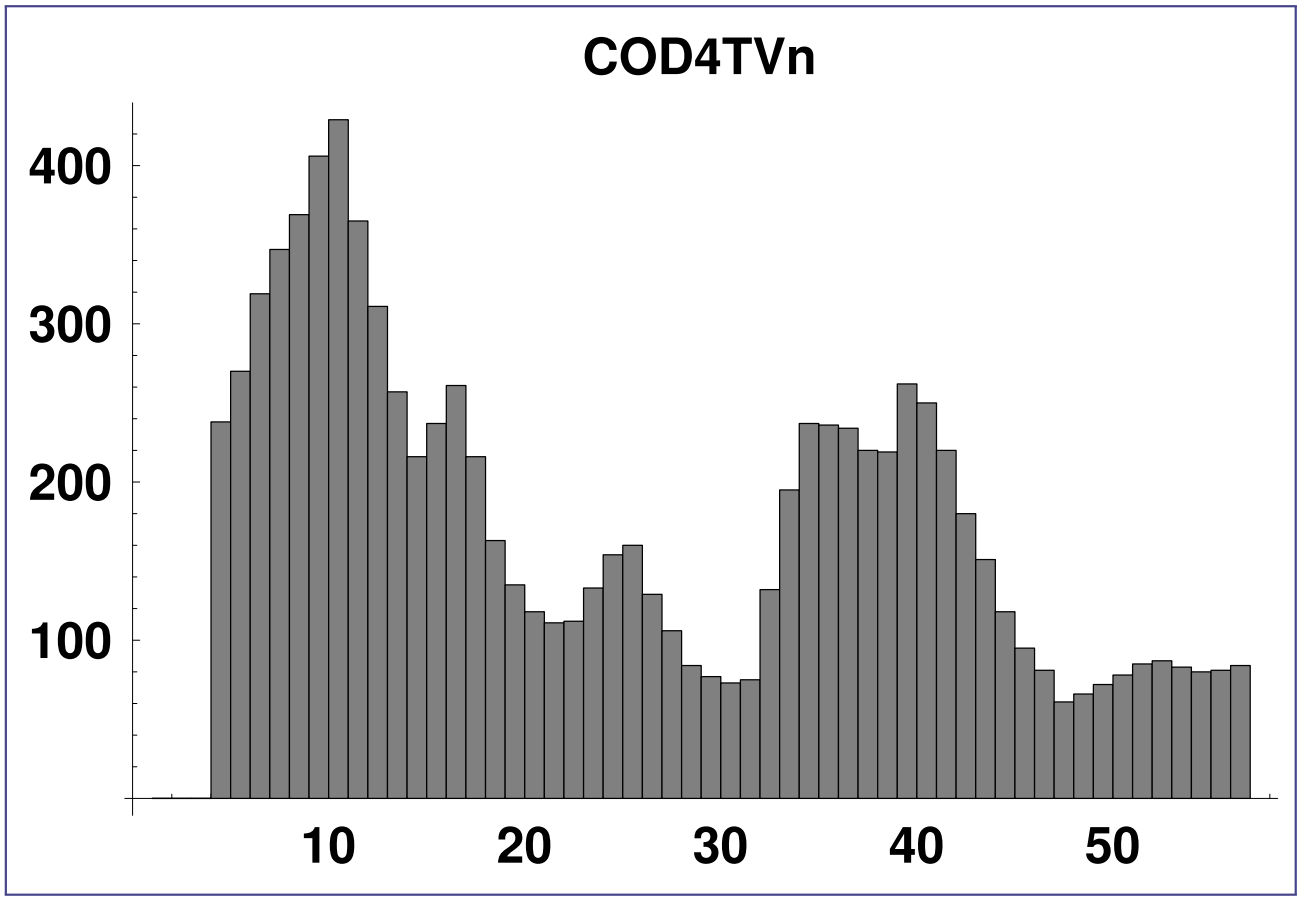
IRD

Variability patterns of abundance



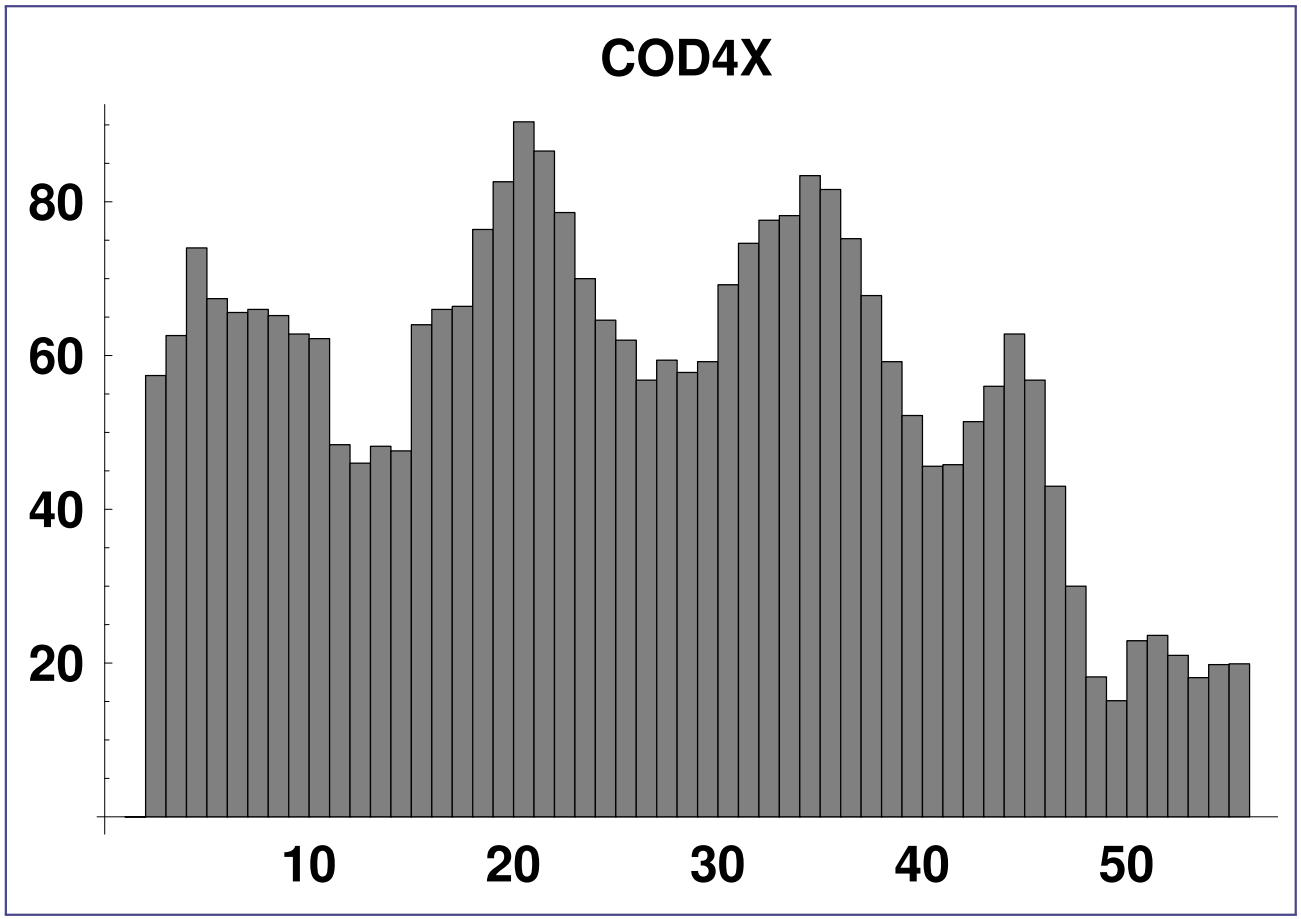
From R. Myers

Variability patterns of abundance



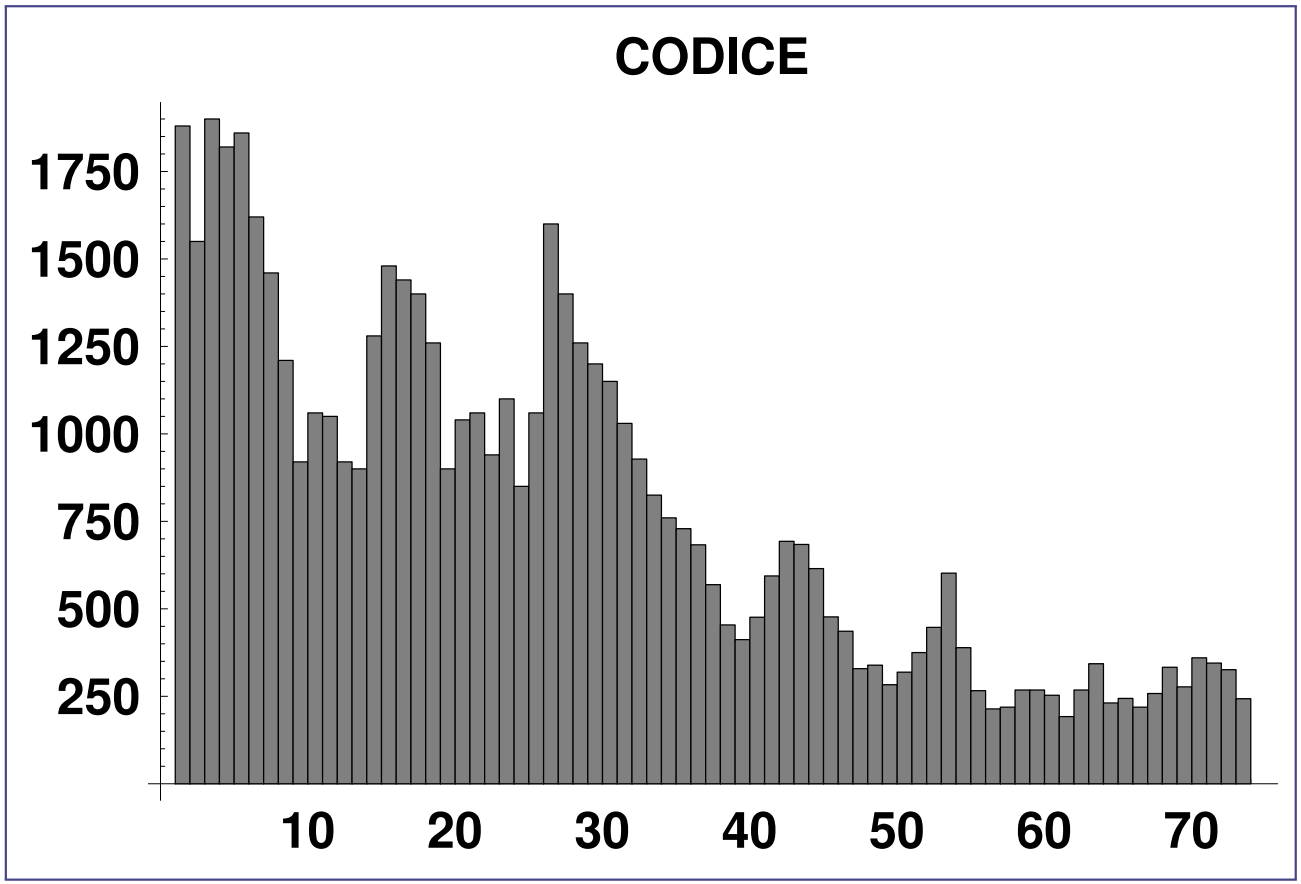
From R. Myers

Variability patterns of abundance



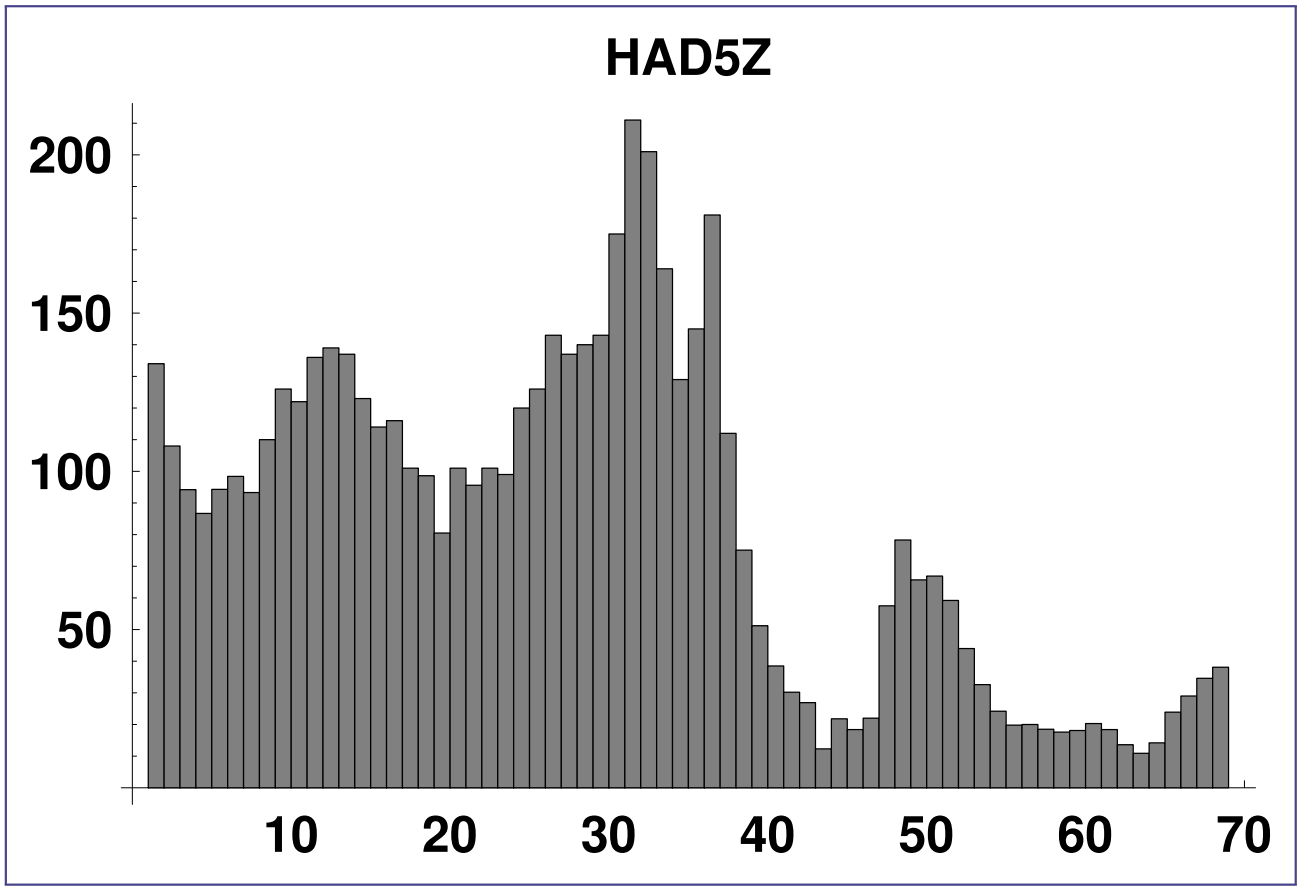
From R. Myers

Variability patterns of abundance



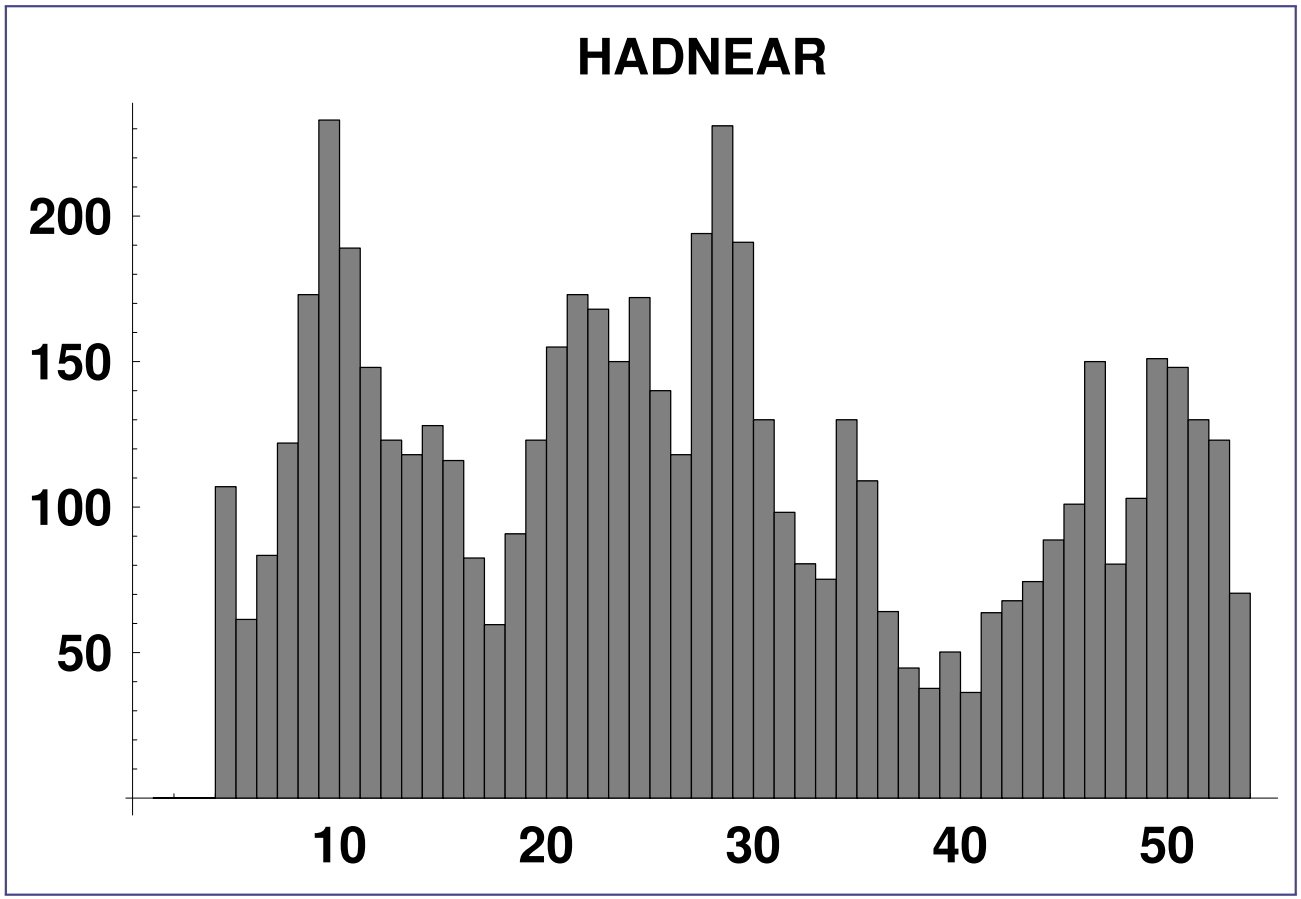
From R. Myers

Variability patterns of abundance



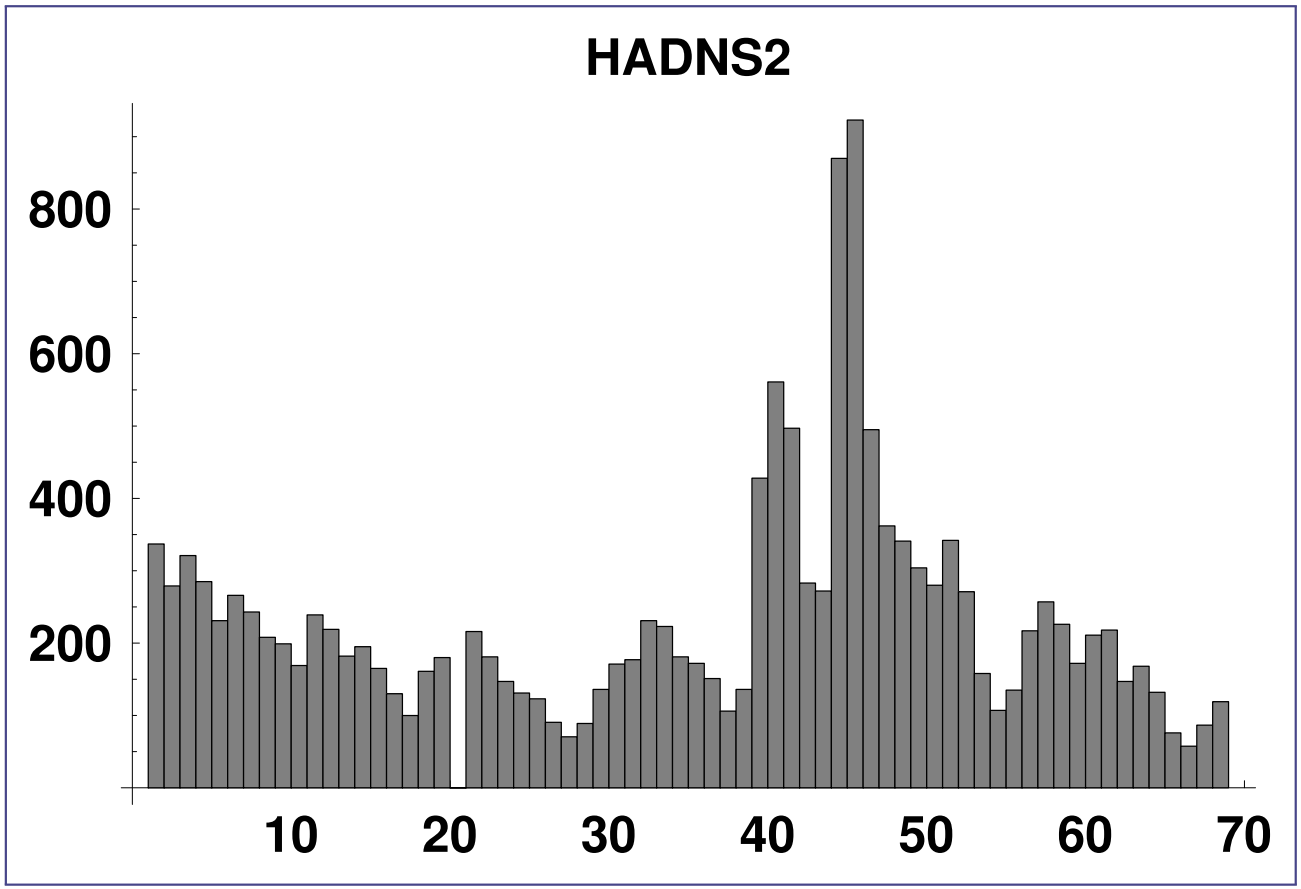
From R. Myers

Variability patterns of abundance



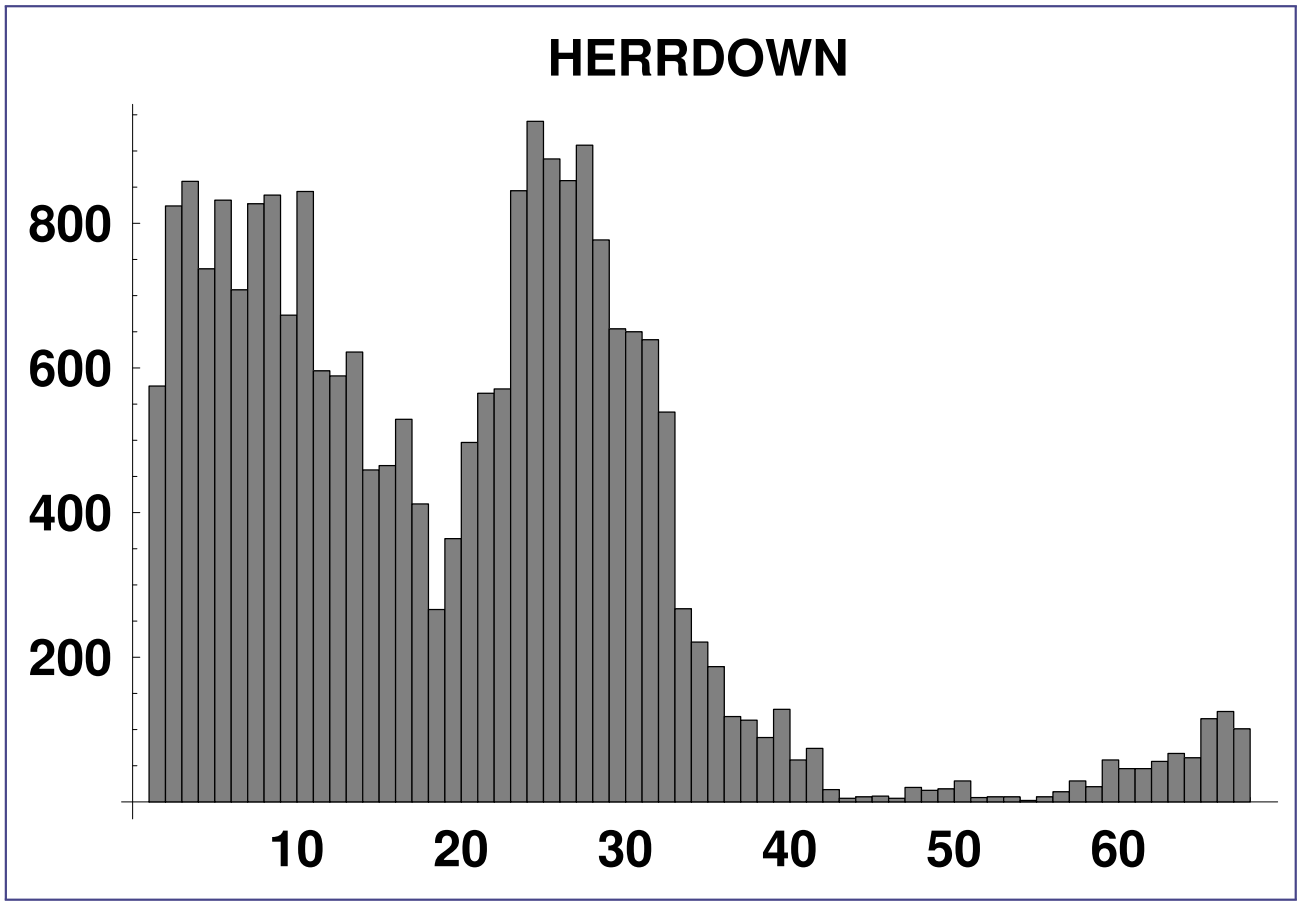
From R. Myers

Variability patterns of abundance



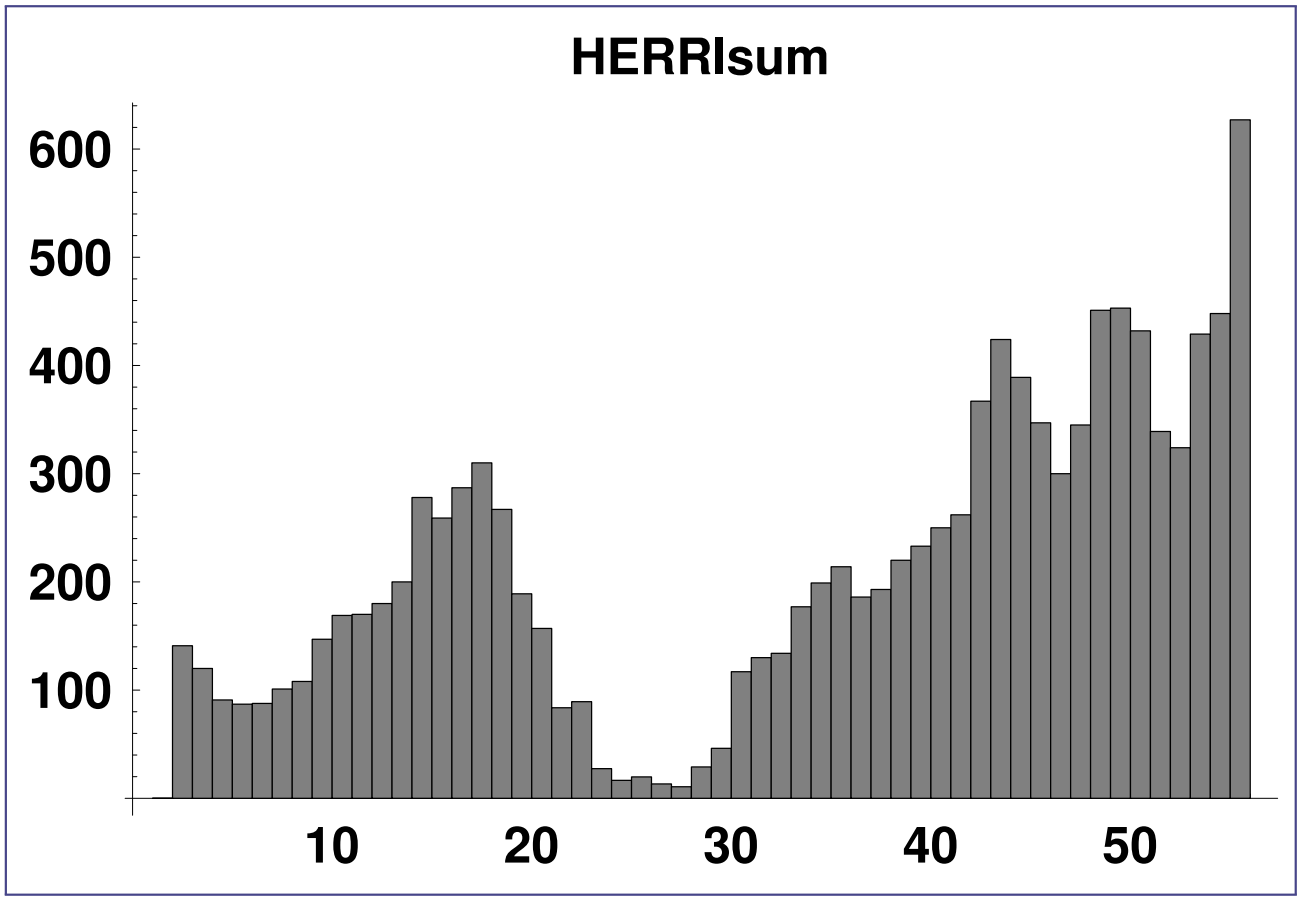
From R. Myers

Variability patterns of abundance



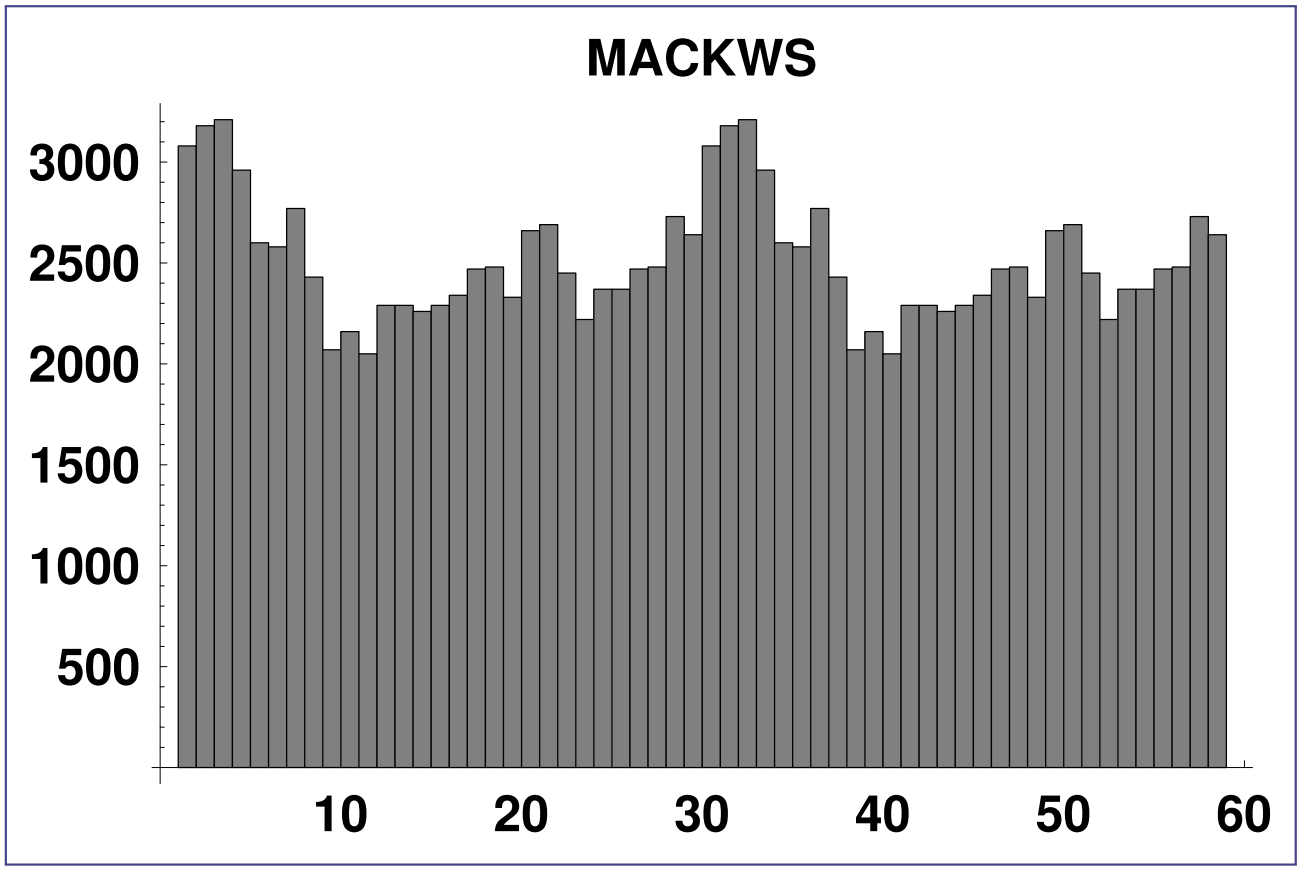
From R. Myers

Variability patterns of abundance



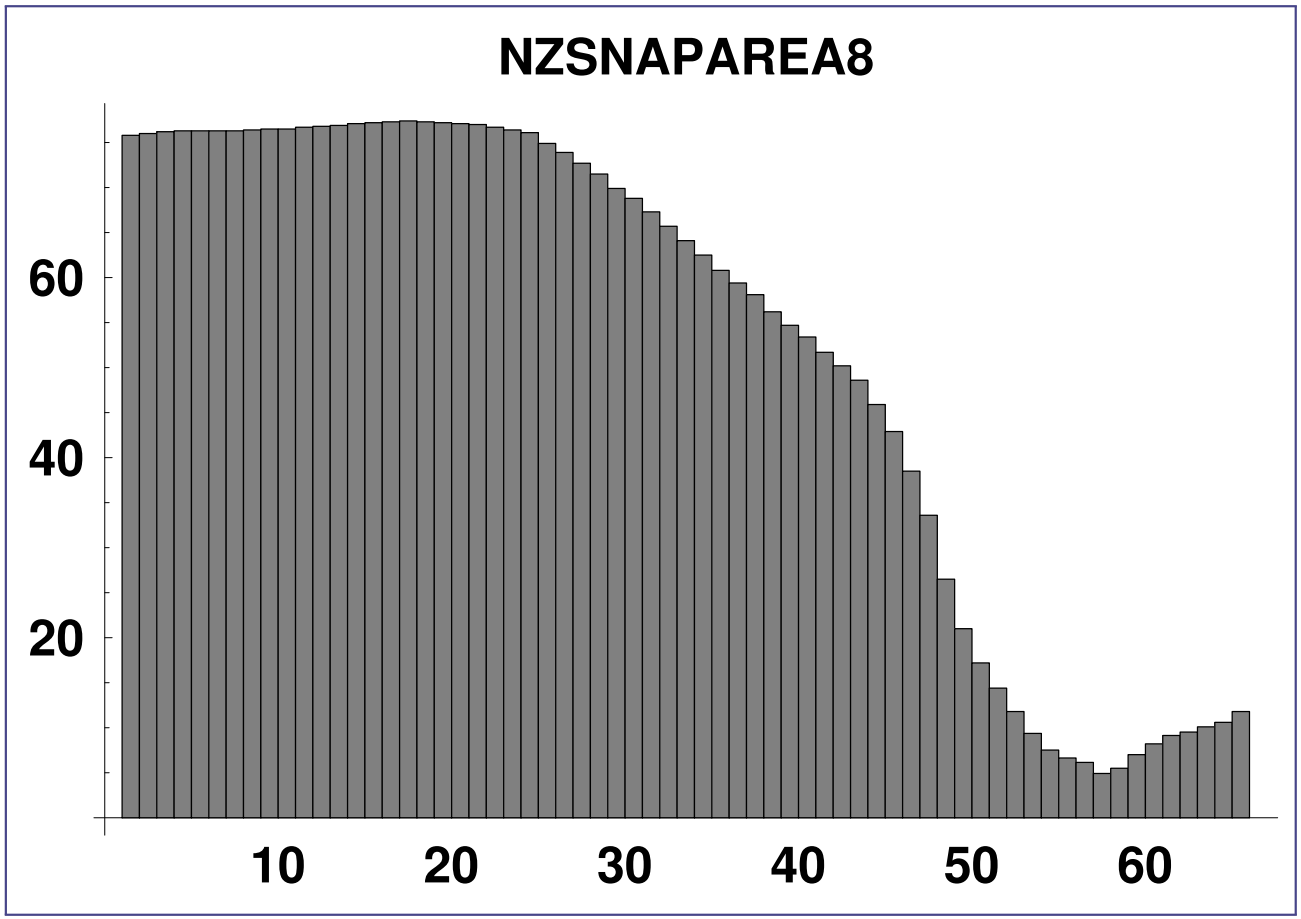
From R. Myers

Variability patterns of abundance



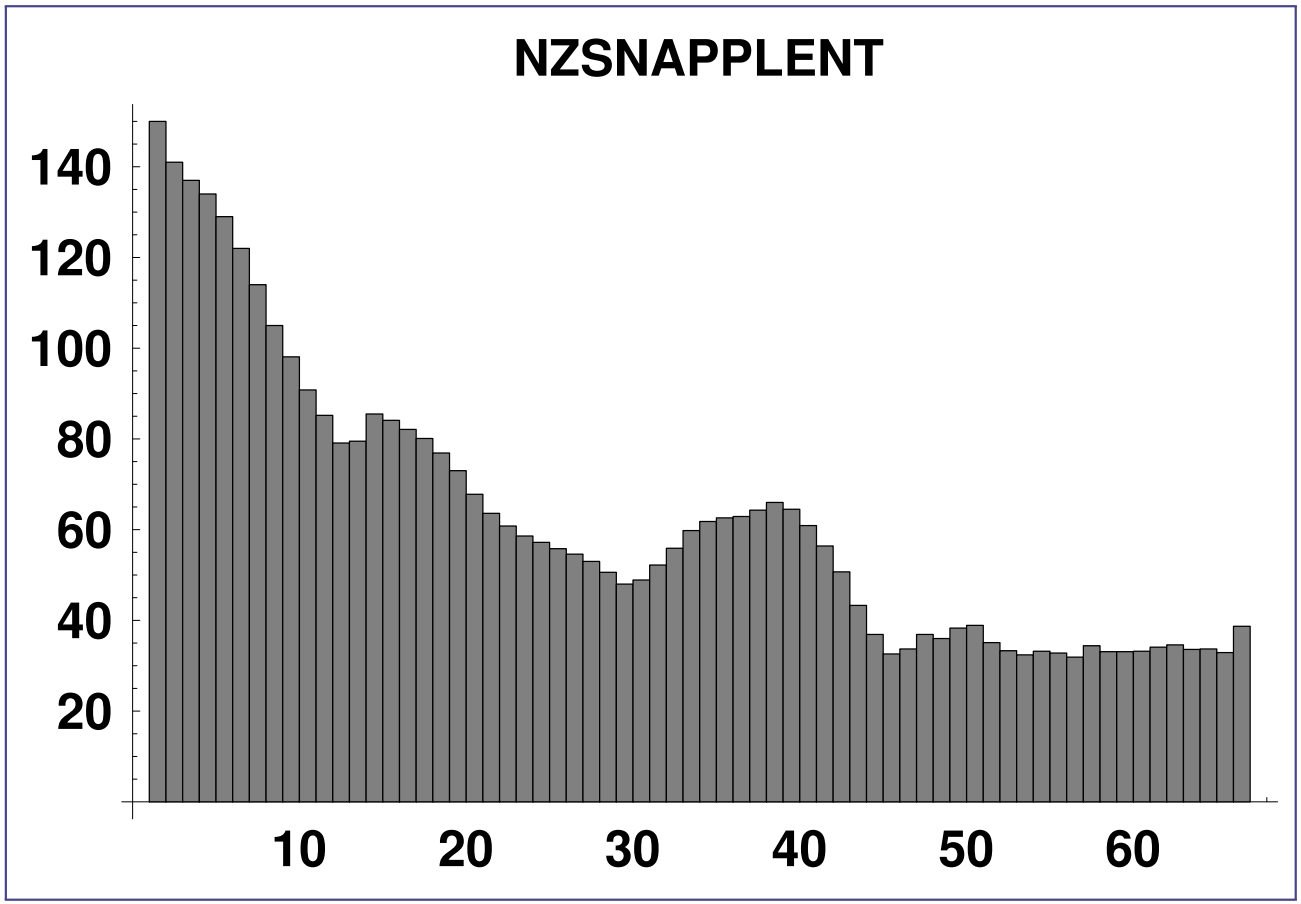
From R. Myers

Variability patterns of abundance



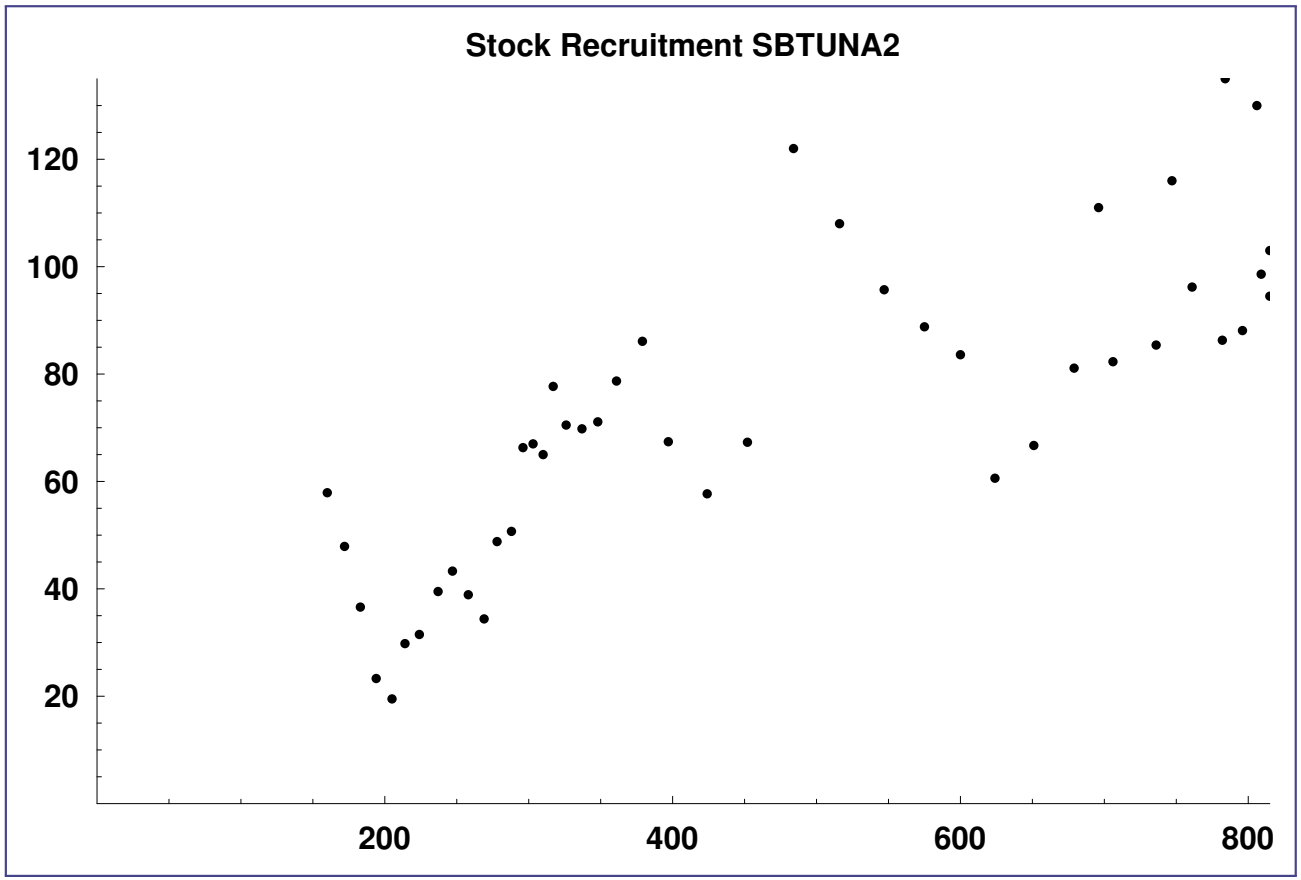
From R. Myers

Variability patterns of abundance



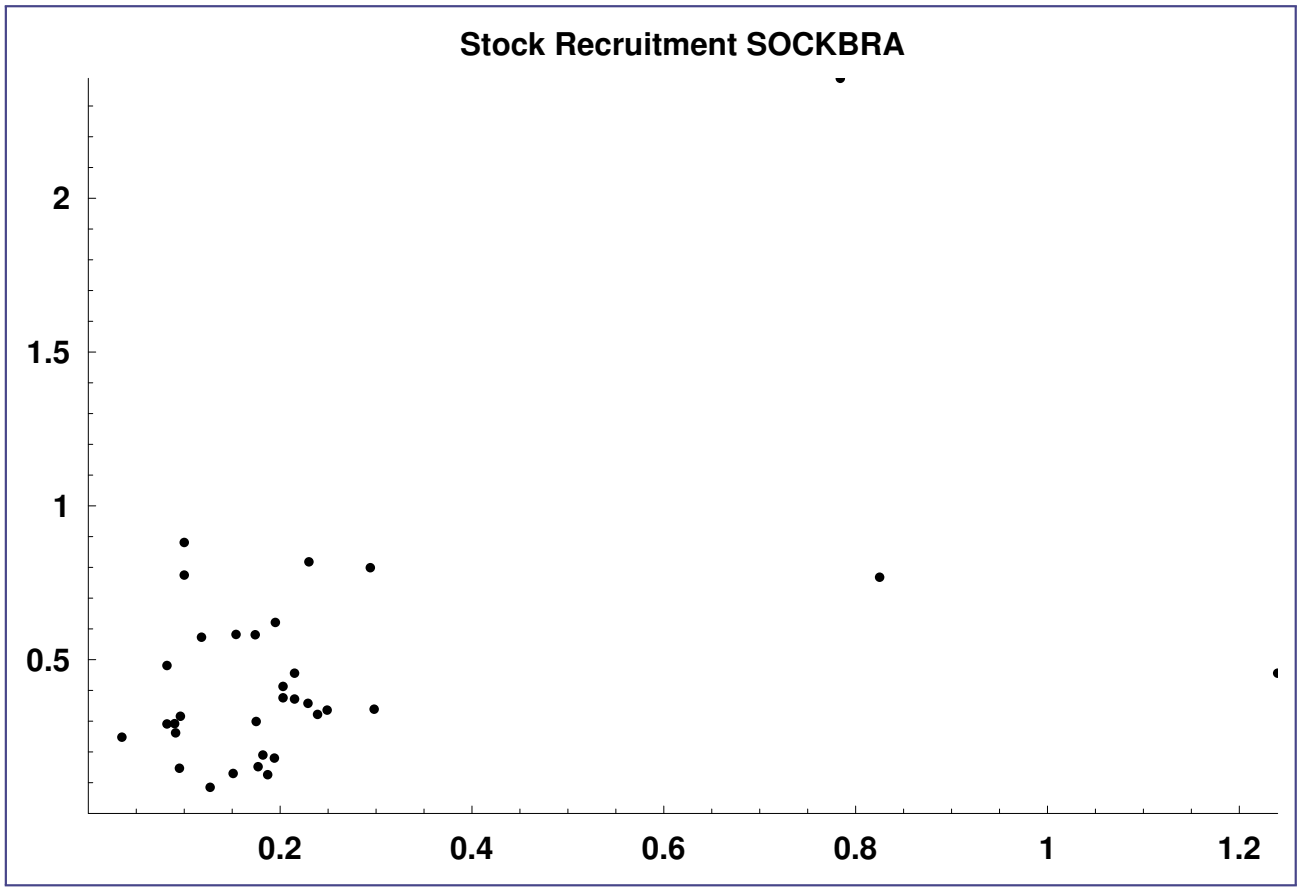
From R. Myers

Stock Recruitment



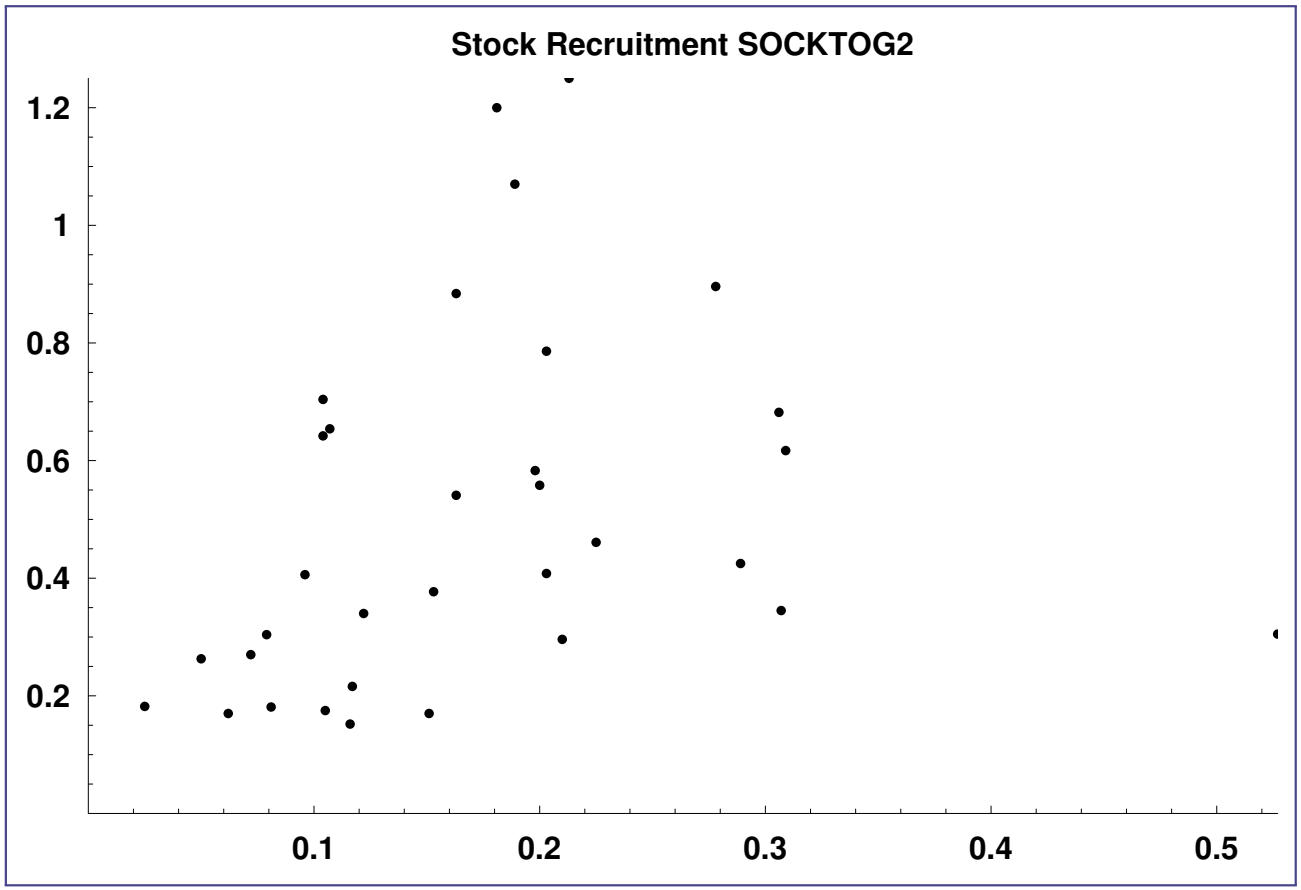
From R. Myers

Stock Recruitment



From R. Myers

Stock Recruitment



From R. Myers

Trophic models

$$\dot{B}_i = \gamma_i \sum_j X_{ji} - \sum_k X_{ik} - \mu_i B_i$$

Functional responses

$$\begin{aligned} X_{ij} &= F_{ij}(B_i, B_j) \\ &= a_{ij} B_i B_j \\ &= a_{ij} B_i B_j / (1 + c_{ij} B_j) \end{aligned}$$

Problems with models

- Functional relationships are not fully supported by empirical evidence
- Resulting dynamics may generate unrealistic patterns of weak temporal variability
- Functional responses are not easy to justify in a multi-species context

Bayesian modelling

A rigorous mathematical response to address these objections is considering observed abundance time series as resulting from stochastic processes

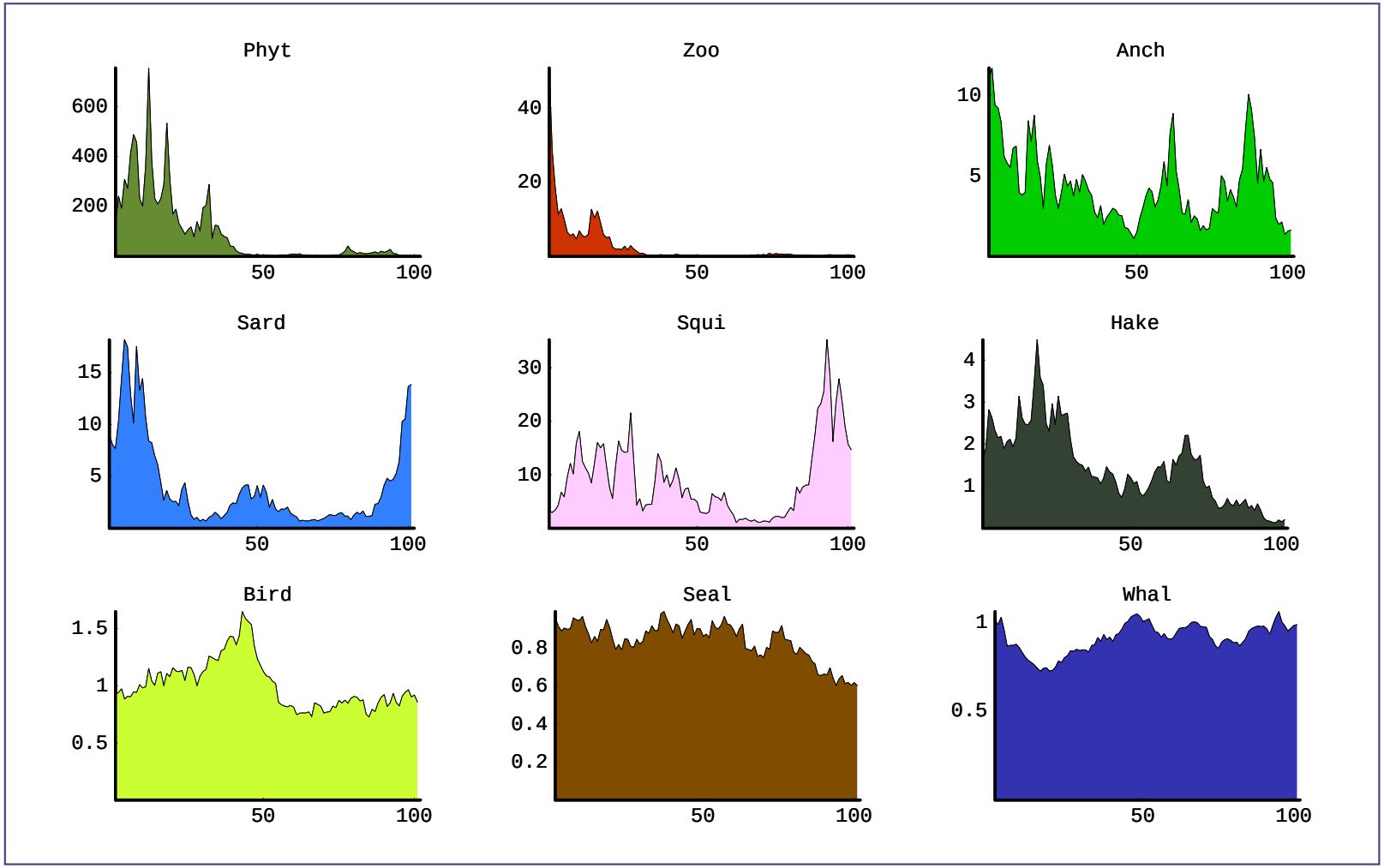
A very first model

Autoregressive stochastic process

$X_s(t+1)/X_s(t) \in LN(0, \rho_s)$;

Parameter ρ_s, the "inertia" of the species is defined in terms of its lifetime.

A very first model



Goals of "tychastic" modelling

- Question assumptions about the nature of functional responses and the structure of stochasticity
- Represent intrinsic variability within an ecological system
- Reconsider the interplay, in stochastic models, between the "structural" part and the stochastic part, relaxing most of the hypotheses about them.

Modeling principles

- Defining the structural part in terms of constraints instead of functional relationships,
- Considering no structure in the stochastic part and no associated probability function;
- The variability patterns appearing in abundance or catch time-series have been used to guide the modeling approach

Assumptions

- Biomass changes are limited according to an inertia principle related to the lifespan of the species;
- Food ingestion is limited according to a satiation constraint;
- A conventional mass balanced equation relating flows and biomass of a given species;

The model is biologically constrained, but its dynamics are largely non-deterministic.

Mathematical formulation

$$\gamma_s(P_s + I_s) \quad = \quad O_s + R_s + Y_s$$

- P_s : biomass consumed by species s ,
- I_s : other nutrients,
- O_s : biomass of s consumed by its predators,
- Y_s : caught biomass,
- γ_s : assimilation efficiency of s
- R_s : other losses of s, $R_s = \mu_s B_s$,
- X_{rs} : predation of species r by species s

Mathematical formulation

$$\gamma_s(\sum_r X_{rs} + I_s) \;=\; \sum_r X_{sr} + Y_s + \mu_s B_s$$

$$B_s \;=\; (1/\mu_s)(\gamma_s(\sum_r X_{rs} + I_s) - \sum_r X_{sr} - Y_s)$$

Mathematical formulation

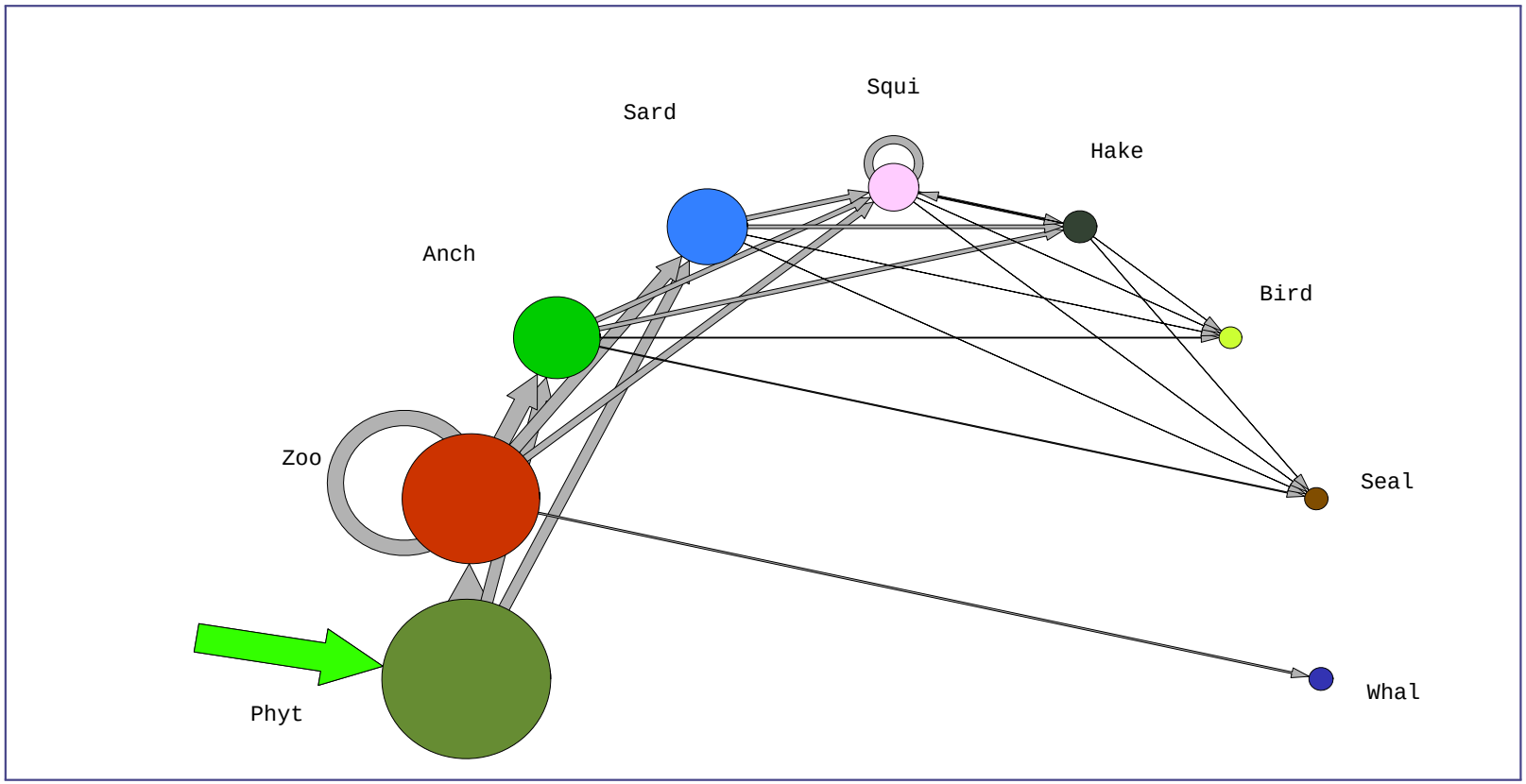
Constraints

- Inertia : $\|\Delta B_s\| \leq \rho_s B_s$, ρ_s is related to lifespan or age at maturity of the species s
- Satiety : There exists tropic flows X_{rs} such taht $\sum_r X_{rs} \leq \sigma_s B_s$.
- Trophic flows X_{rs} are such that : $\gamma_s(\sum_r X_{rs} + I_s) = \sum_r X_{sr} + Y_s + \mu_s B_s$.

Mathematical formulation

- A state is said to be feasible if these three constraints are fulfilled.
- The dynamics through the recurrence mechanism: The state of the system at time $t+1$ is randomly chosen in the set of feasible states, according to state at time t.

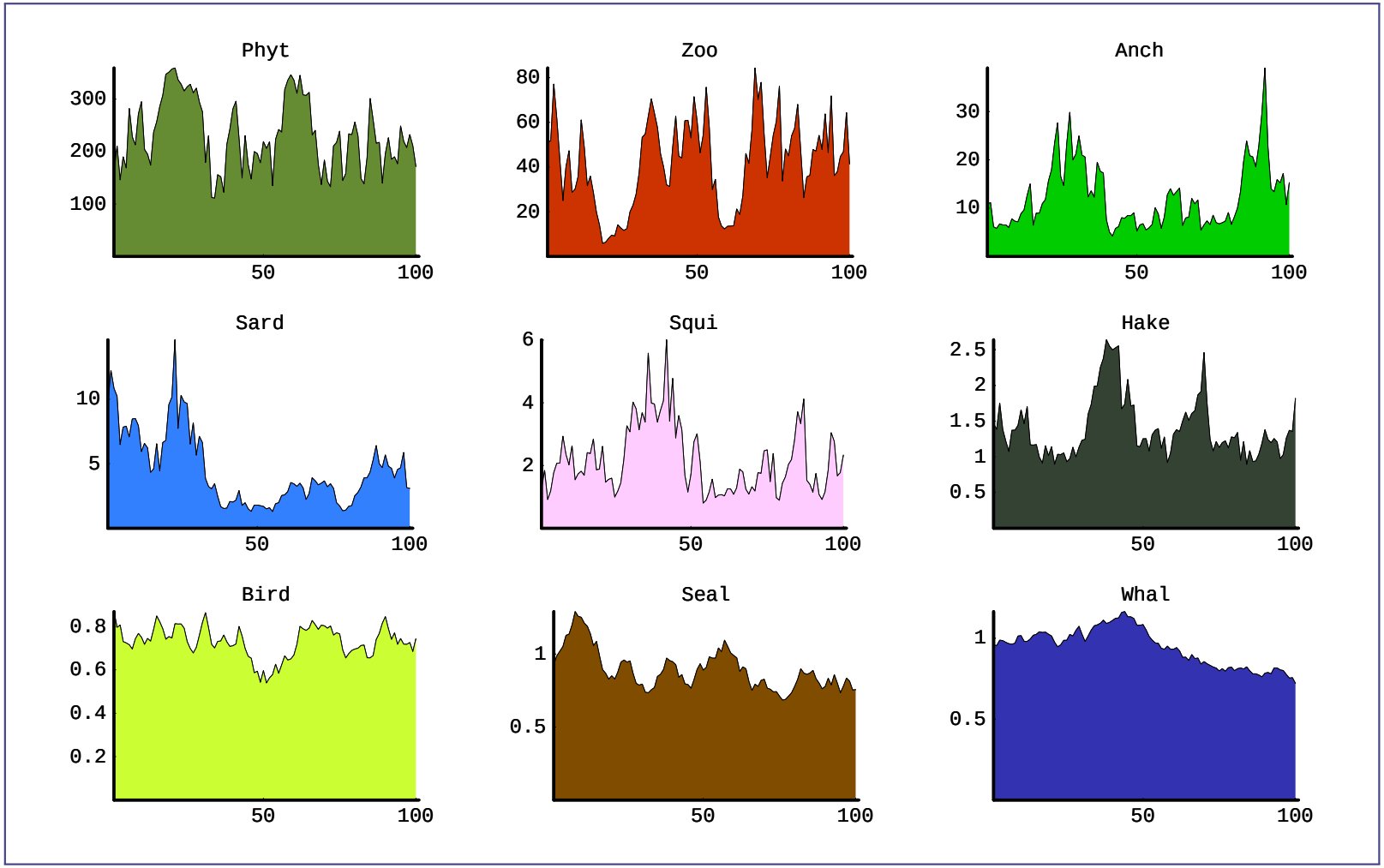
Input



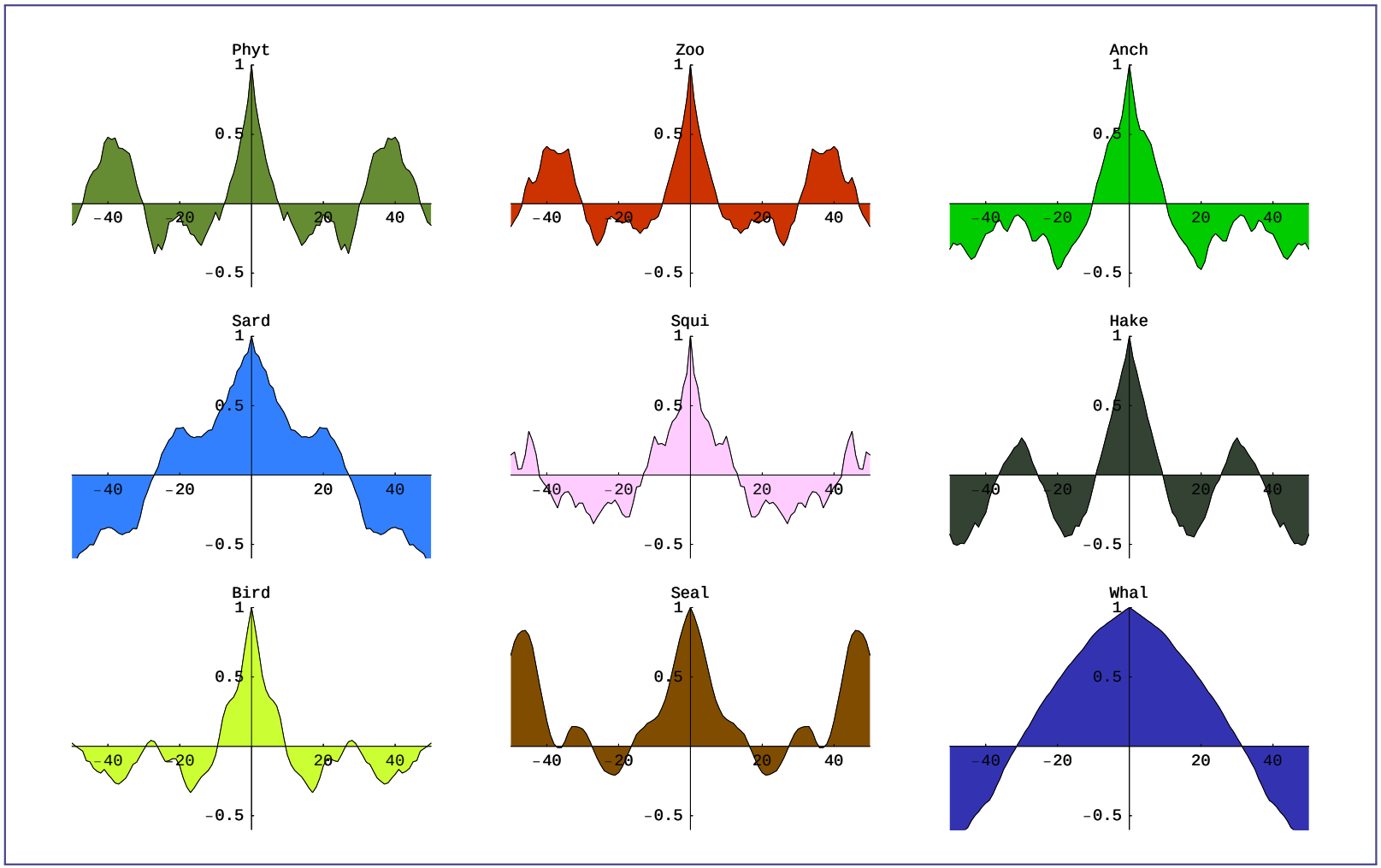
Input

Species s	Import	Initial biomass	Efficiency γ_s	Maintenance μ_s	Inertia ρ_s	Satiety σ_s
Phyt	3000	126.	2.0	15	0.85	27.1
Zoo		50.8	0.3	12	0.75	90.8
Anch		10.0	0.09	0.5	0.7	21.2
Sard		9.0	0.08	0.2	0.55	15.4
Squi		3.2	0.1	0.1	0.7	8.3
Hake		1.6	0.06	0.05	0.14	5.8
Bird		0.92	0.1	0.07	0.12	0.77
Seal		0.96	0.06	0.05	0.1	0.92
Whal		1.0	0.05	0.05	0.05	1.11

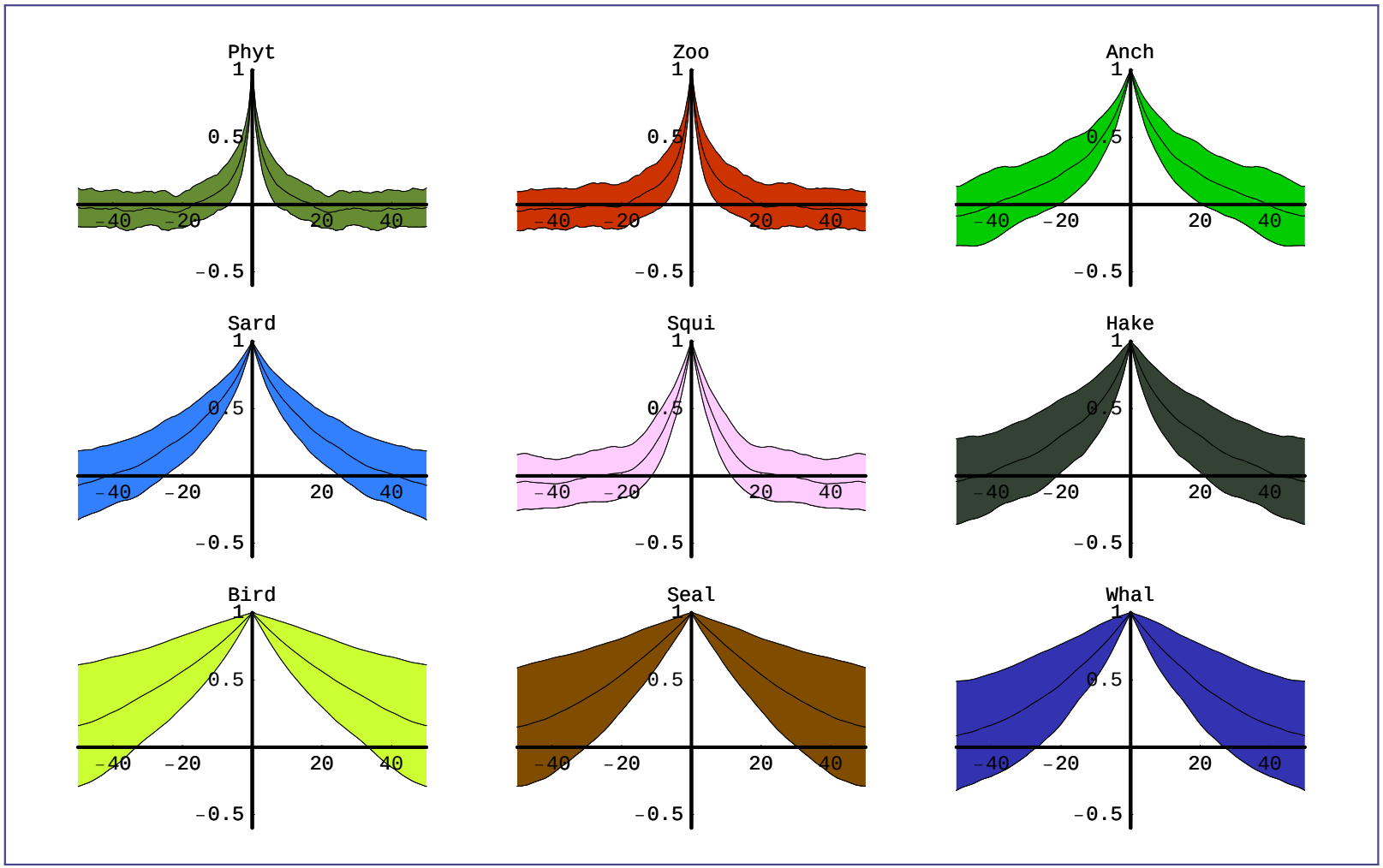
Reproduction of pseudo cycles



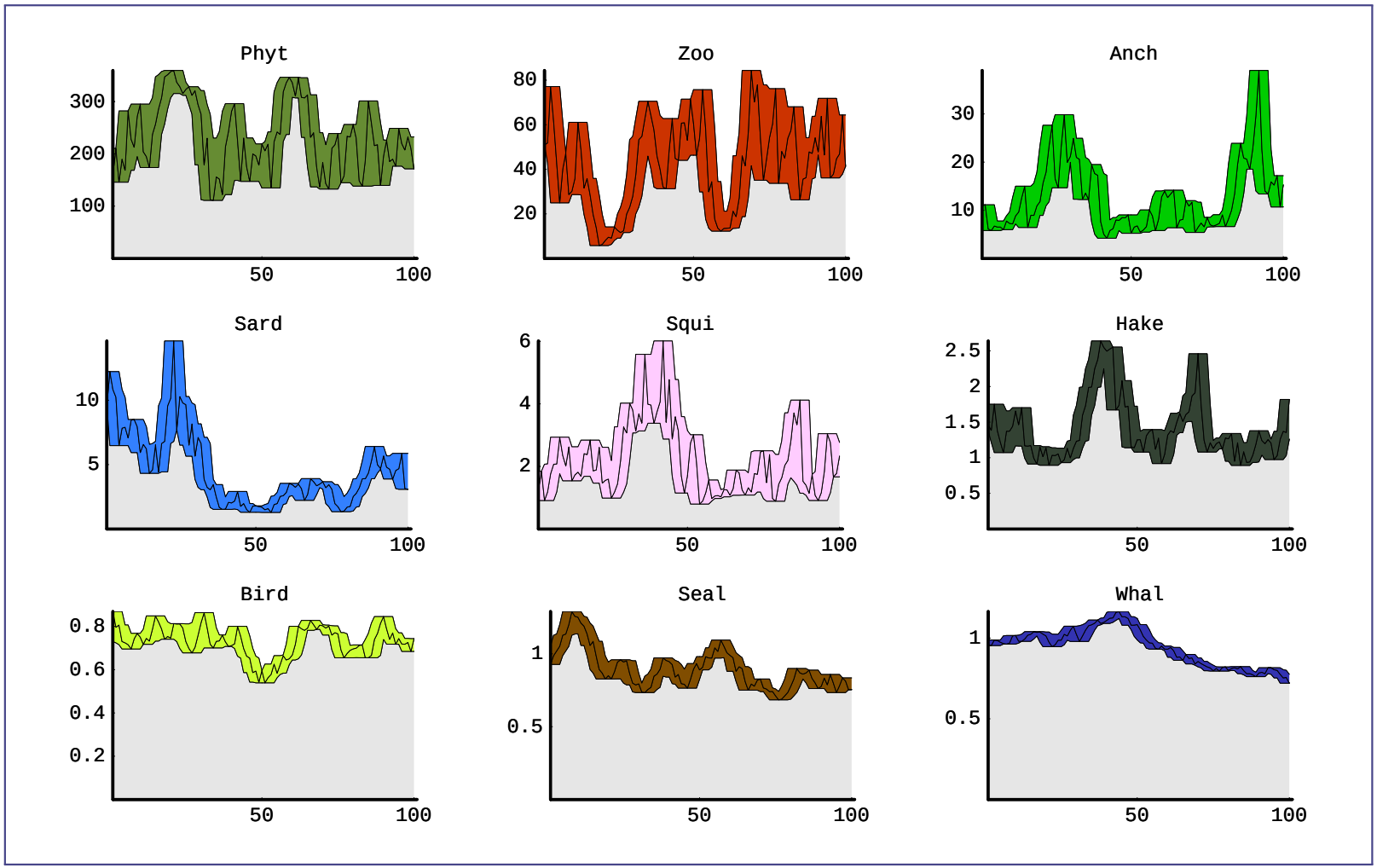
Reproduction of pseudo cycles



Reproduction of pseudo cycles



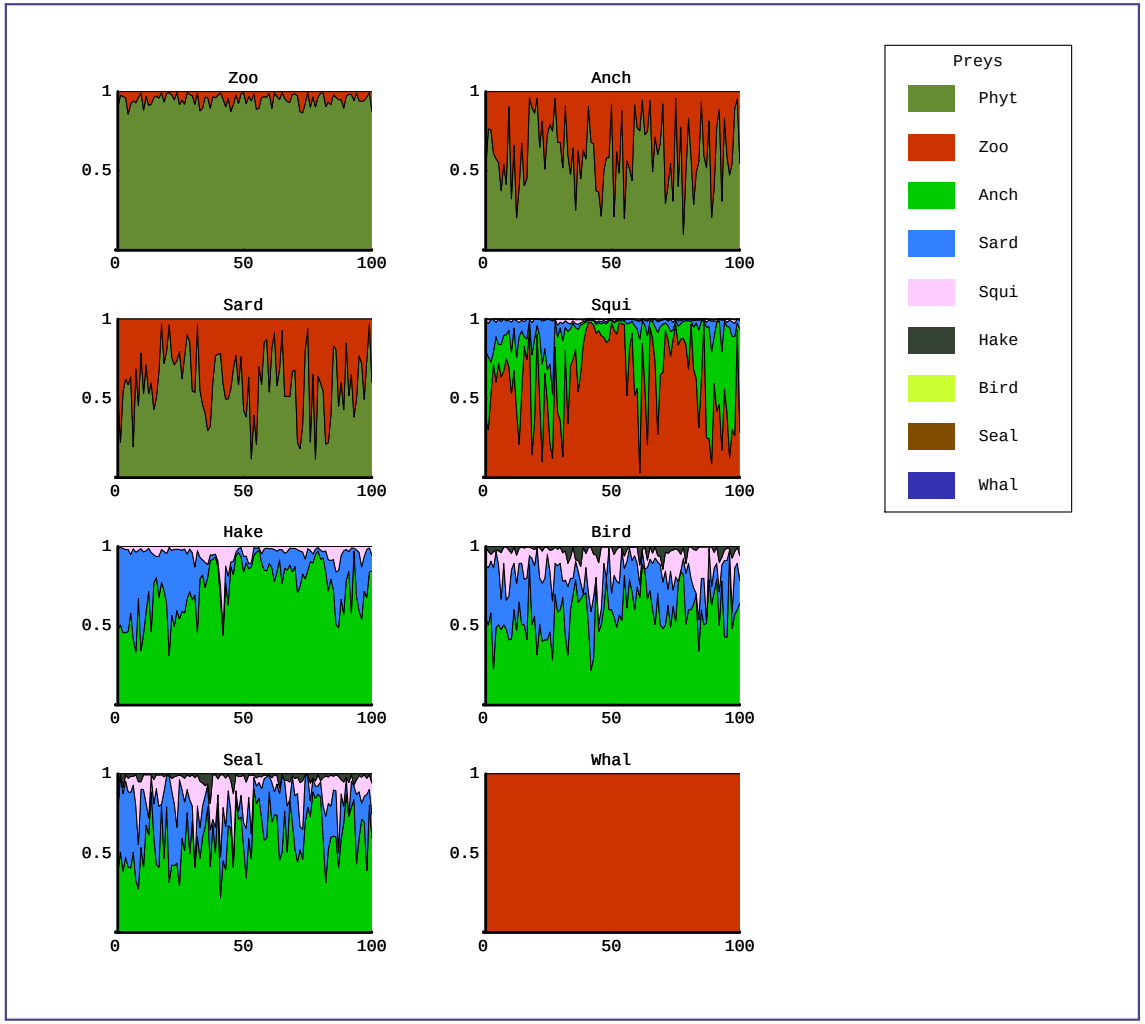
Reproduction of pseudo cycles



Reproduction of pseudo cycles

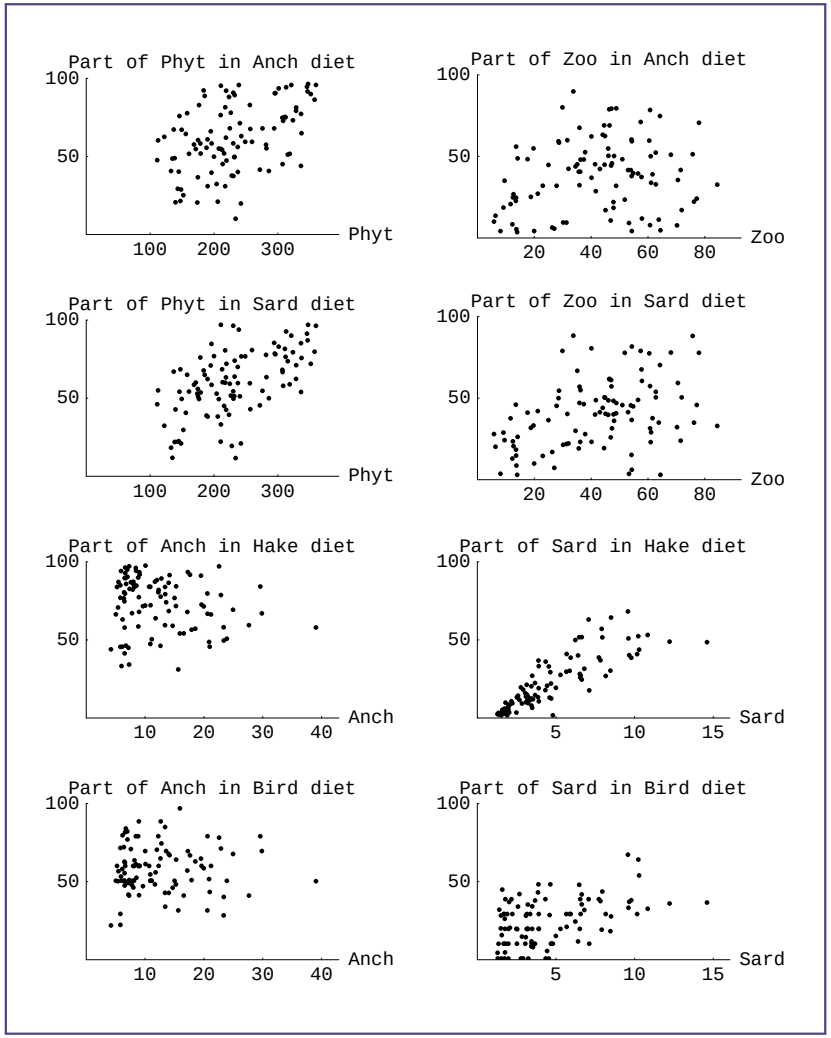
	Variations	Volatility
Phytoplankton	343(75)	442(59)
Zooplankton	731(372)	742(81)
Anchovy	1445(1677)	928(108)
Sardine	1294(803)	758(87)
Squid	1265(768)	942(89)
Hake	356(228)	190(15)
Birds	333(186)	167(13)
Seals	258(123)	139(15)
Whales	138(100)	71(6)

Reproduction of diet patterns

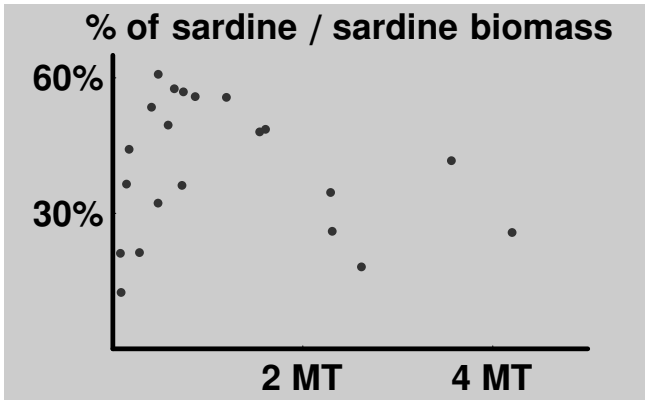


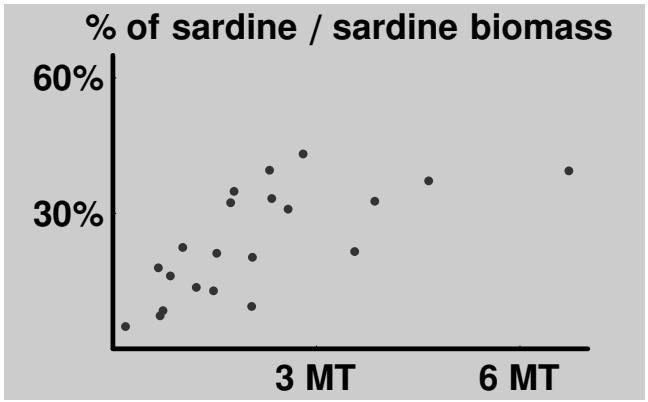
From T. Crawford

Reproduction of diet patterns

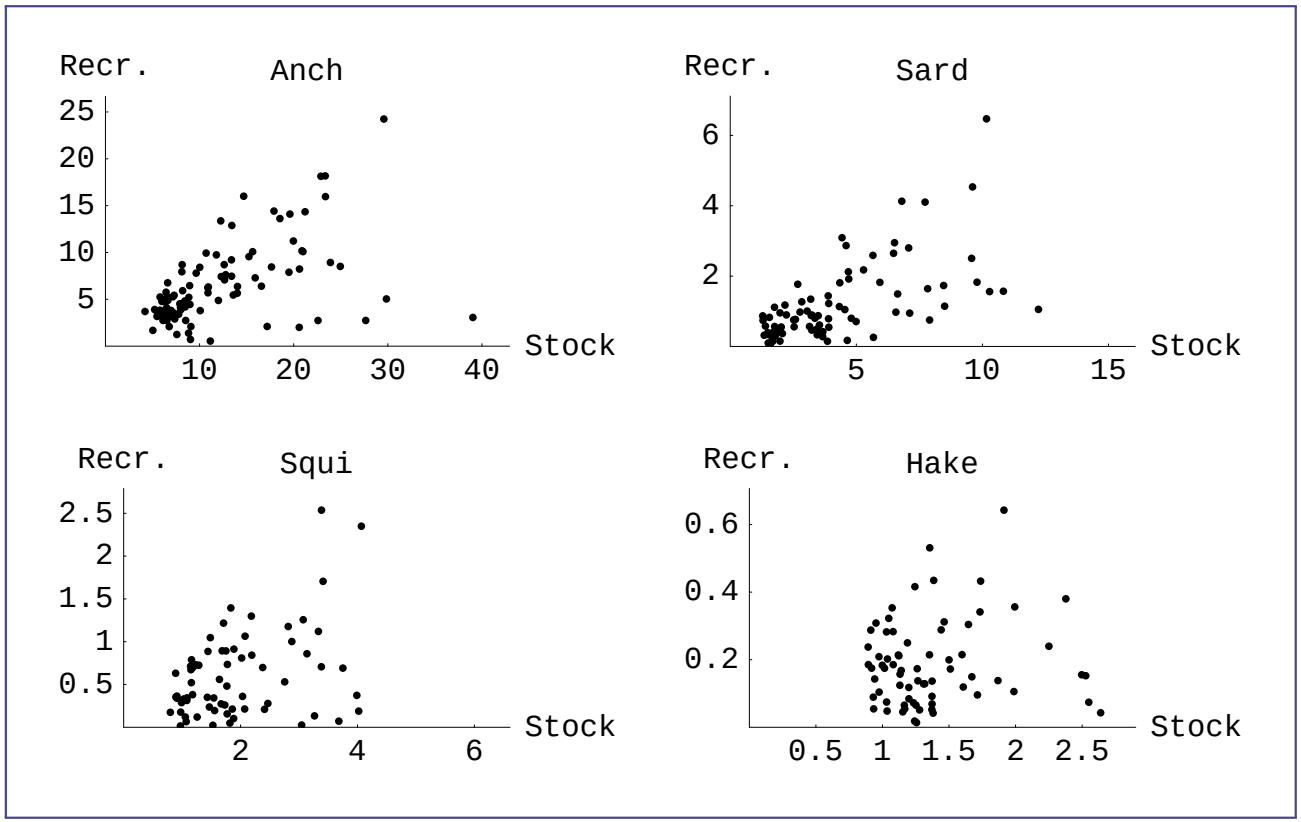


Reproduction of diet patterns

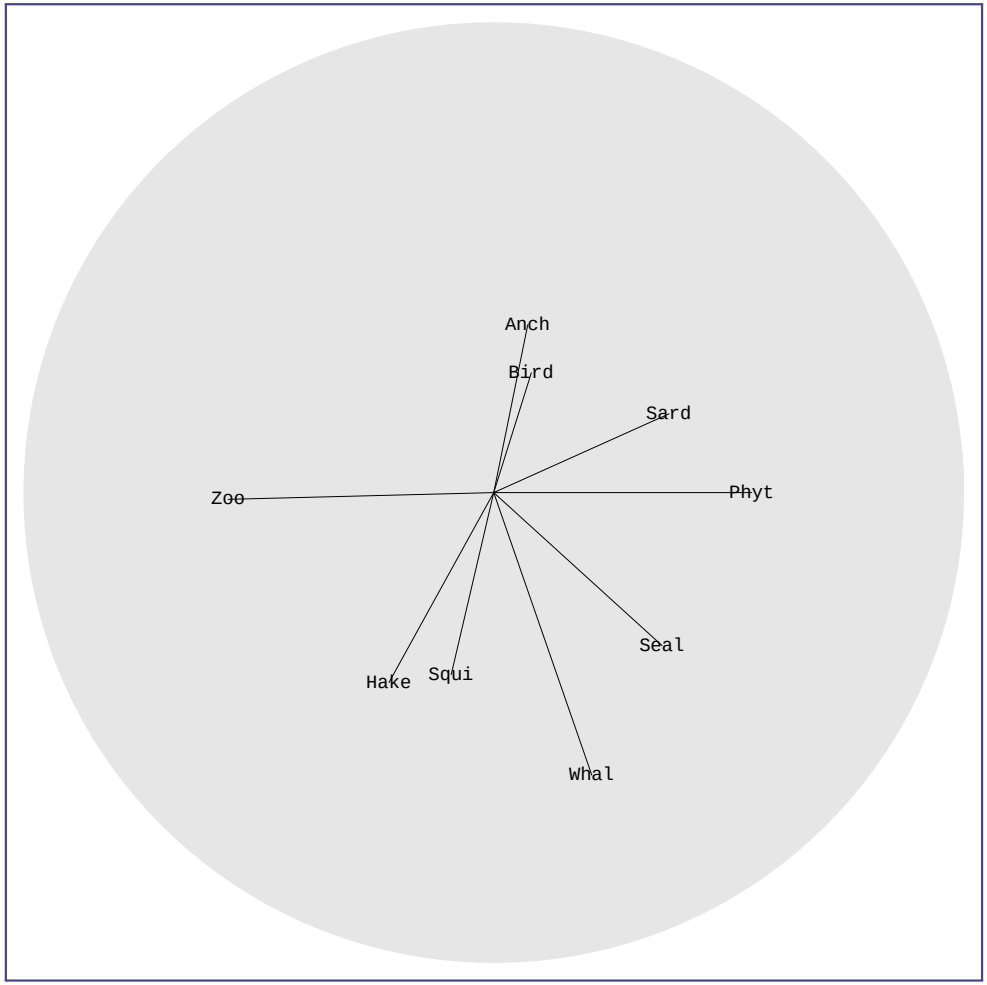




Reproduction of stock recruitment



Reproduction of correlations



Reproduction of correlations

	Phyt	Zoo	Anch	Sard	Squi	Hake	Bird	Seal	Whal
Phyt	100(0)								
Zoo	-82(9)	100(0)							
Anch	-2(22)	-15(28)	100(0)						
Sard	-3(20)	-1(25)	-10(27)	100(0)					
Squi	4(24)	-11(26)	8(28)	5(27)	100(0)				
Hake	-4(26)	4(29)	-2(32)	7(34)	1(32)	100(0)			
Bird	0(25)	1(29)	2(35)	-7(37)	1(32)	-4(43)	100(0)		
Seal	-3(23)	4(26)	0(30)	-1(39)	8(30)	11(48)	-6(51)	100(0)	
Whal	-4(25)	6(26)	-5(27)	1(34)	2(31)	3(46)	1(51)	5(46)	100(0)

How to interpret results ?

A critical point of view on causality schemes which are, usually, inexplicit in conventional models, being rashly included in functional relationships.

- Encounters between prey and predators species are functions of their respective biomass, determine the predation and thus the changes of their biomass
- A predator species seeks, from several potential prey species, its food in order to survive, and that this determines the predation and thus the changes of its biomass and that of its prey

How to interpret results ?

- Assuming a functional response means identifying the driving ecological force as being the predation strength.
- With the inertia principle considered in this study, we suggest that other dynamical processes, for example related to survival strength (i.e. the instinctive capacity to shift the diet for surviving local detrimental conditions), can be evoked when interpreting observed patterns.

VIVRE POUR MANGER / MANGER POUR VIVRE

Using this model as a null model

Stock recruitment relationships

	Null	Model
Null	Emphasis on constraints; defining mono species management in terms of constraints	Avoid the possibilities of a possible mono-species management
Model	Over confidence in mono-species management	Setting and improving mono species management

Using this model as a null model

Functional responses

	Null	Model
Null	Emphasis on constraints; defining ecosystem management in terms of constraints	Avoid the possibilities of a possible ecosystem management
Model	Over confidence in ecosystem management	Setting and improving ecosystem management

Marine ecosystems modeling

Contrary to common recommendations, fisheries biologists still mostly use deterministic models, both for exploratory and management purposes.

Moving towards ecosystem based fisheries management by recognizing interactions between exploited as well as non-exploited species operating as part of the whole ecosystem, may further exacerbate this problem.

Marine ecosystems modeling

Relationships between scientists, fishermen and managers are difficult, with or without the possibility of a deterministic explanation of the underlying dynamics of marine ecosystems. The approach proposed here, leading to emphasis being placed upon the reference points identified from the analysis of structural constraints (and associated thresholds) can be an alternative to a more classical management principle, based on target points.

Marine ecosystems modeling

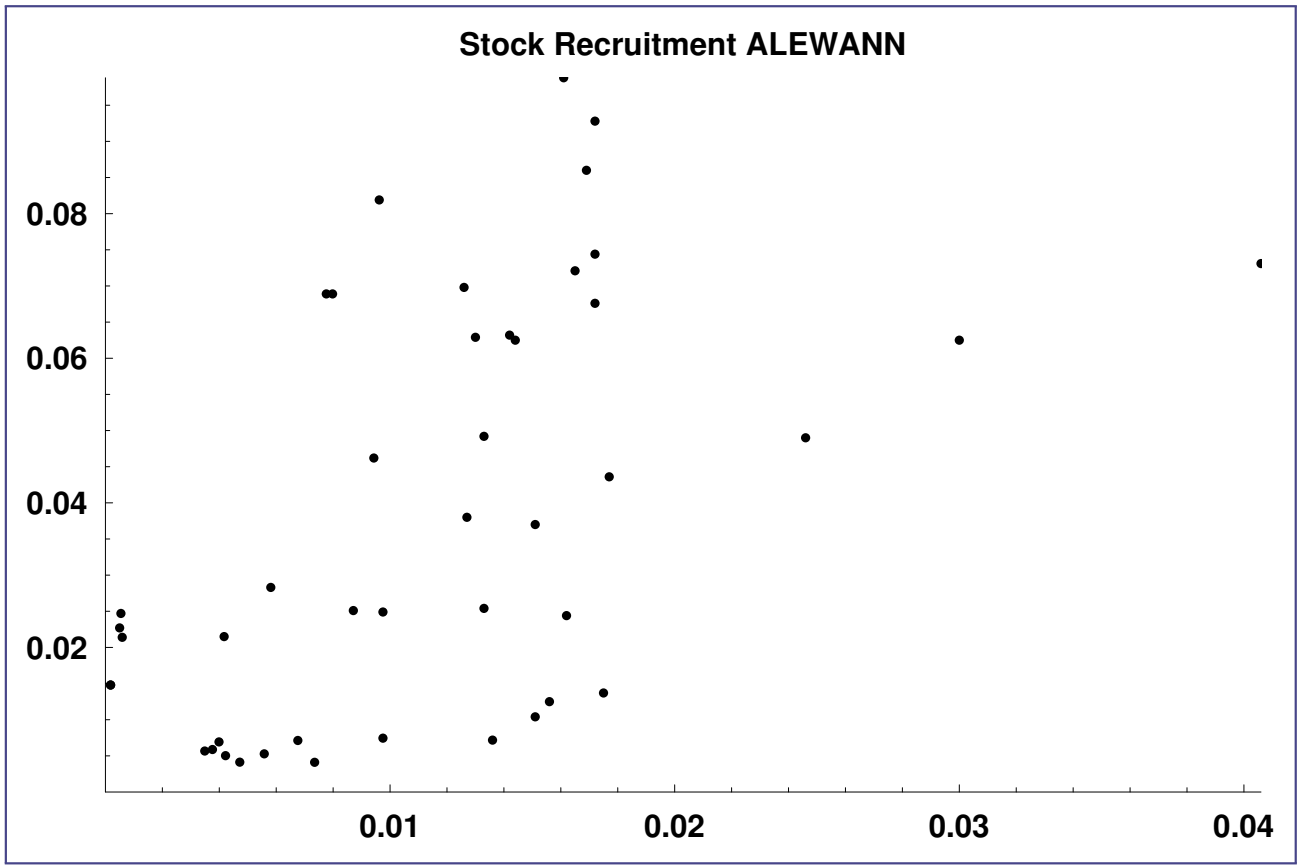
Critically questioning the fundamental assumptions and hypotheses underlying our models should be central when elaborating management options, for terrestrial ecosystems as well for marine ecosystems.

Referring to a null model without any functional relationships and environmental or anthropogenic forcing can help to avoid misleading advice based on the belief that we can explain the causes of the observed patterns, whereas they may simply result from basic structural constraints within which the ecosystem functions.

Appendix

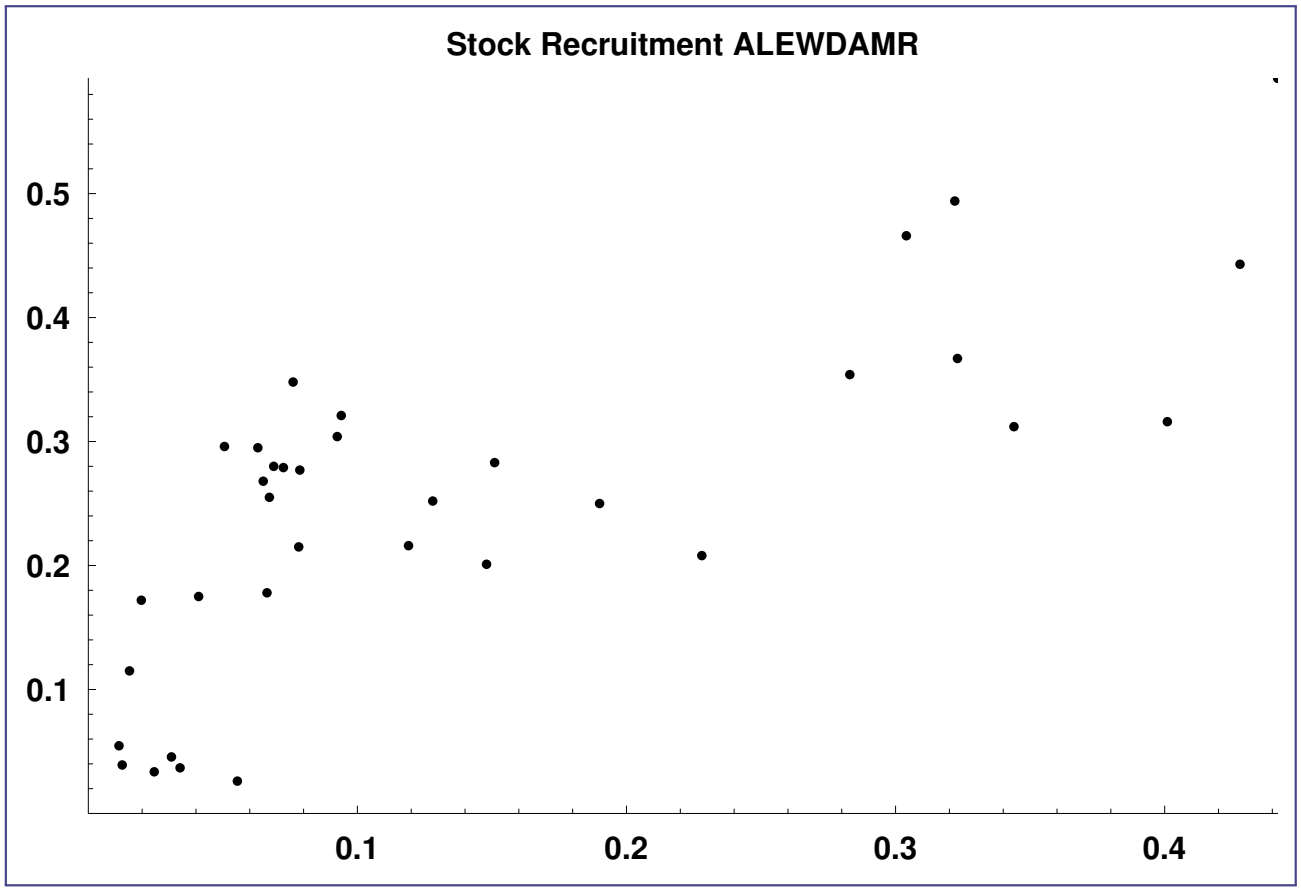
Stock recruitment Plots

Stock Recruitment



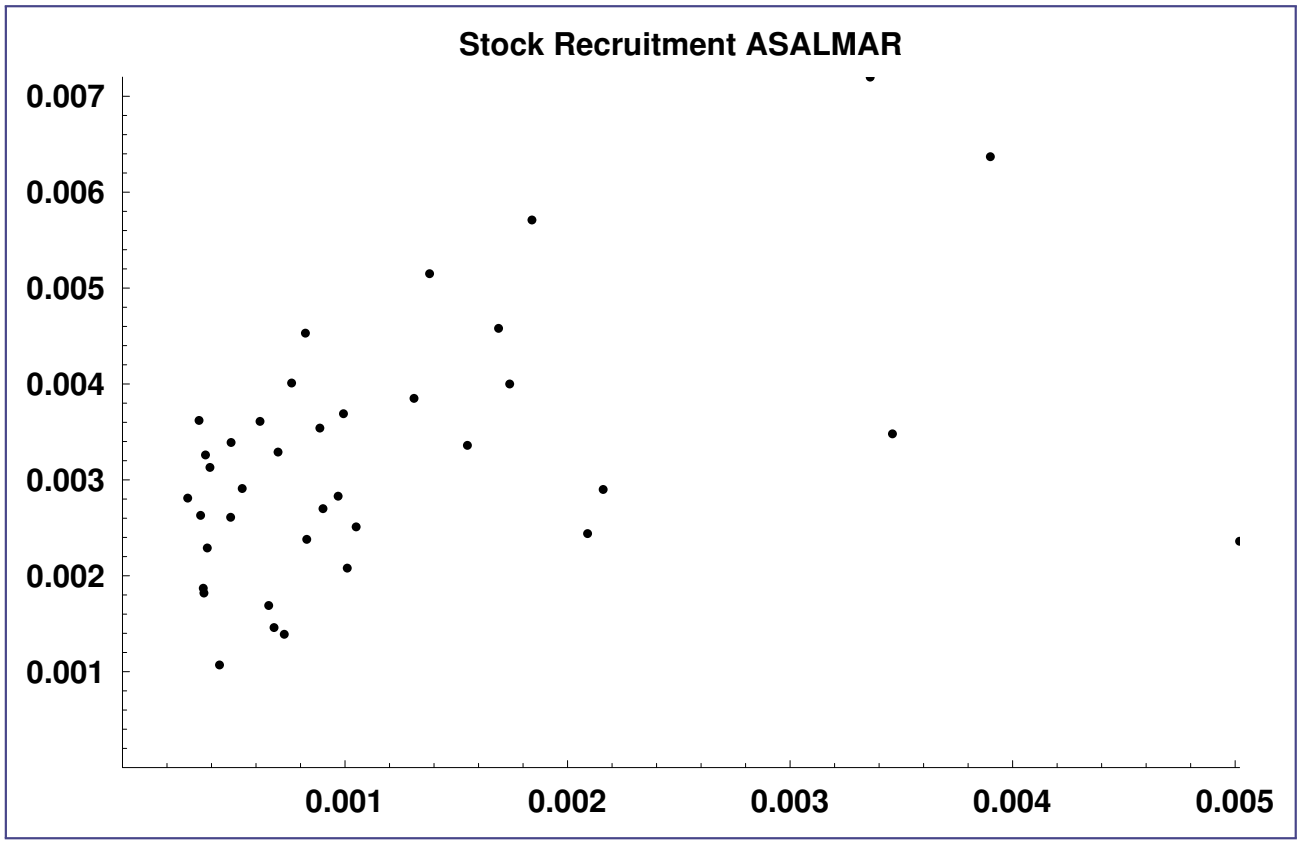
From R. Myers

Stock Recruitment



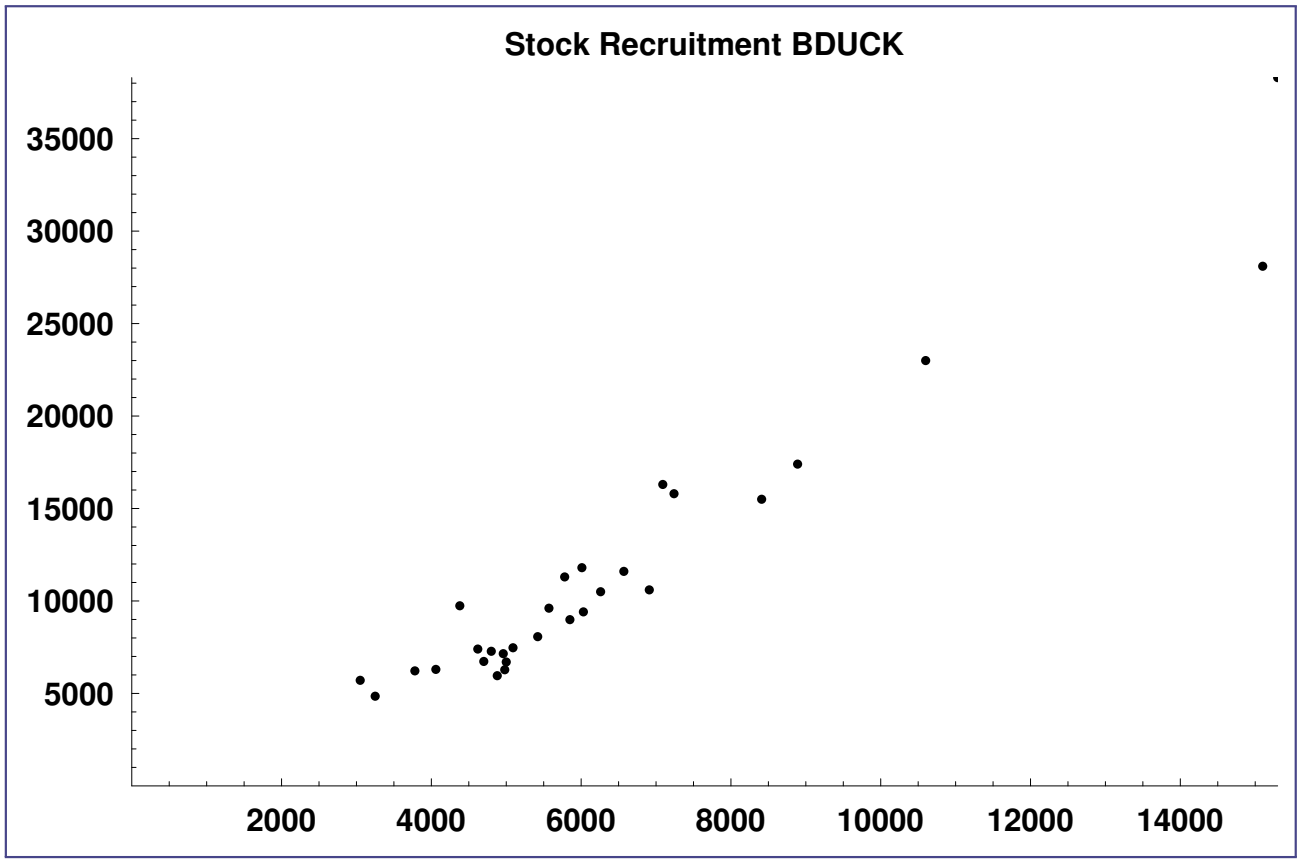
From R. Myers

Stock Recruitment



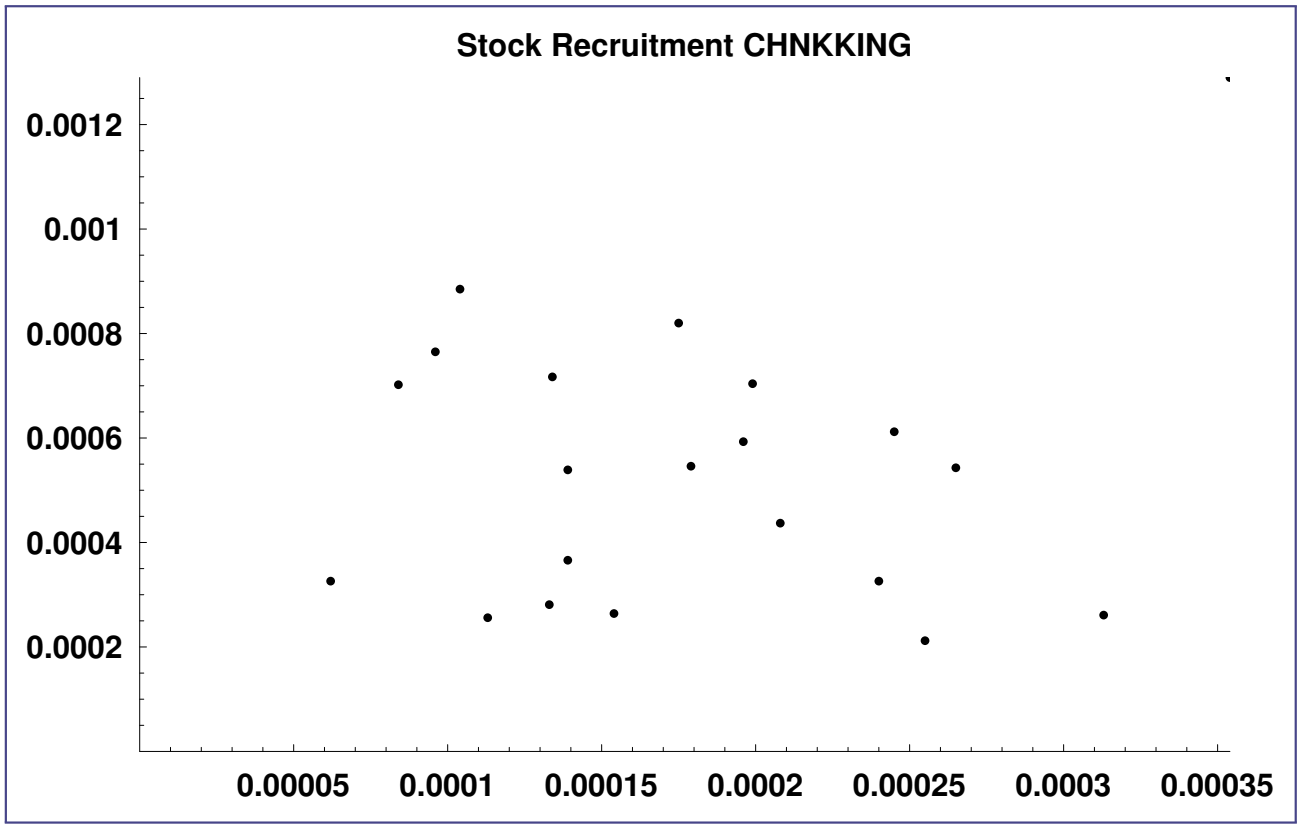
From R. Myers

Stock Recruitment



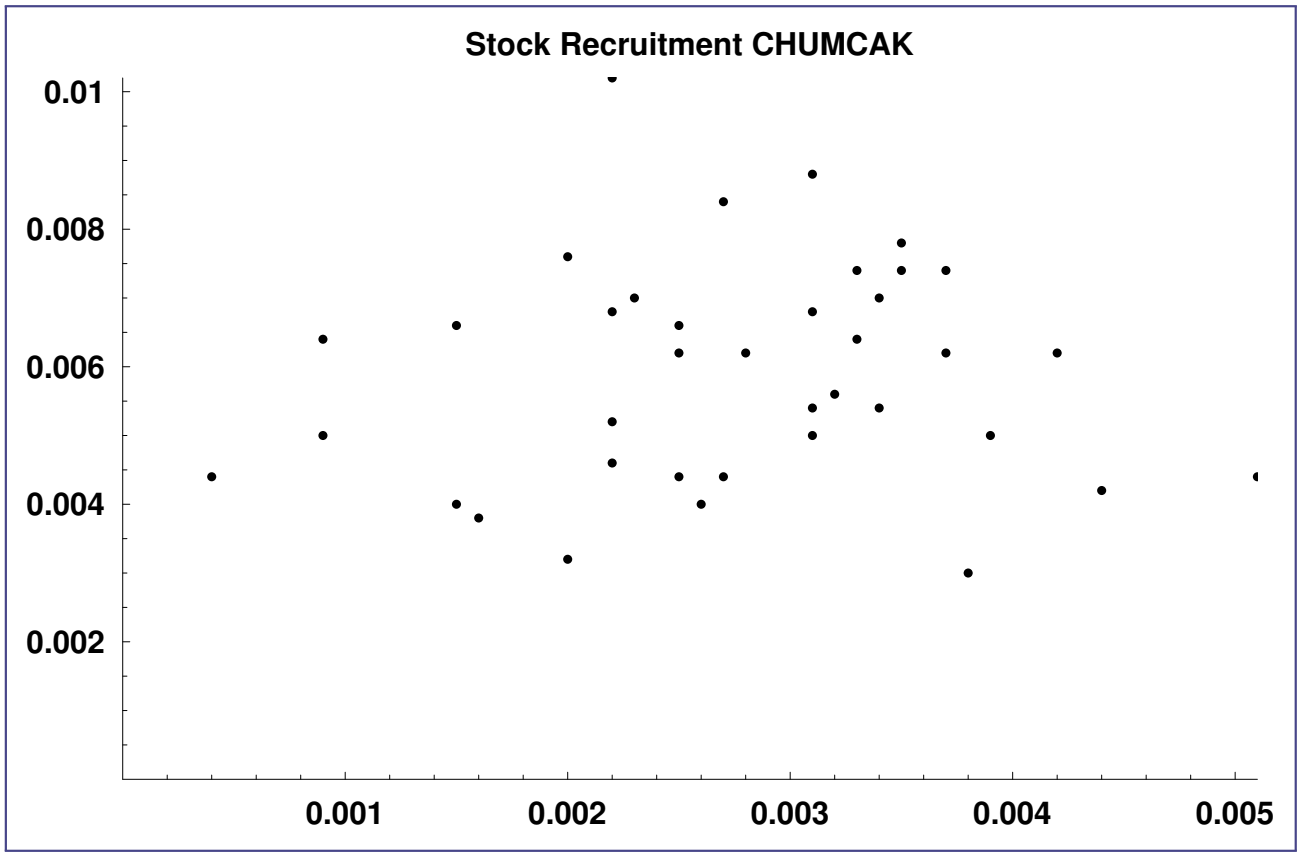
From R. Myers

Stock Recruitment



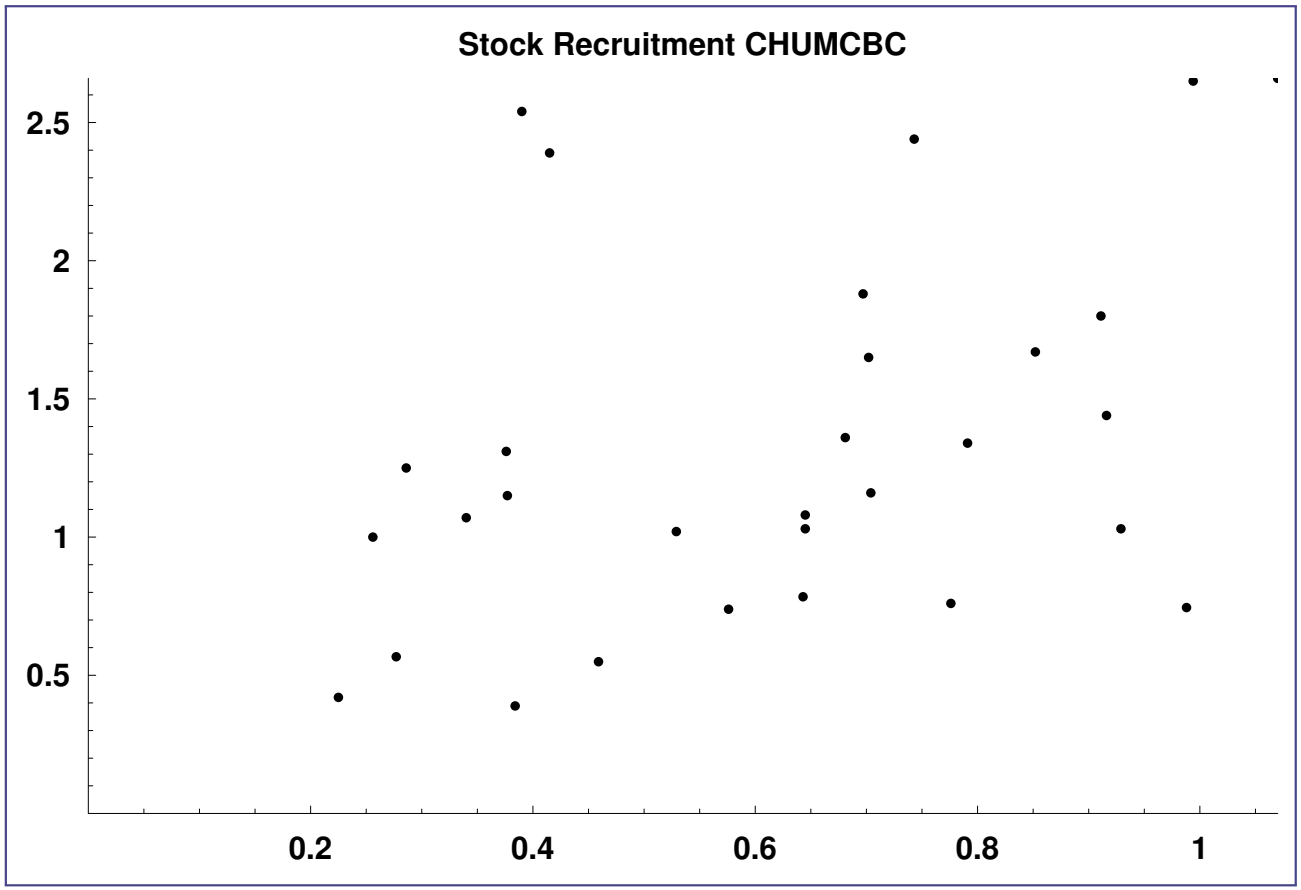
From R. Myers

Stock Recruitment



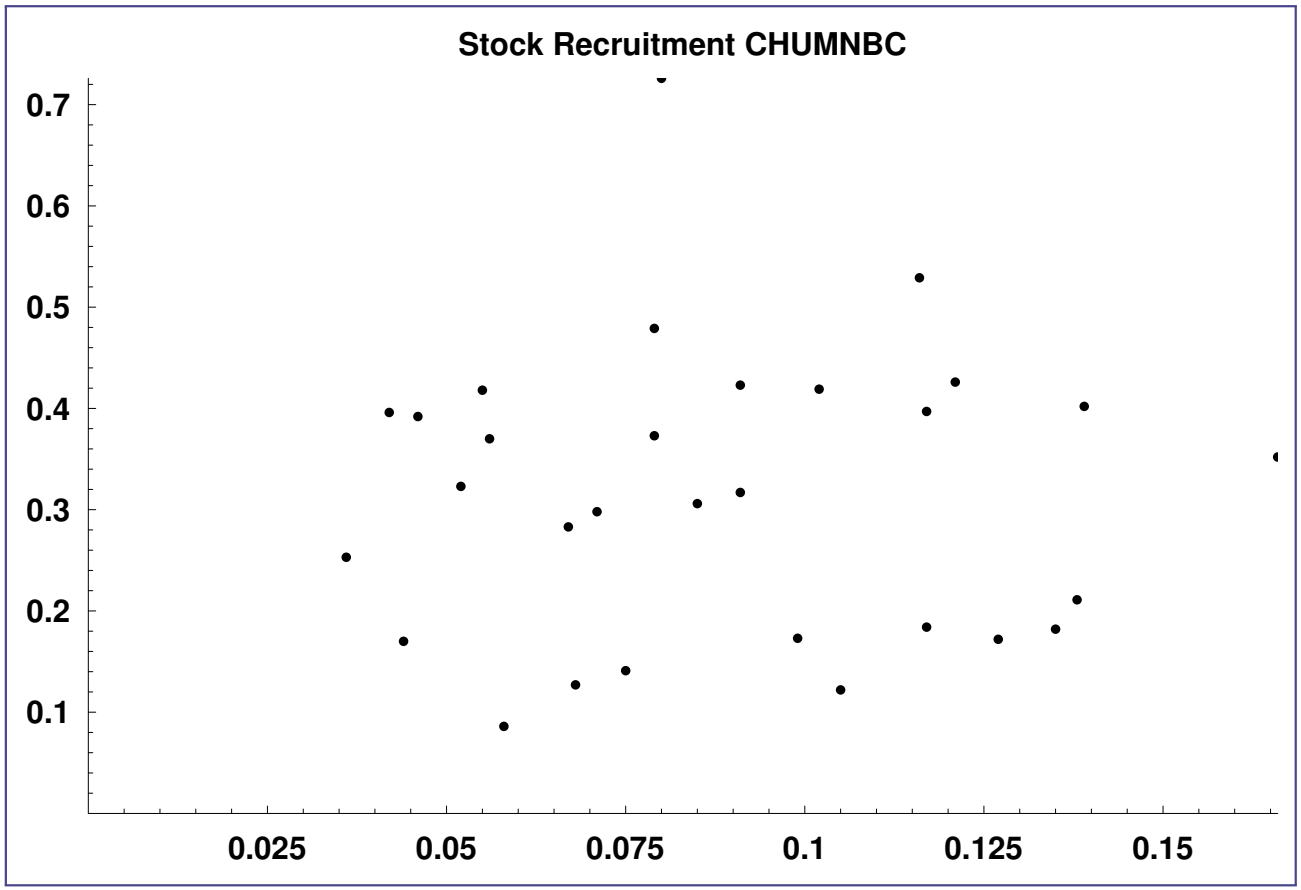
From R. Myers

Stock Recruitment



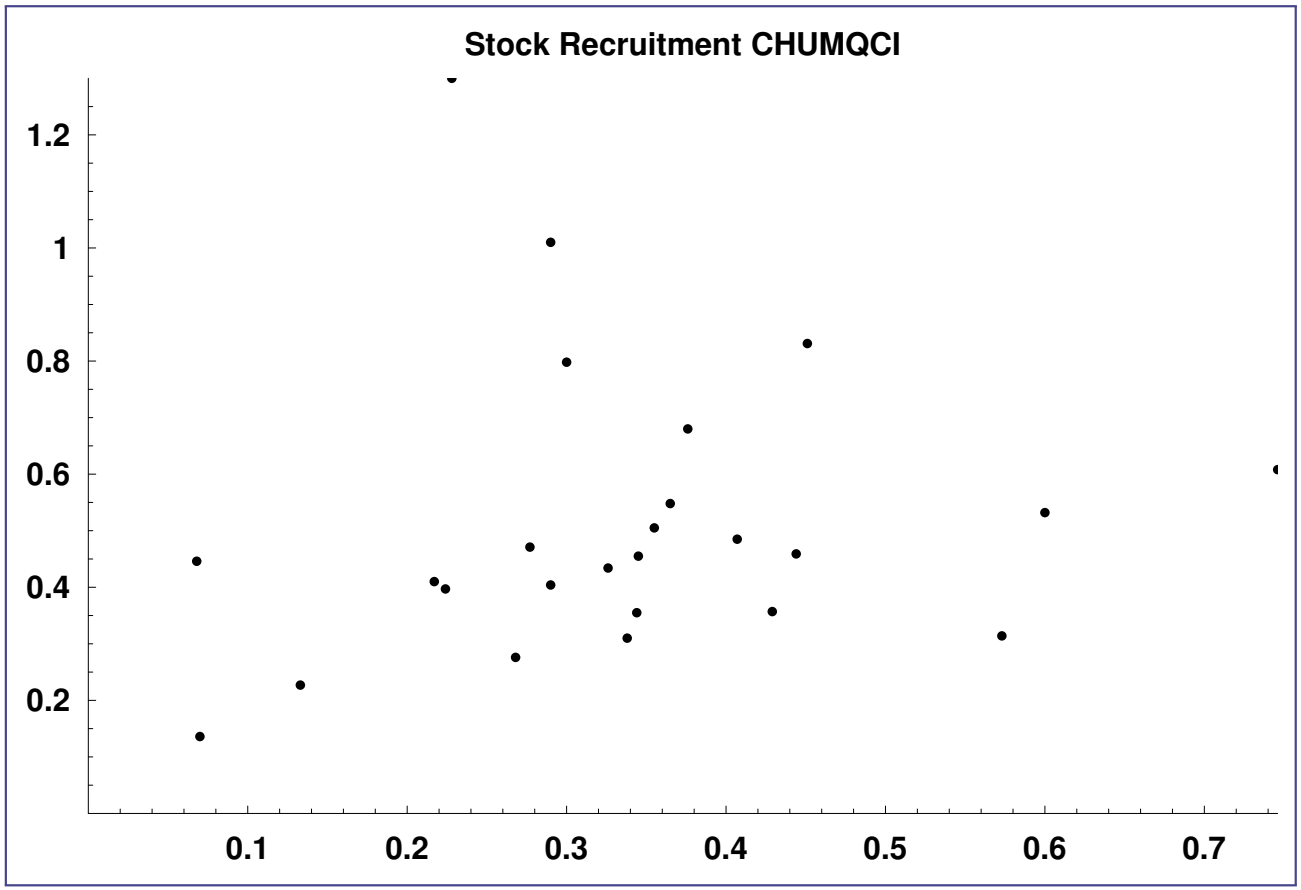
From R. Myers

Stock Recruitment



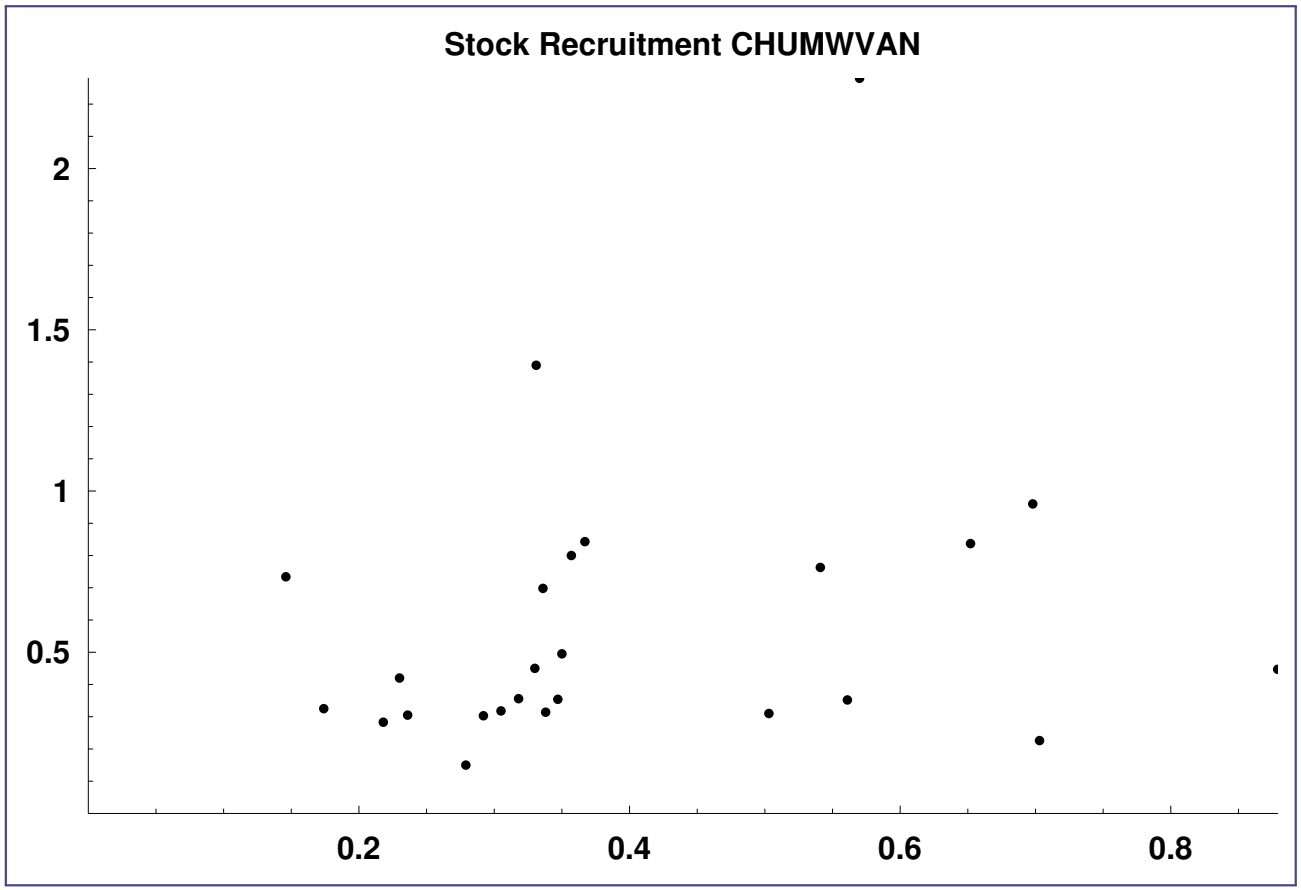
From R. Myers

Stock Recruitment



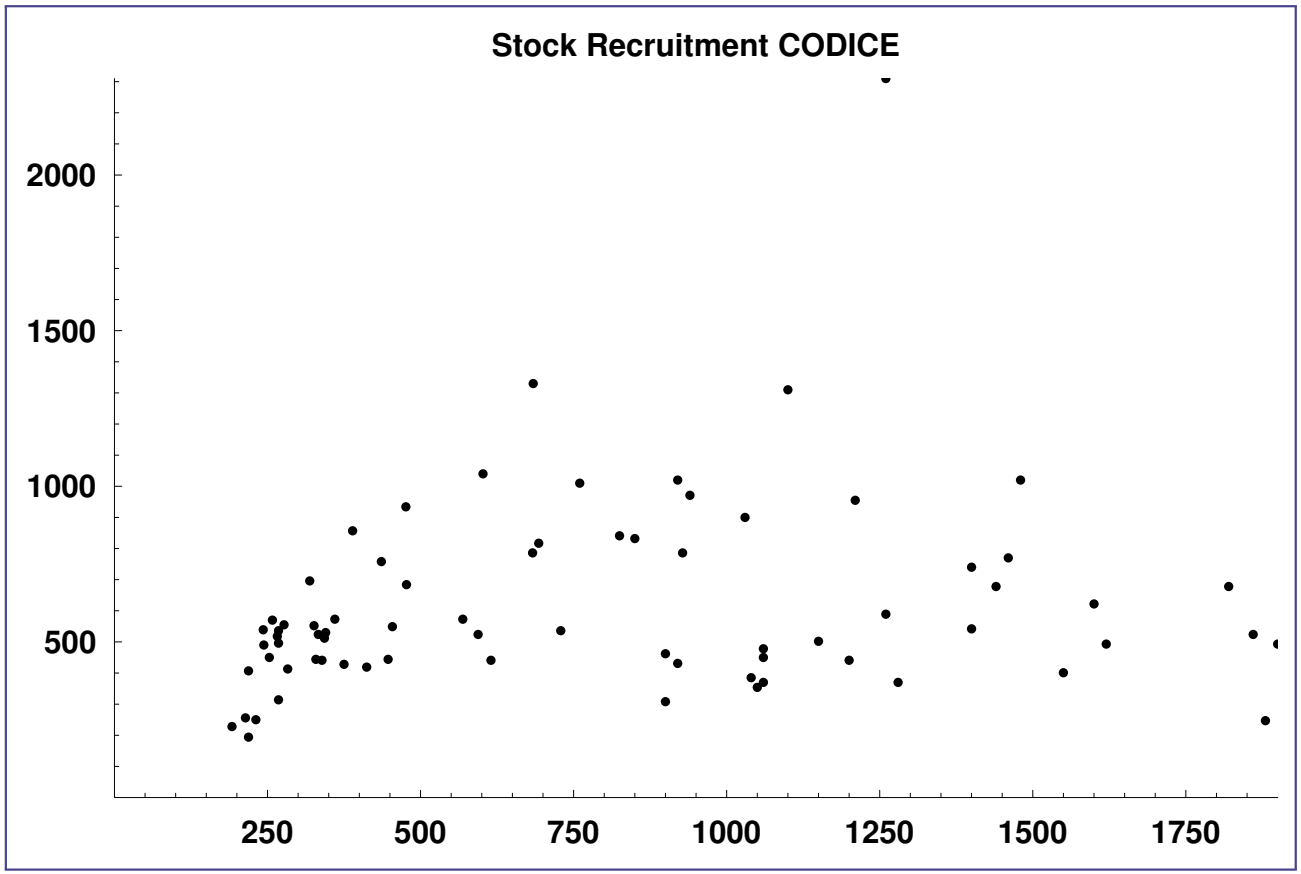
From R. Myers

Stock Recruitment



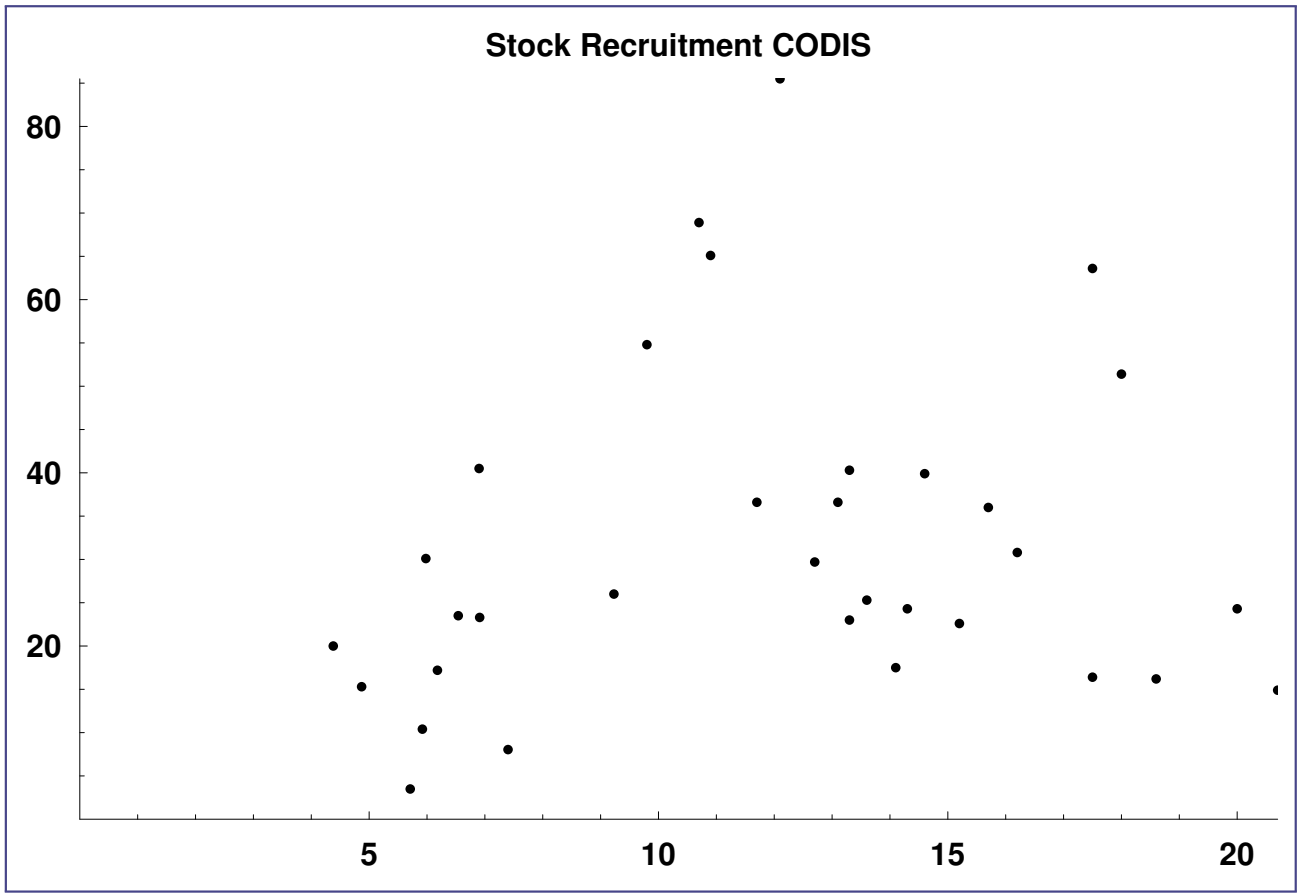
From R. Myers

Stock Recruitment



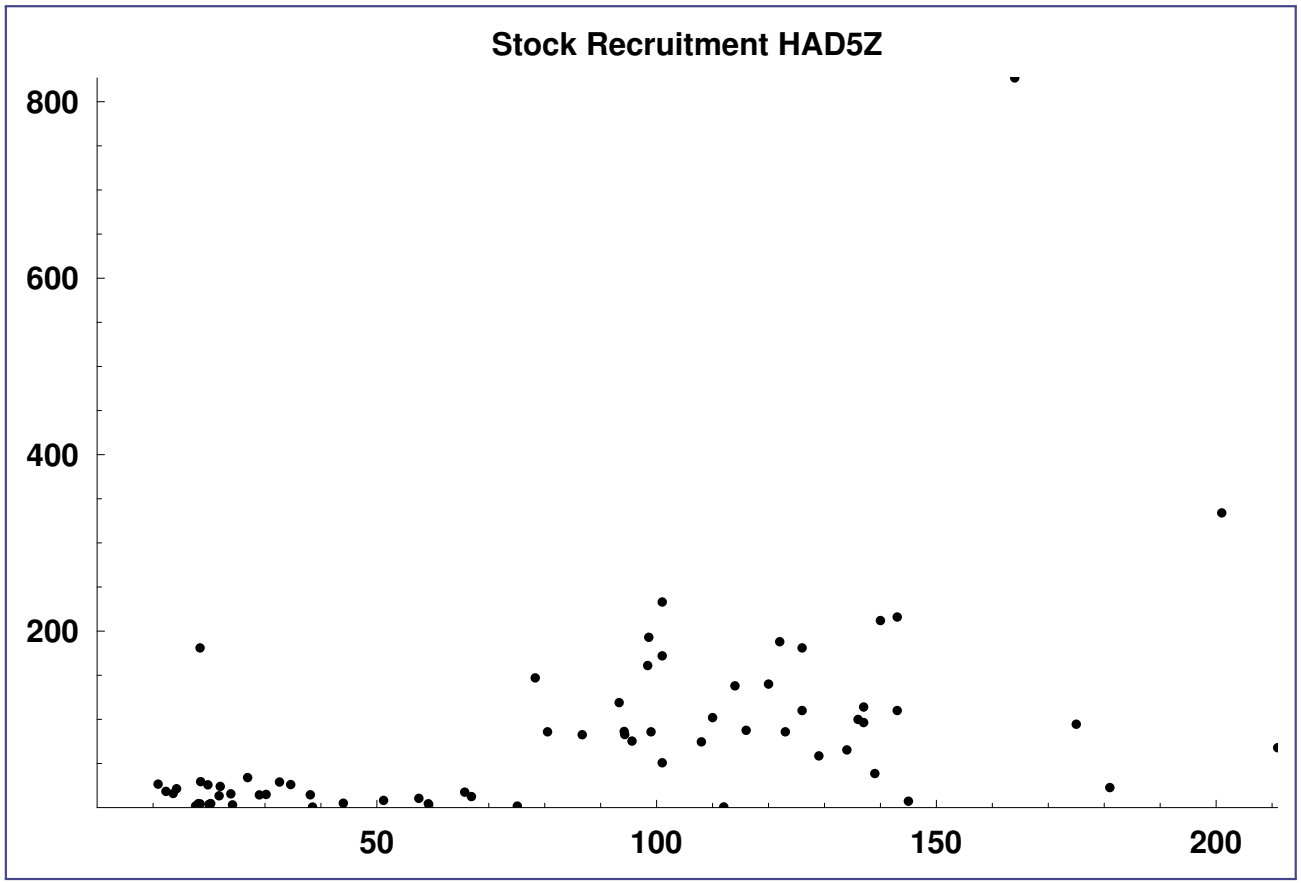
From R. Myers

Stock Recruitment



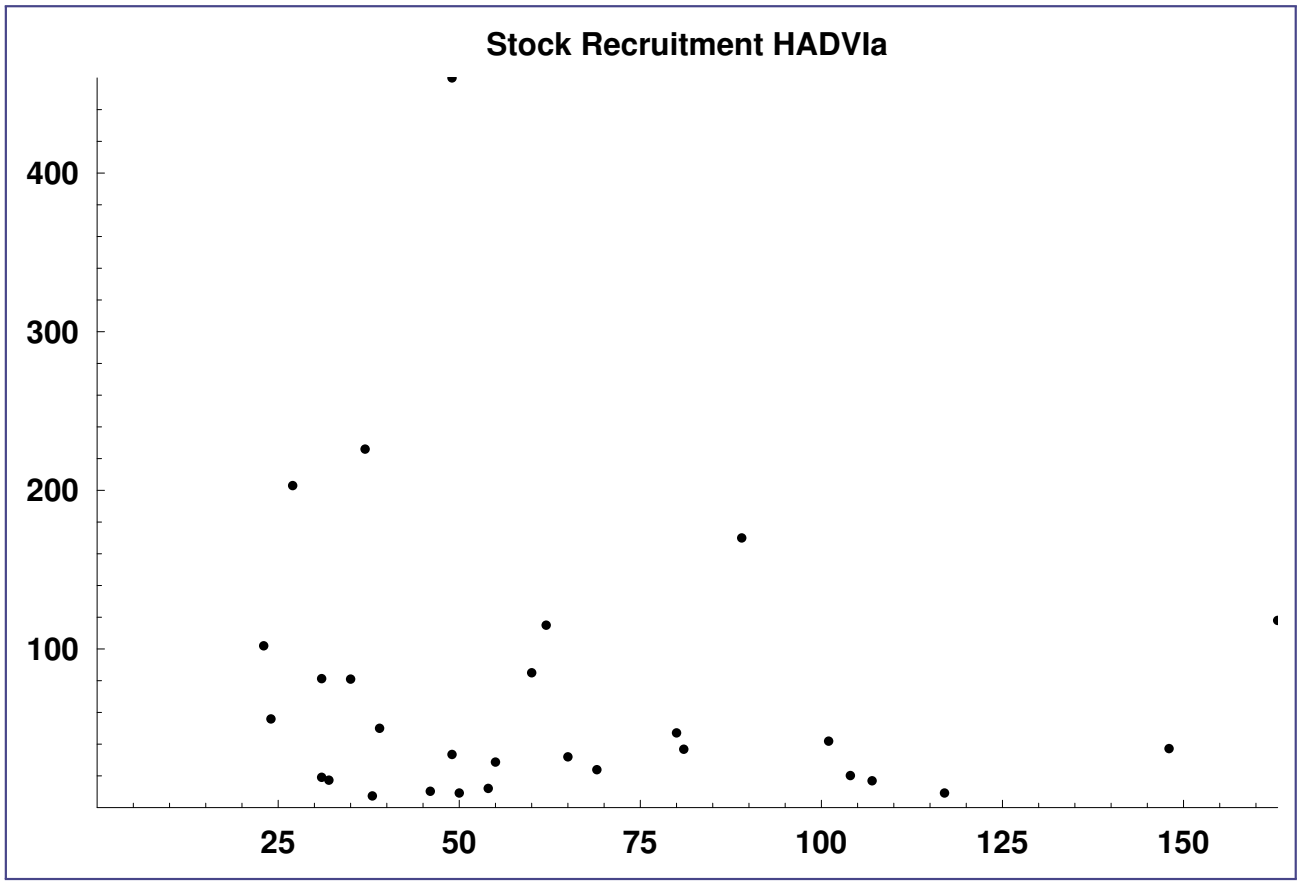
From R. Myers

Stock Recruitment



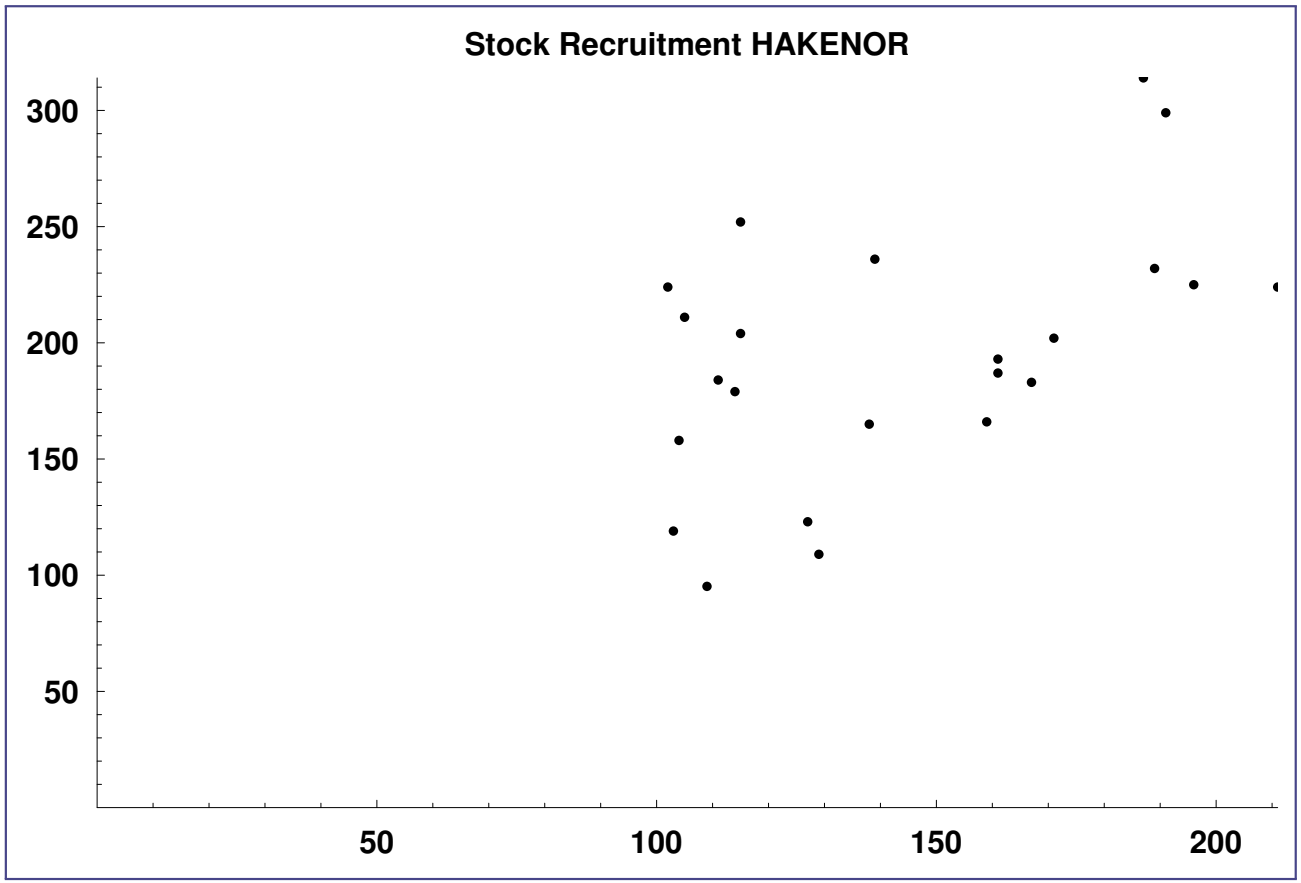
From R. Myers

Stock Recruitment



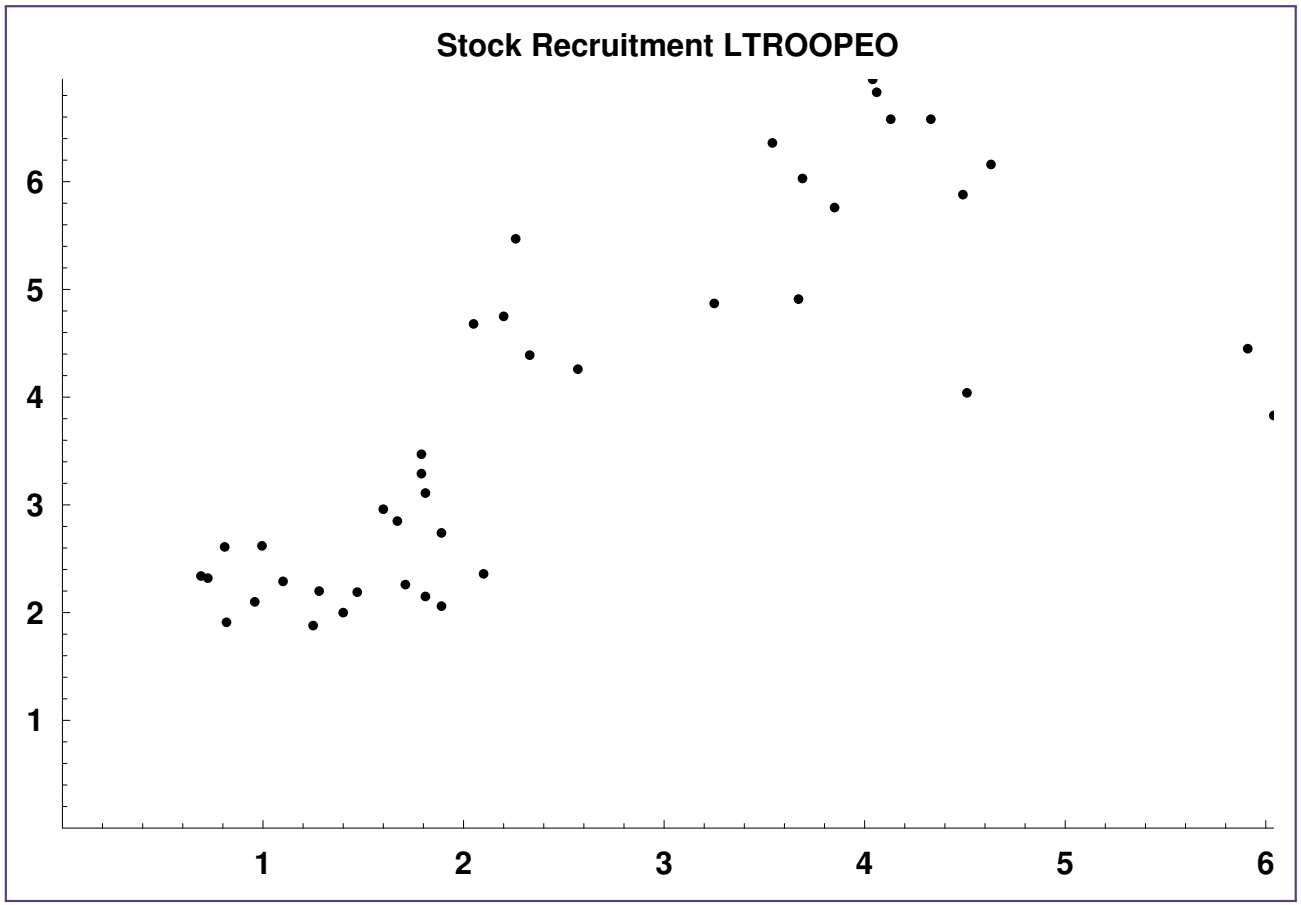
From R. Myers

Stock Recruitment



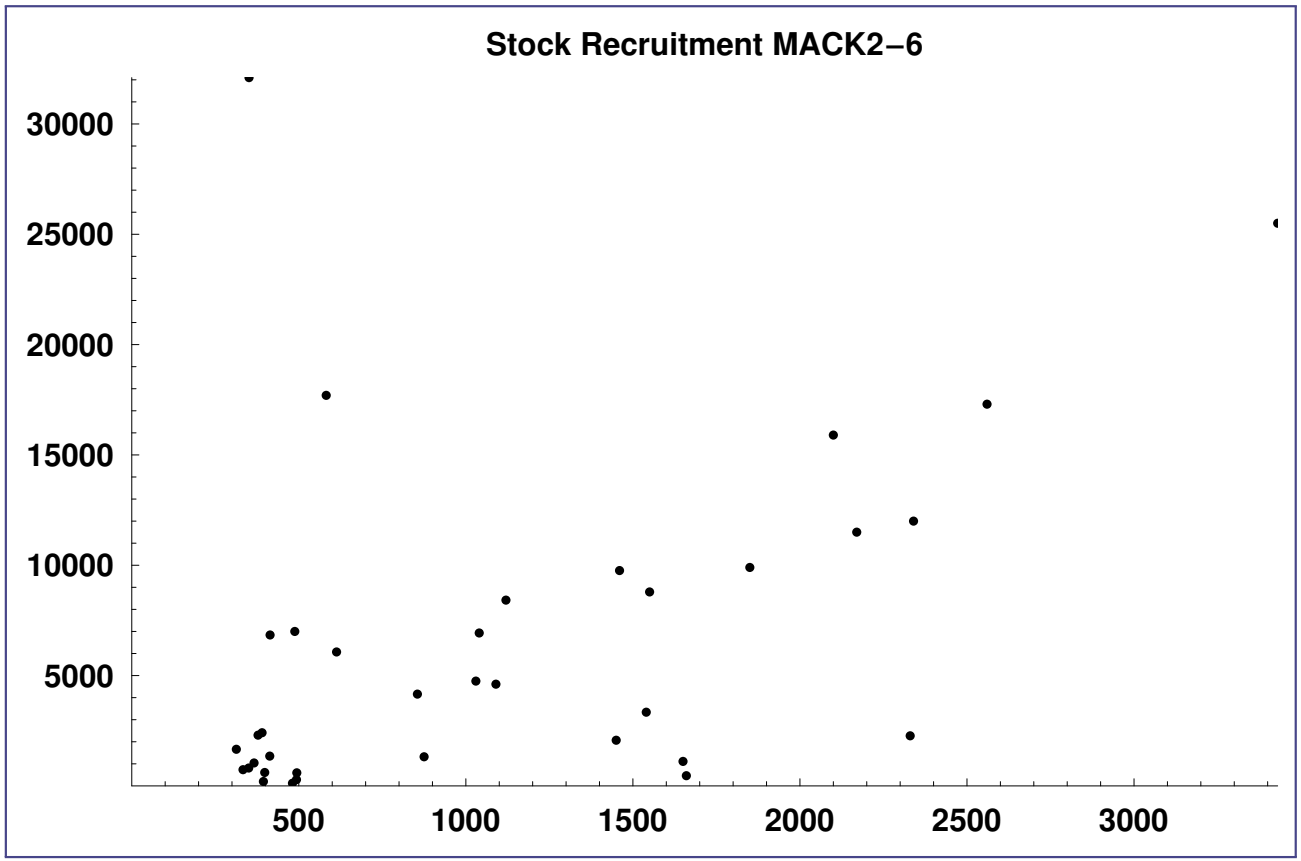
From R. Myers

Stock Recruitment



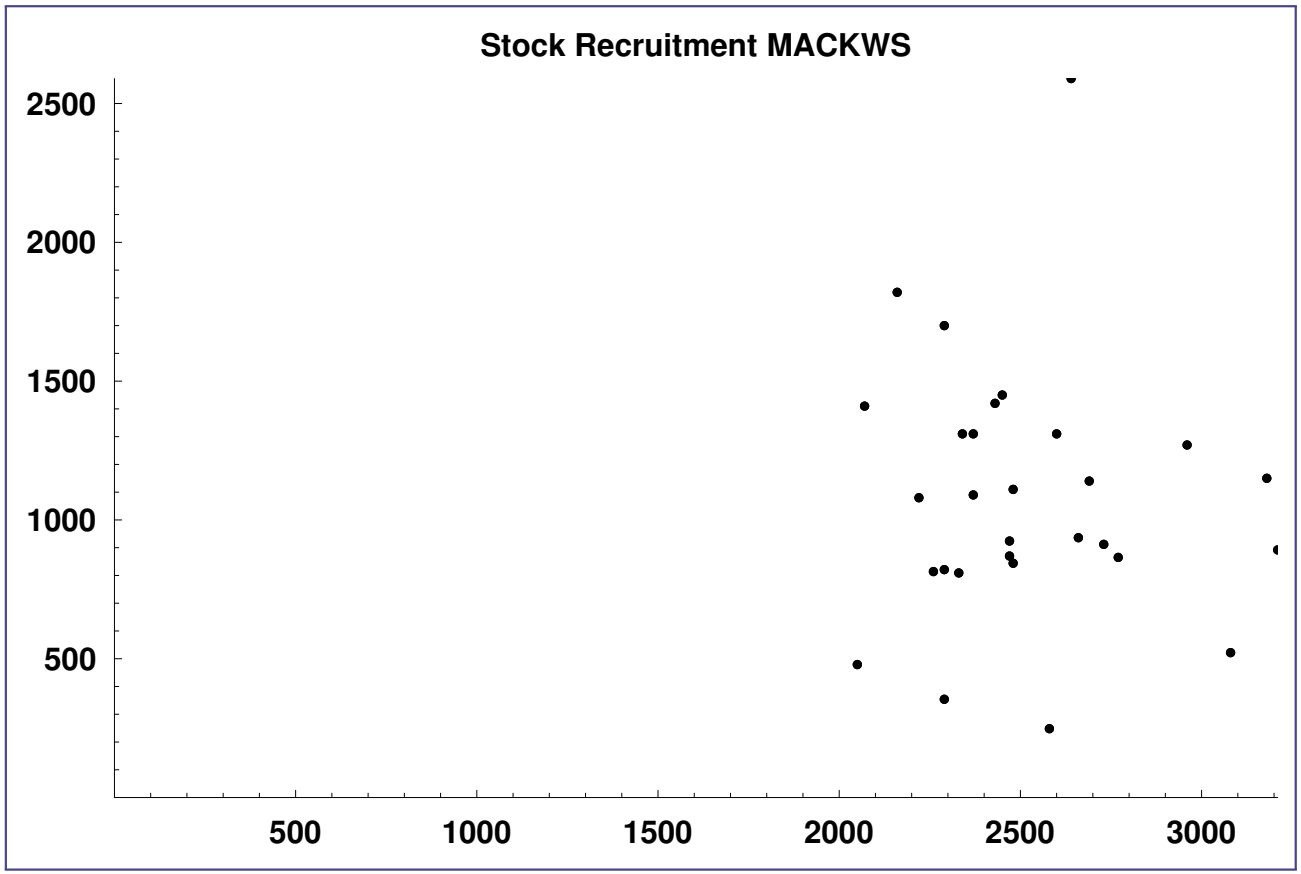
From R. Myers

Stock Recruitment



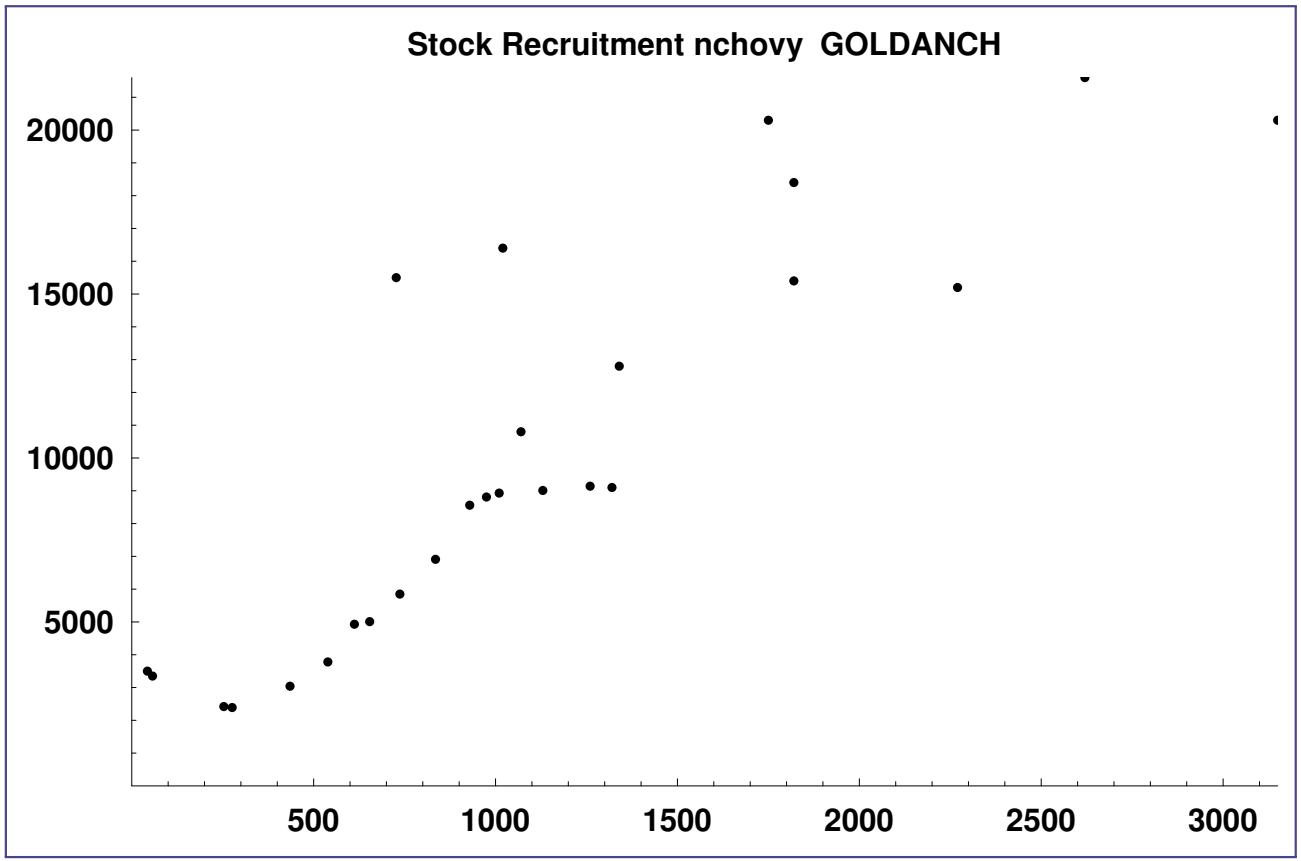
From R. Myers

Stock Recruitment



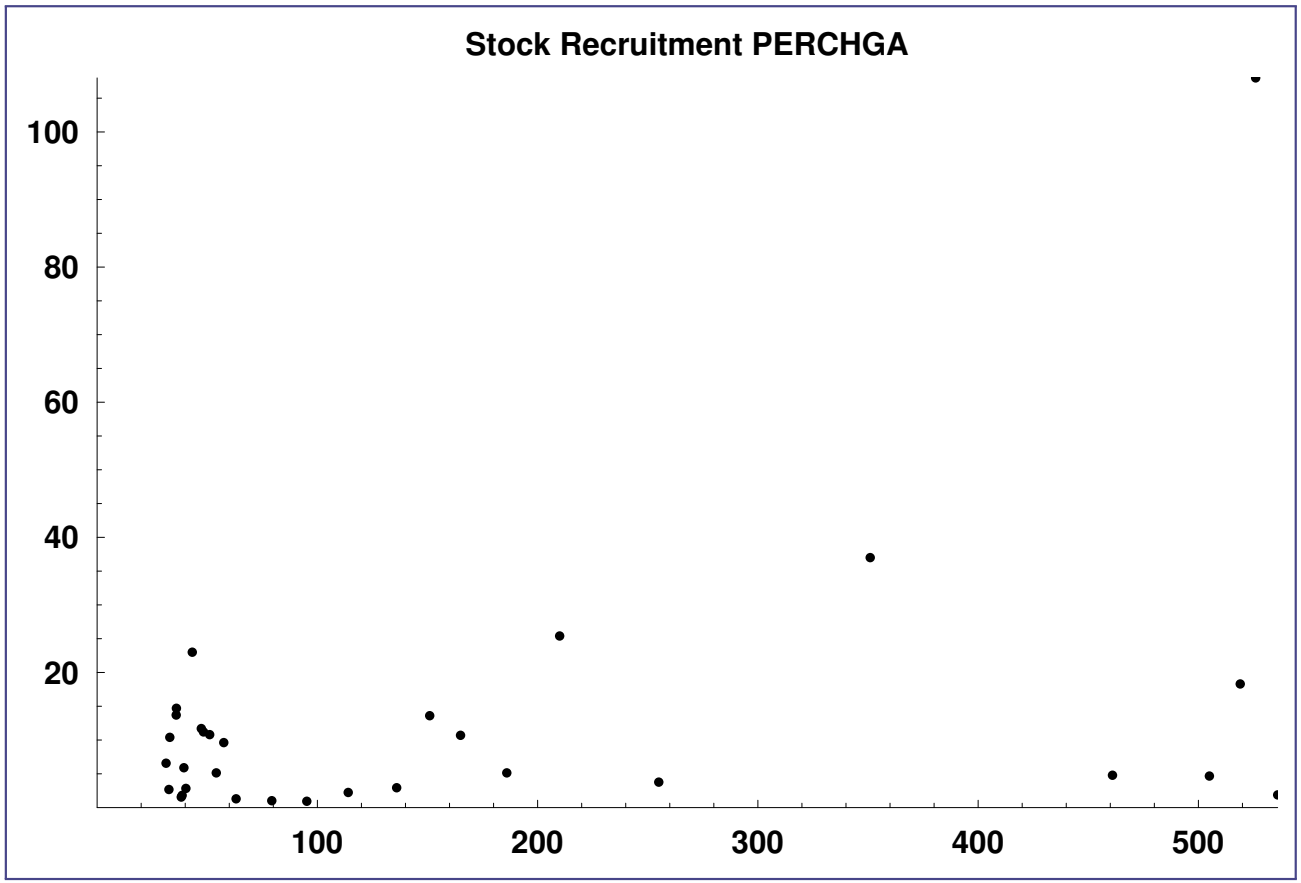
From R. Myers

Stock Recruitment



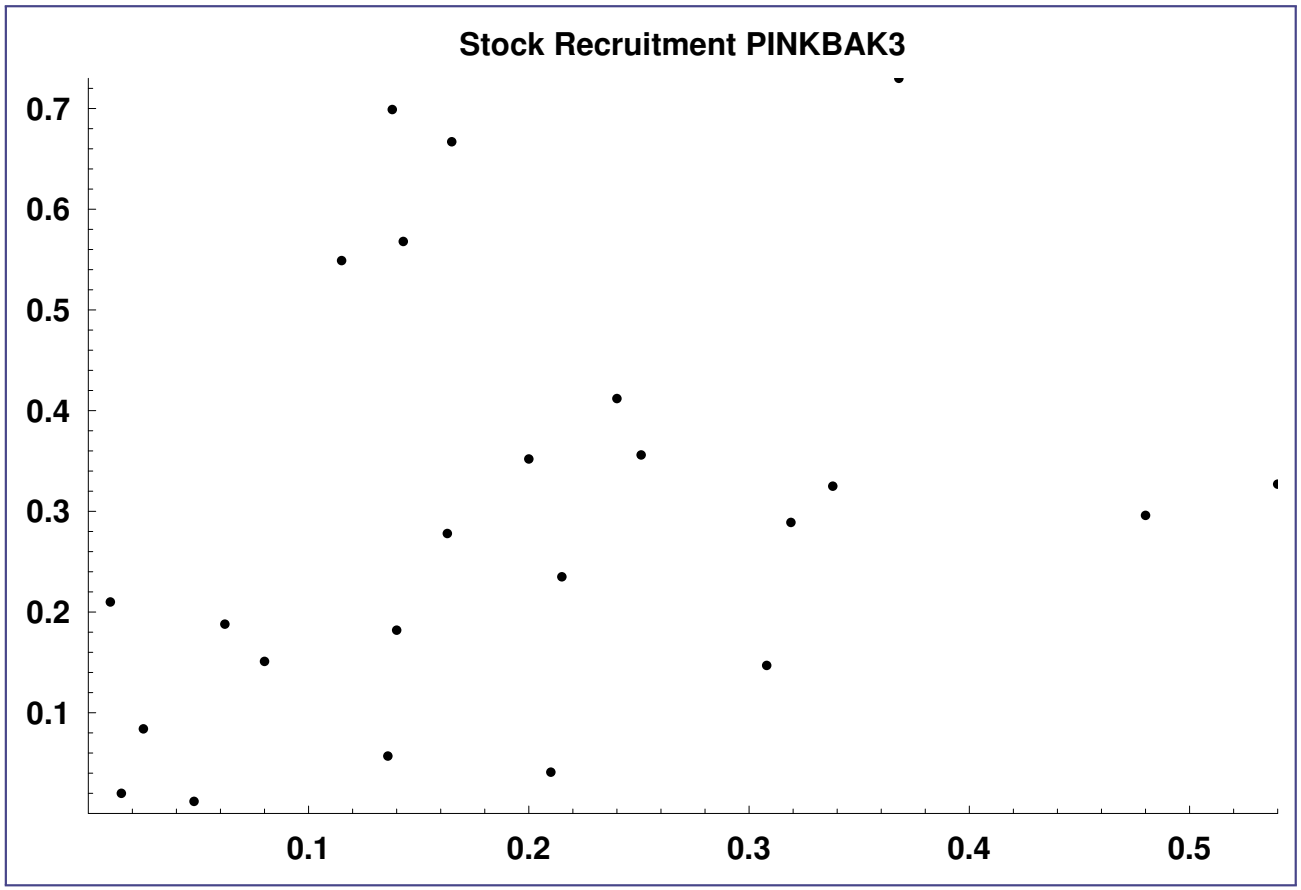
From R. Myers

Stock Recruitment



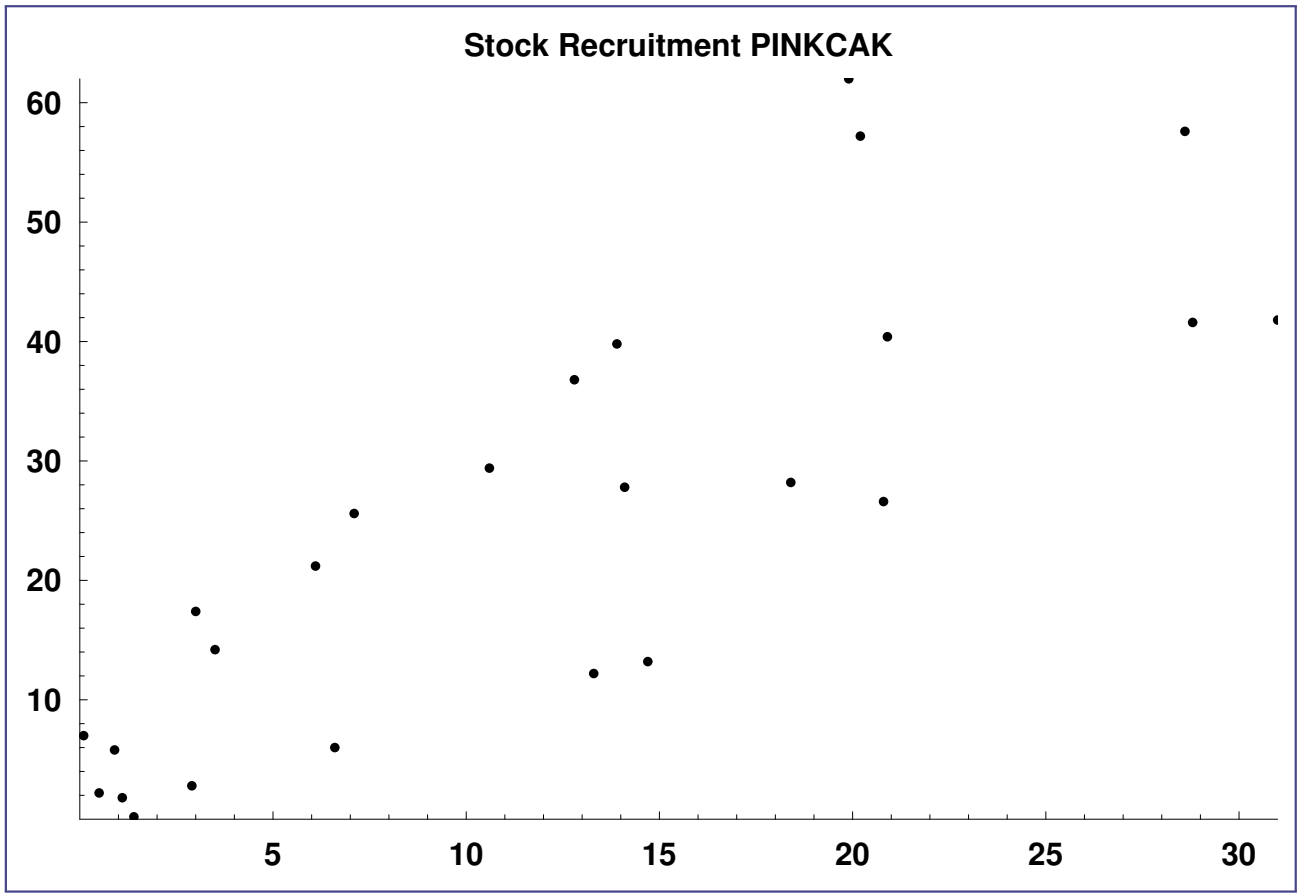
From R. Myers

Stock Recruitment



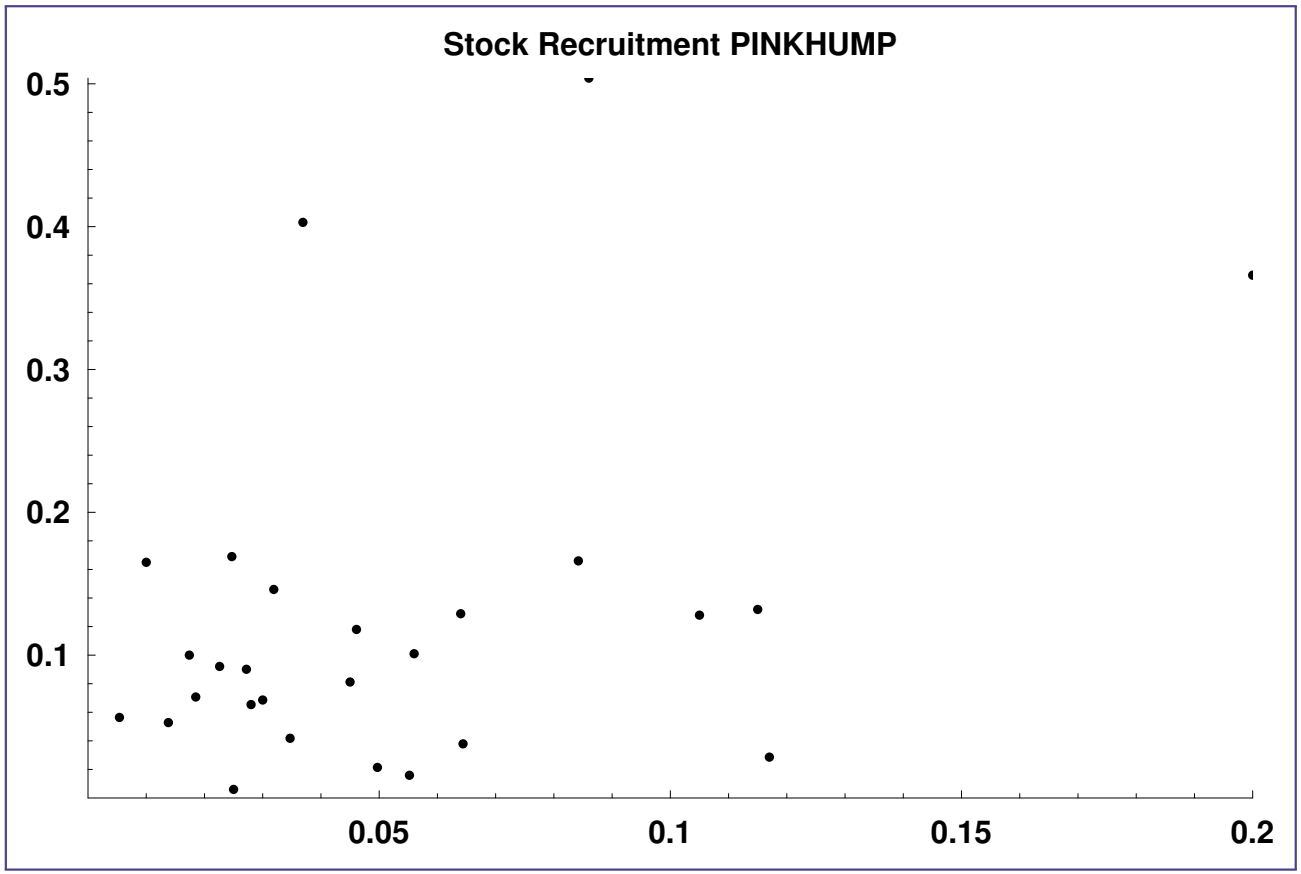
From R. Myers

Stock Recruitment



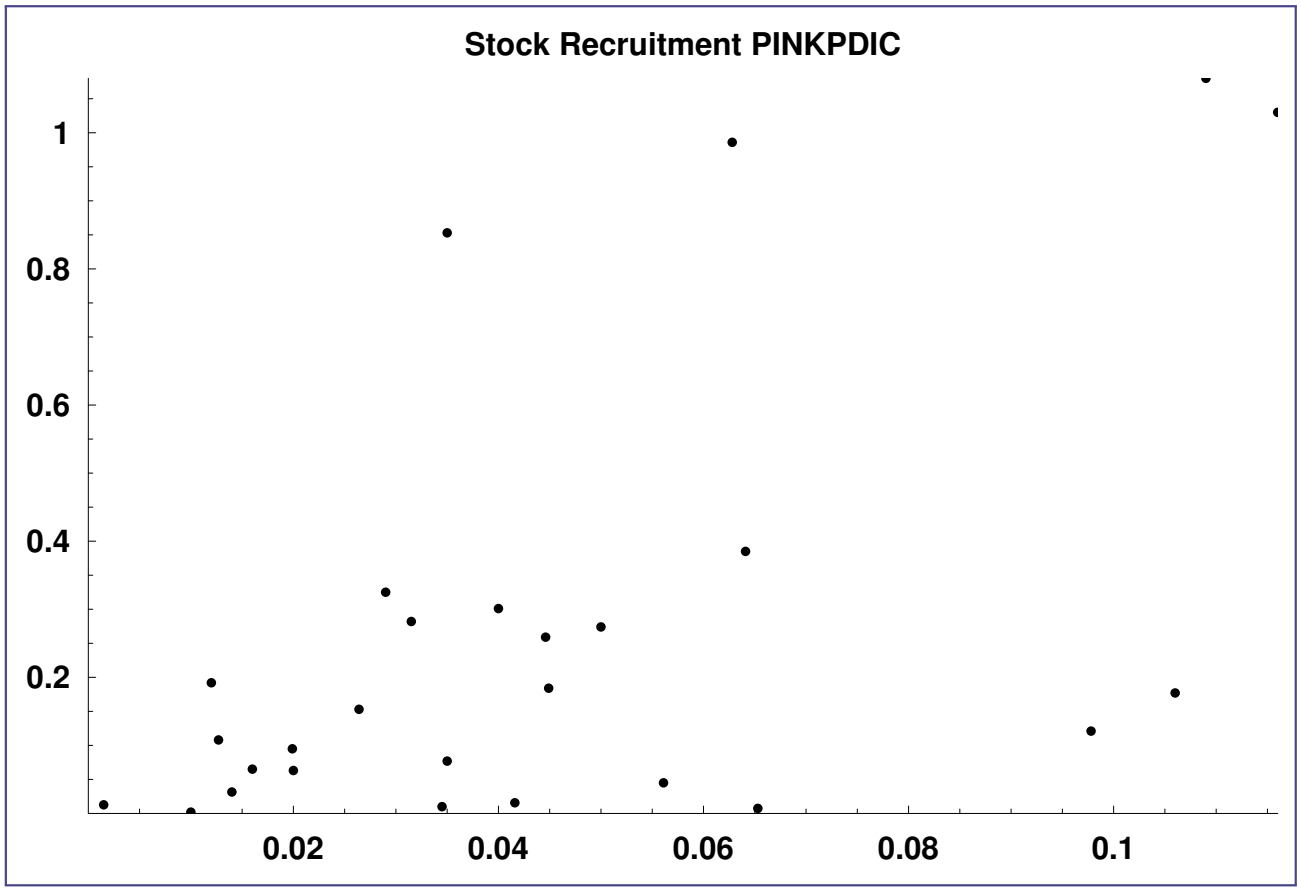
From R. Myers

Stock Recruitment



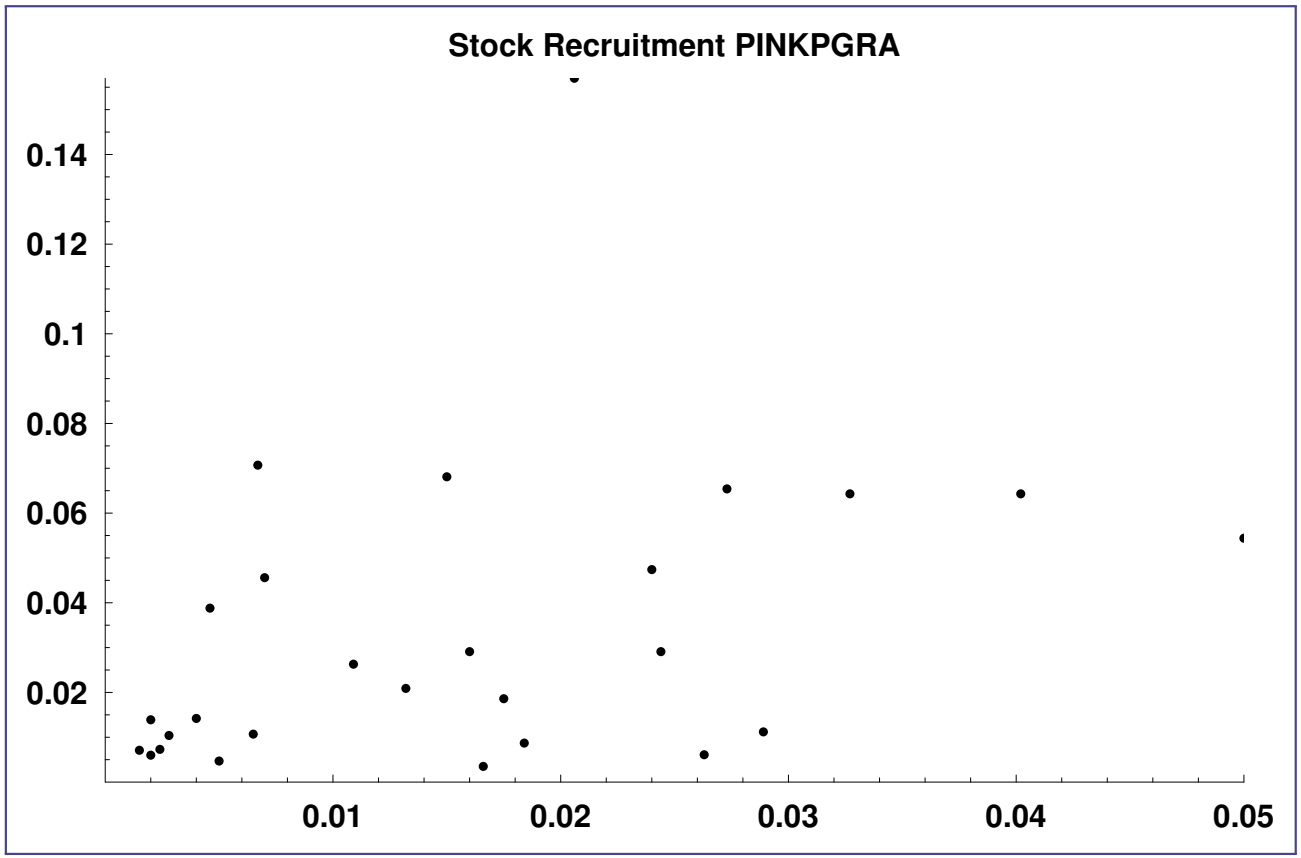
From R. Myers

Stock Recruitment



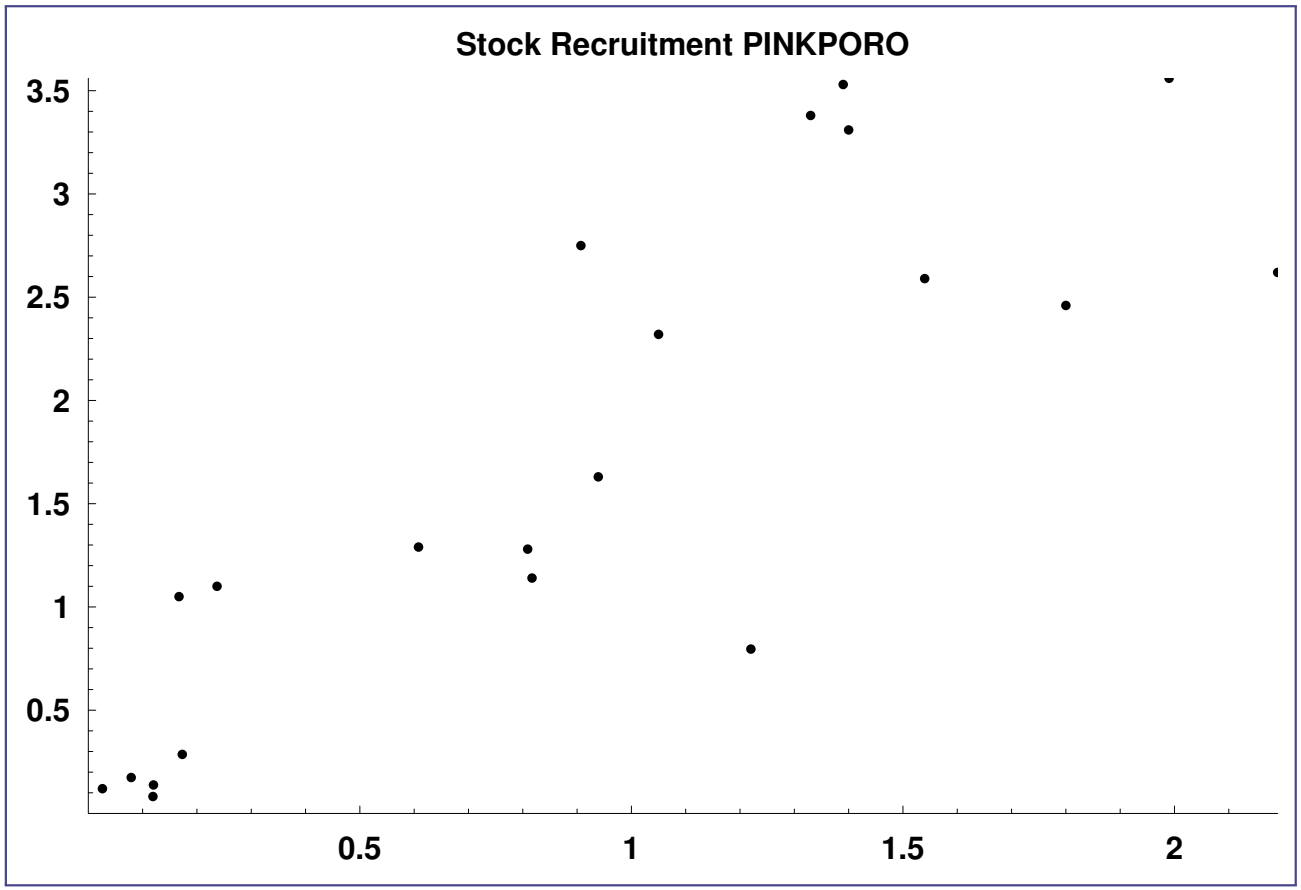
From R. Myers

Stock Recruitment



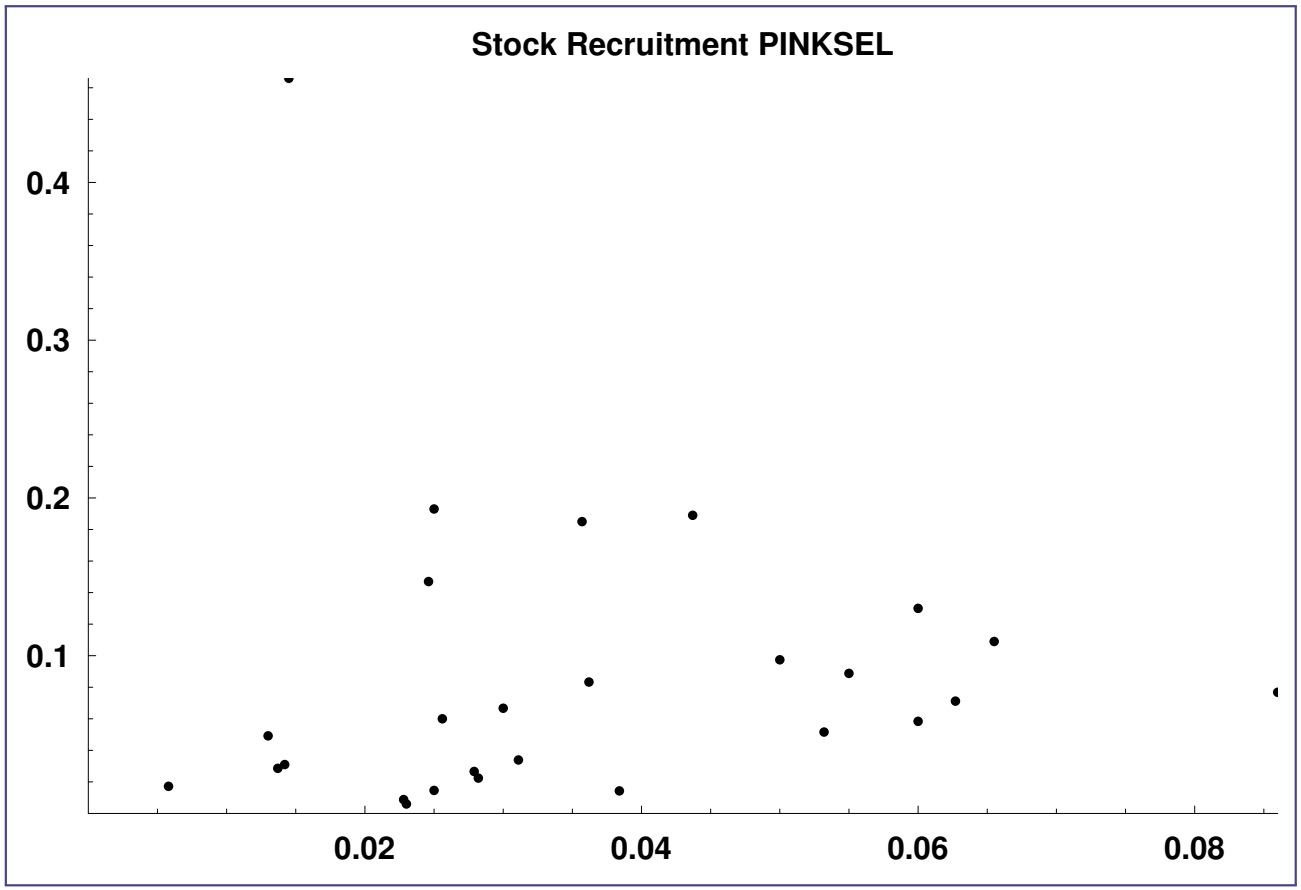
From R. Myers

Stock Recruitment



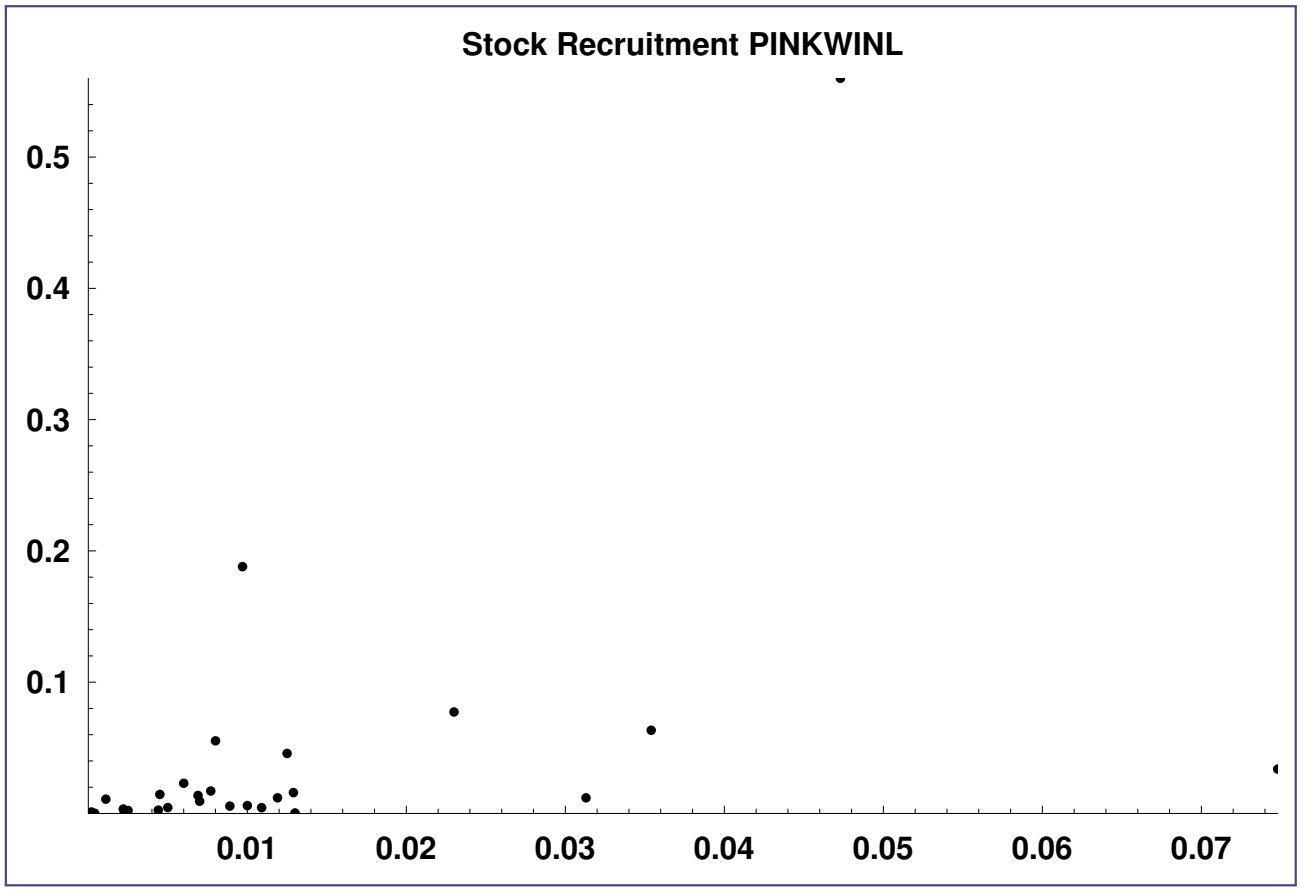
From R. Myers

Stock Recruitment



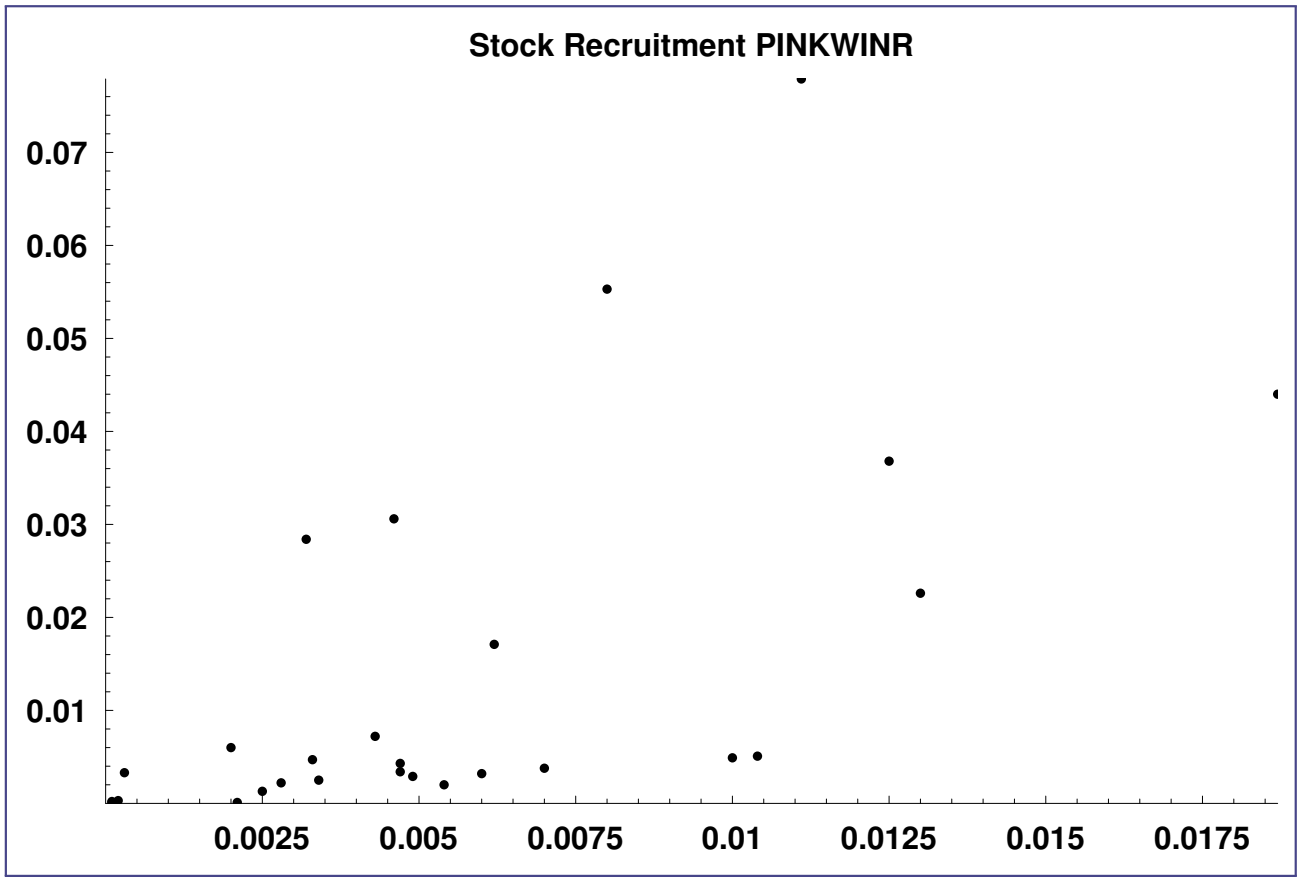
From R. Myers

Stock Recruitment



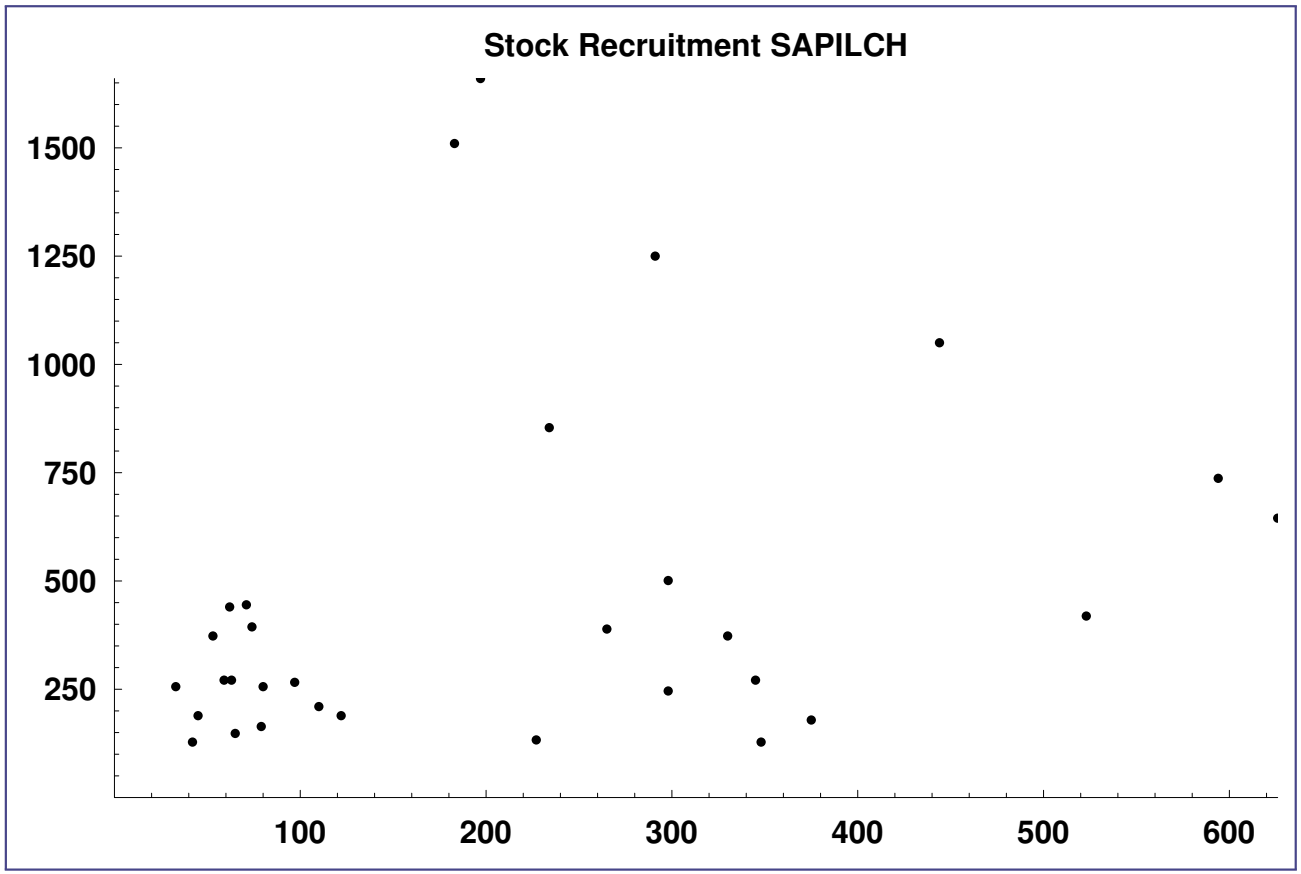
From R. Myers

Stock Recruitment



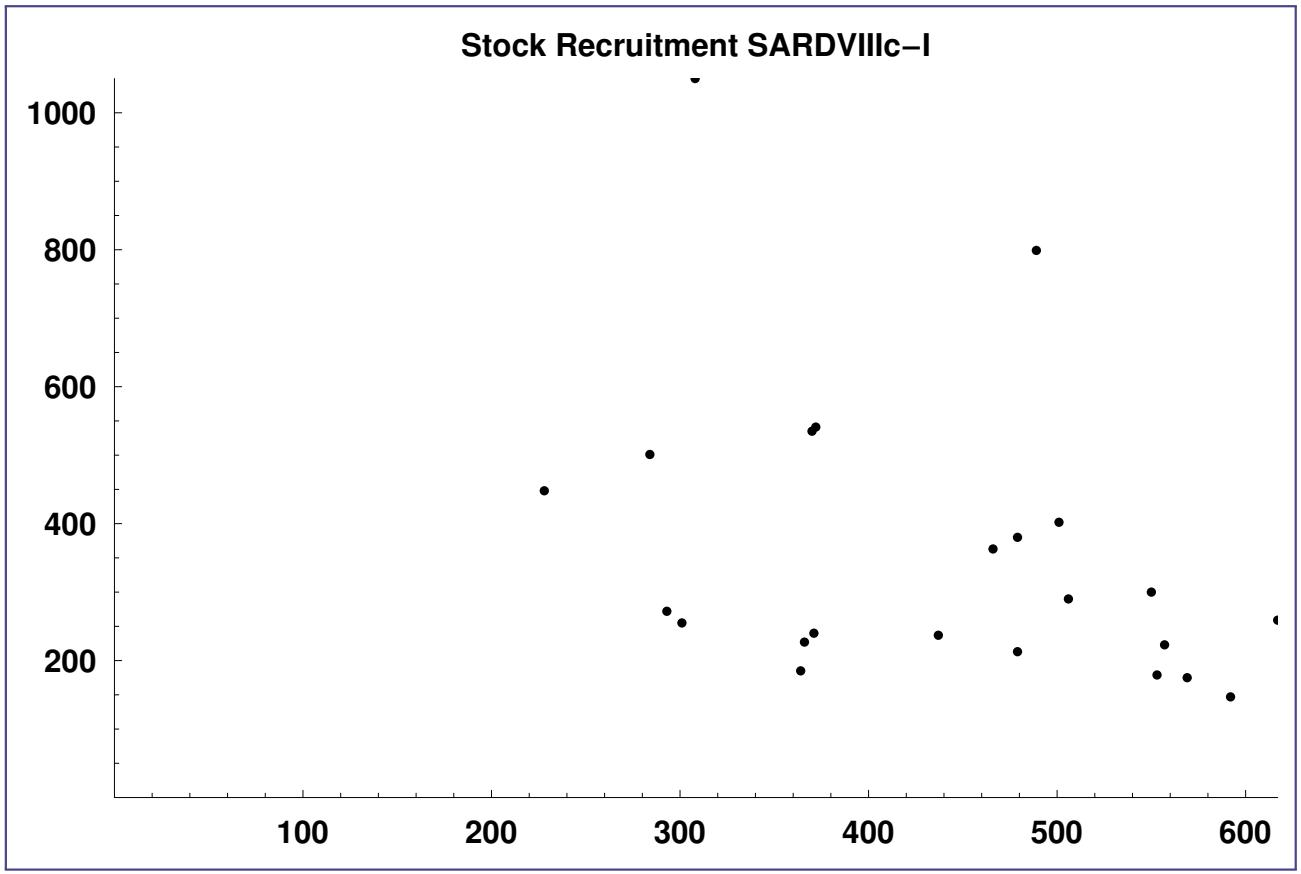
From R. Myers

Stock Recruitment



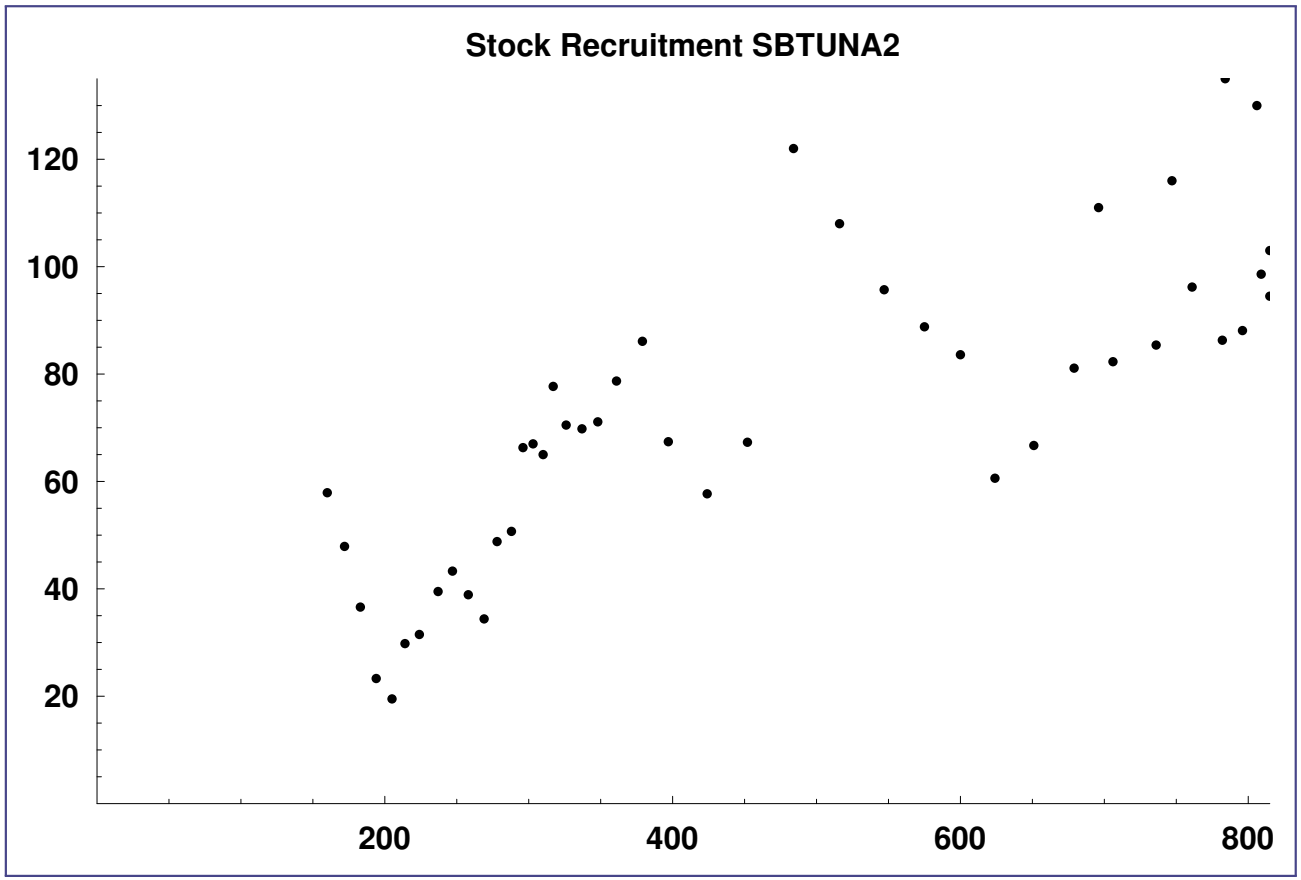
From R. Myers

Stock Recruitment



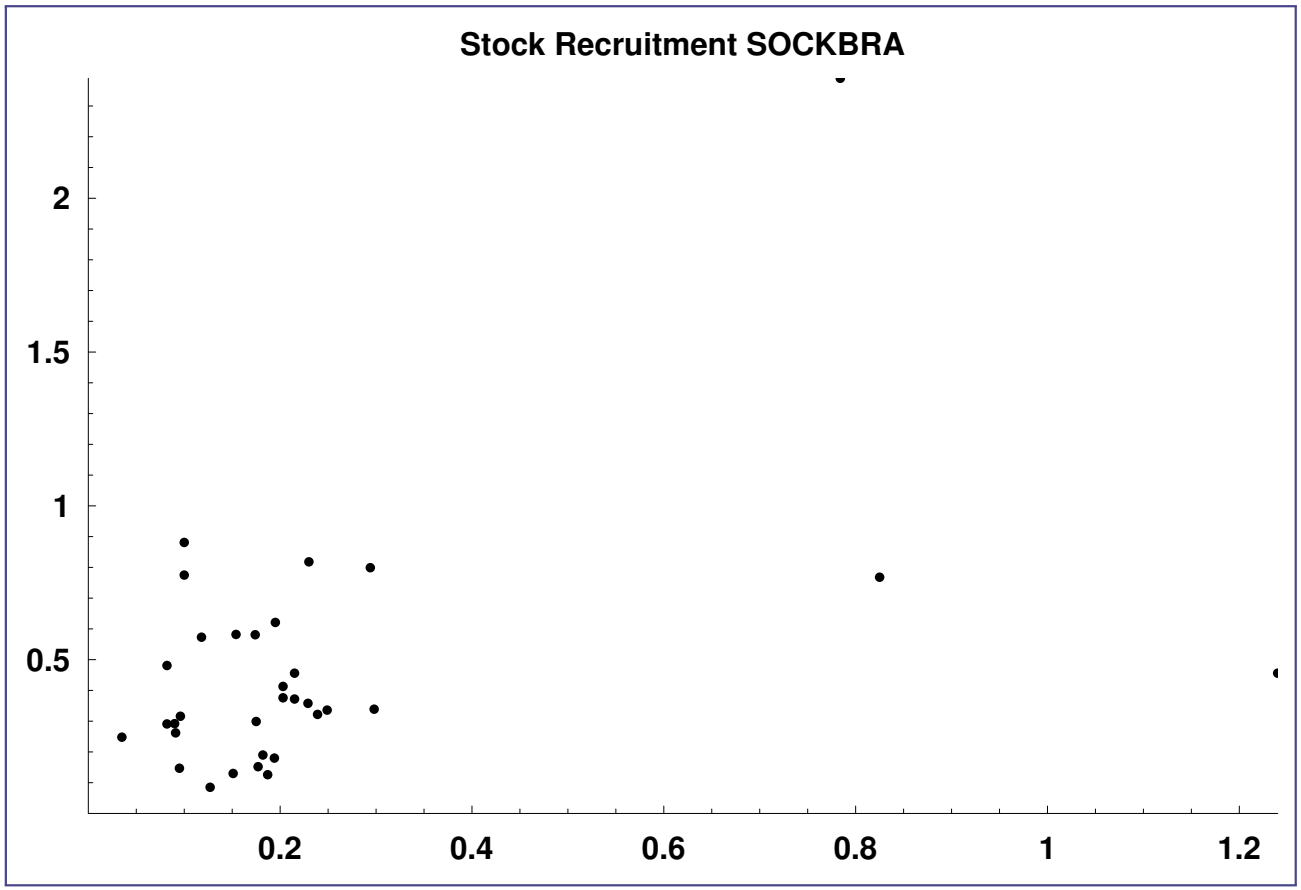
From R. Myers

Stock Recruitment



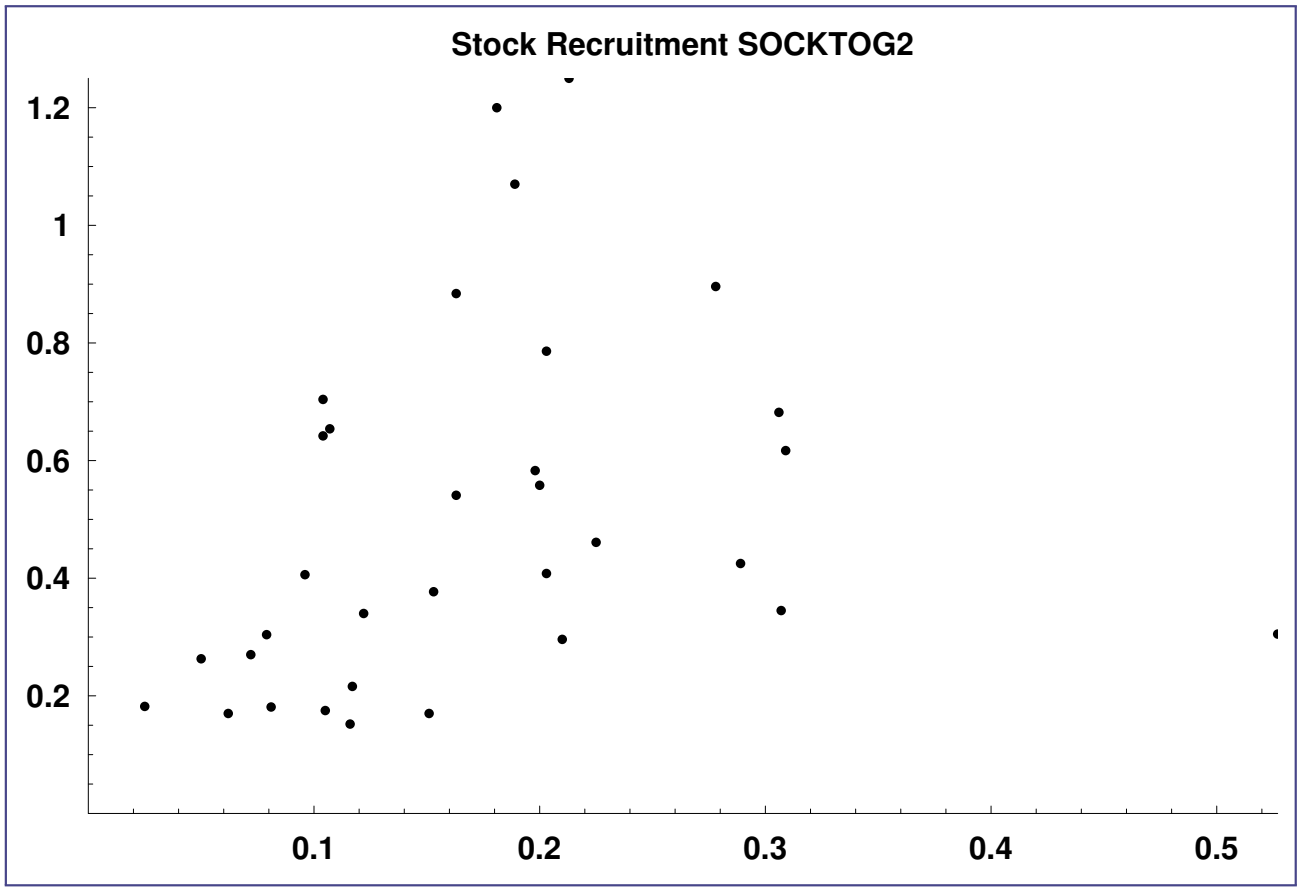
From R. Myers

Stock Recruitment



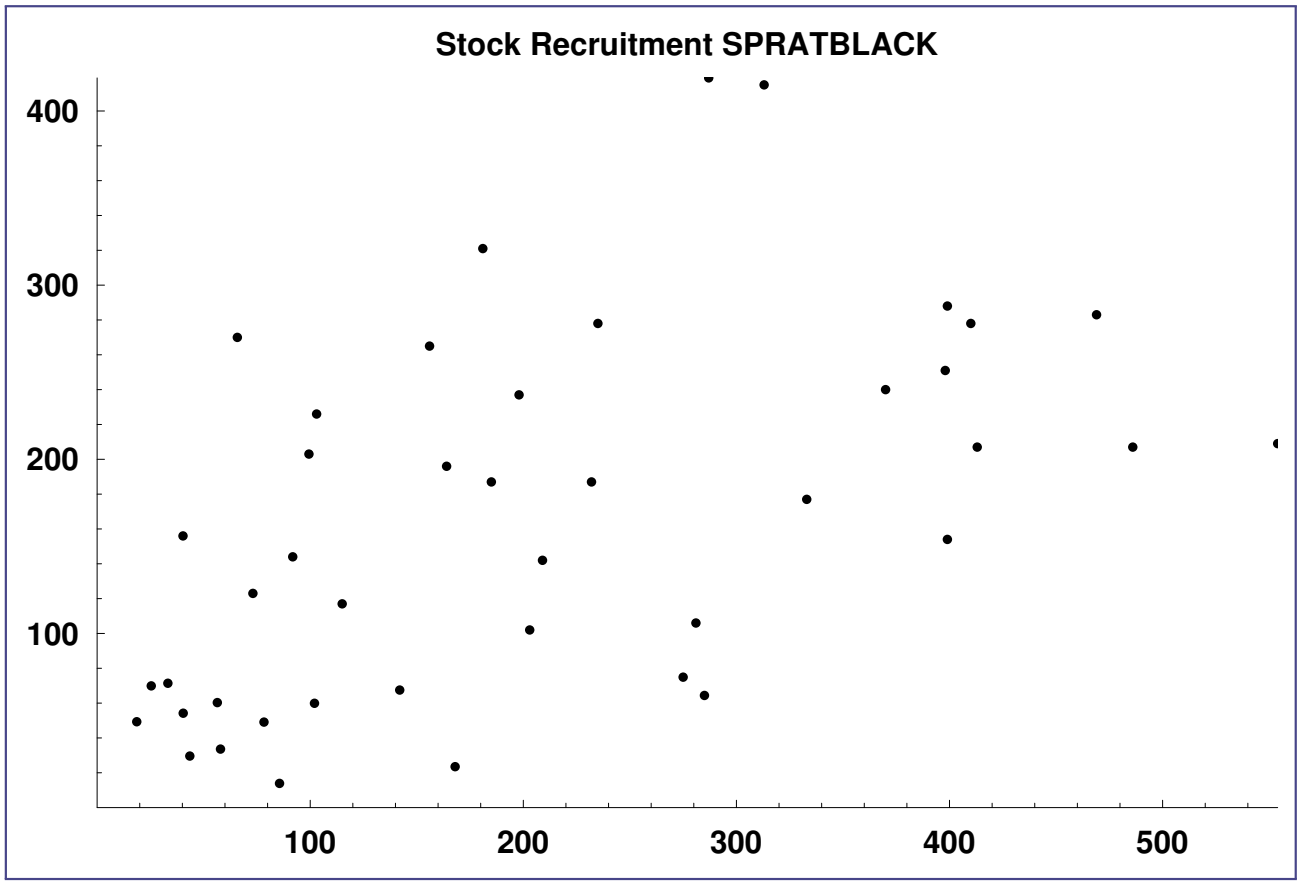
From R. Myers

Stock Recruitment



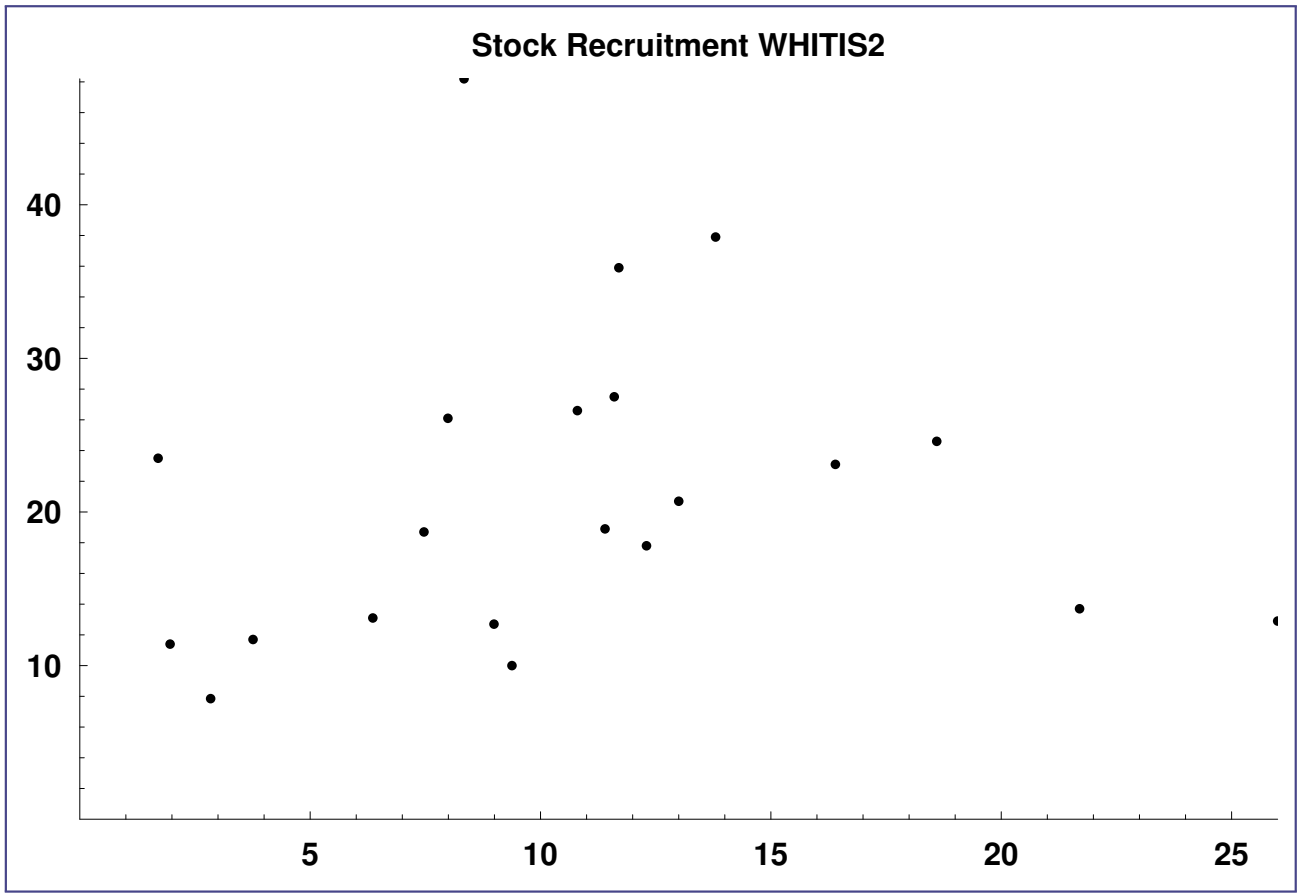
From R. Myers

Stock Recruitment



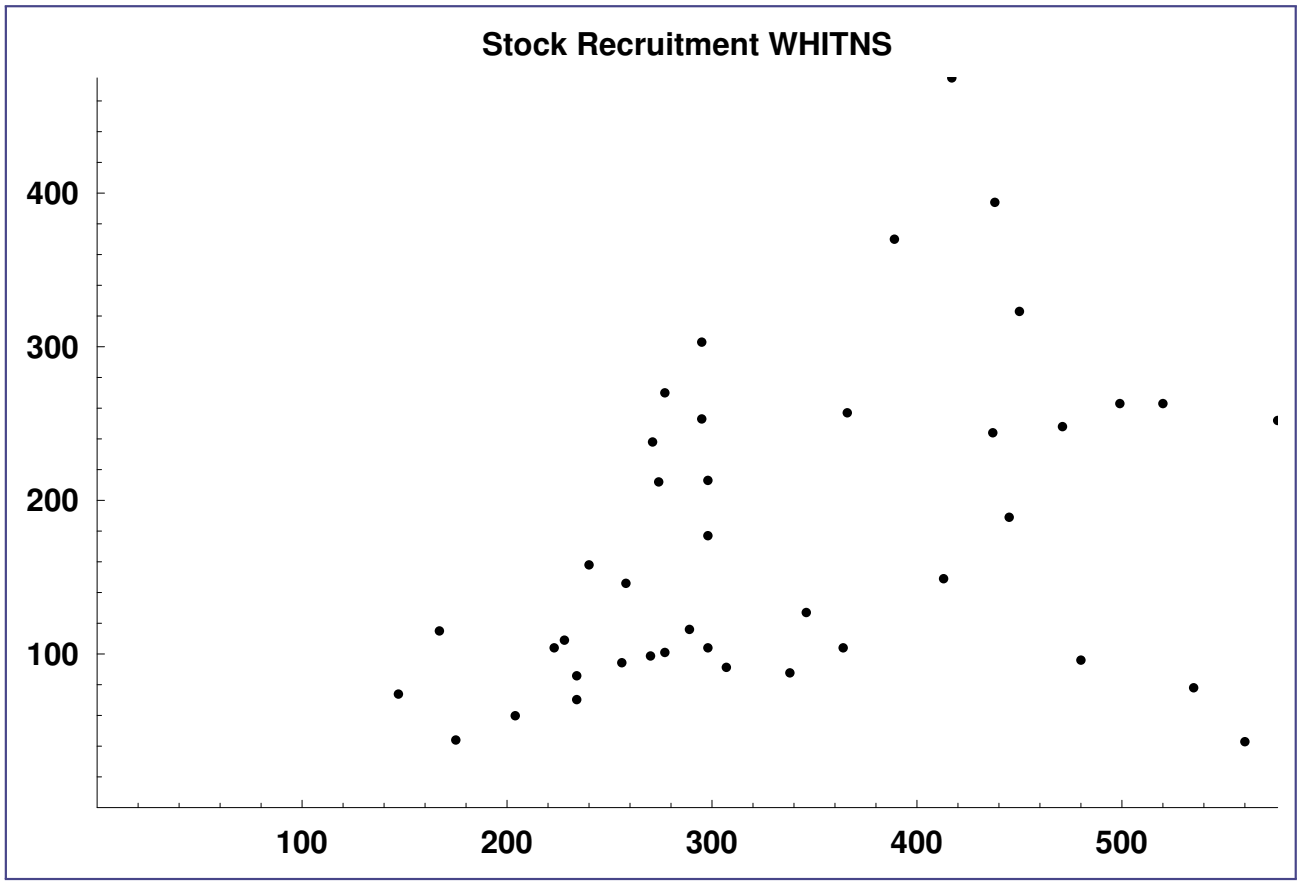
From R. Myers

Stock Recruitment



From R. Myers

Stock Recruitment



From R. Myers

Is this a neutral Darwinian approach?

Darwinism : Evolution through variation, heredity and selection.

An alternative interplay of indeterminism and constraints.

Two types of constraints : from heredity (evolvability) and selection.

Variation : mechanism at an individual level.

Variability : patterns at a population level. Discuss constraints and causation : and then determinism and indeterminism

Is this a neutral Darwinian approach?

A population of states. Then

- Variation : through "open" random choice
- Selection : through satiation and mass balance equations
- Heredity/Lignage : through inertia constraint
- Variability : patterns in time series