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Performance of some harvest control rules

by

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Introduction and background

Previous meetings of COMFIE, SGPAFM and ACFM have indicated that there is a need to define a concept of a "precautionary region" for both the conduct of fishing and for fisheries advice. The definition of such a region should take into account the fundamental ideas underlying the precautionary approach (PA), whether precise wording is used or not. A harvest control rule (HCR) which is inside a predefined precautionary region will be defined to be "acceptable". Similarly, a harvest control rule which violates any of the principles of the PA will be defined to be "unacceptable".

A fair debate has ensued concerning the question of whether an advisor should define a harvest control rule (SGPAFM) or not (Horwood and Stokes, 1998). This is a moot point in the current context, since the issue is the definition of a precautionary region of advice and implementation. This is equivalent to putting down a definition of a fishery which is in accordance with the precautionary approach. Definition of a precautionary region requires the definition of bounds which must limit catches (and advice). This is equivalent to defining a harvest control rule which bounds any implemented control rule.

The present paper evaluates possible definitions of bound on implemented harvest control rules. Although possibly confusing, it should be noted that such a bound is in itself a potential harvest control rule (HCR) and defines the maximum allowable yield which can be taken in any given stock situation if the PA is to be adhered to. Any further requirement, such as the maximisation of profit, can only be optimised with the same or lower yields. For the rest of this paper, the distinction between a bound and an implementation will be omitted but it is understood that the HCRs considered in the paper are only upper bounds.

Although not needed in principle, an important ingredient of an HCR can be the definition of "how to get from here to there", i.e. action during a possible phase-in period. Thus it may be argued that severe reductions in catches are unacceptable in certain circumstances. On the other hand, the PA does imply that if current fishing is not sustainable, then certain immediate and minimal reductions in catches are required. Thus the PA does indicate certain properties of the phase-in period in addition to the medium-term HCR. For example, a phase-in method which increases current F to non-sustainable levels before dropping F towards an acceptable level is not in accordance with the PA. Similarly, a phase-in method which has high probability of this event, or high probability of stocks dropping below currently minimal and low biomass levels is not acceptable.

In one sense, the present paper describes a search for a description of an HCR which is a minimal requirement in terms of satisfying the PA, yet giving maximal catches.

Although analyses along these lines have been undertaken before, an analysis which uses data on a large number of ICES stocks is required. This paper describes simulations of a number of harvest control laws for 33 ICES stocks, considerably extending earlier simulations (COMFIE) which only used simulated populations.

Criteria for acceptable harvest control laws

The various international agreements listed e.g. in SGPAFM indicate that F must be below F_{crash} with high probability. This is to hold at all times, i.e. fishing should always be conducted at sustainable levels. Thus, there needs to be an evaluation of the probability of F being above F_{crash}. Rather than placing initial restrictions on parameters, an HCR will simply fail if this probability is not negligible.

Action should be taken immediately if the stocks are overexploited, giving minimal requirements on the phase-in period. The interpretation of this must be that catches must be reduced at least by some initial amount to ensure that depleted populations do not continue on their downwards trend, but increase with high certainty initially and end up above B_{lim}.

The biomass should be above B_{lim} with high probability, at least after an initial phase-in period. This has traditionally been interpreted to mean that F should be reduced to zero in the medium term, if B is close to B_{lim}.

The form of the basic harvest control rules tested will be taken as usual for the medium-term. Thus the logic underlying HCRs considered by various bodies will be assumed to apply. This indicates that fishing mortality should be no more than F_{msy} when biomass is above B_{msy} and reduced to zero as biomass drops to B_{lim}. The parametric for of the reduction in F as biomass drops from B_{msy} to B_{lim} is in principle quite flexible, but only linear reductions in F will be considered in this paper.

For the phase-in period, reluctance to immediate catch reduction will be modeled by assuming that catches can not be reduced by more than a certain percentage from one year to the next. Different values of this percentage are then tested in order to evaluate whether the PA implies certain levels.

Definition 1: A harvest control rule, or technique for providing fisheries advice, or informal annual method for determining catches is *in accordance* with the PA if the inflicted fishing mortality on the stock is, with high probability, below the upper bound defined by the linear control rule in the (B,F)-plane given by the points (0,0), (B_{lim} ,0), (B_{msy},F_{msy}), (∞,F_{msy}).

If an HCR exceeds the upper bound with non-negligible probability (possibly after a phase-in) then it is clearly in violation of the PA. The definition of "non-negligible" is subjective but it is clear that a probability of e.g. over 25% is not negligible. Thus, a harvest control rule which exceeds this upper bound with more than 25% probability will clearly violate the PA.

Data sets

The data used are taken from the most recent stock assessments provided by ICES, covering the following 33 stocks.

1. Arctic Cod
2. Arctic Greenland Halibut
3. Arctic Haddock
4. Arctic Redfish
5. Faroe pleateau Cod
6. Faroe Haddock
7. Faroe Saithe
8. Iceland Saithe
9. Baltic Cod in divisions 22-24
10. Baltic Cod in divisions 25-32
11. Kattegat Cod
12. Herring in the Gulf of Riga
13. Sole in the Skagerrak and Kattegat
14. Cod in sub-area IV-b
15. Rockall Haddock
16. Irish Sea Plaice
17. Scakarak Sea Saithe
18. Irish Sea Sole
19. Scow Whiting
20. Cod in areas IIIA (Skagerakk) IV and VIID

21. Plaice in sub-area IV
22. Plaice in the Kattegat and Skagerrak
23. North Sea Sole
24. Pandalus in Skaggerak and Norwegian Deeps
25. Cod in the Wetern Channel
26. Black Angerfish in divisions VIIIC and IXA
27. Megrim in divisions VIIIC and IXA
28. Anglerfish in divisions VIIA-K andVIII A-B
29. Celtic Sea Plaice
30. Plaice in the Eastern Channel
31. Celtic Sea Sole
32. Sole in the Eastern Channel
33. Iceland Cod

Reference points are based on a number of biological measurements comprising,

1) mean weight, proportion mature at age,
2) assessment results including the stock size in numbers at age, fishing mortality at age and related quantities such as the selection pattern and most recent average fishing mortality,
3) estimates of a stock-recruitment function.

The value of $F_{0.1}$ is used in some harvesting regimes and has been found to be promising in some simulated scenarios. This is computed as usual (Beverton&Holt) based on the selection pattern and mean weight at age.

The current (i.e. most recent) fishing mortality is also needed for comparative purposes. This is used to define one particular harvest control rule, namely $F_{s.q.}$, corresponding to continued fishing at the current fishing mortality.

Data for the stock recruit function are taken from stock summary tables, appropriately time lagged according to the age of entry to the fishery. Obviously, parameters such as F_{crash}, F_{MSY} and B_{MSY} are well defined given a stock-recruit function and other biological parameters.

Preliminary analysis

Several quantities need to be defined in order to set up and evaluate an HCR. In particular, values are needed for target and limit reference points for fishing mortality and biomass, a minimum set of which is F_{lim} and B_{lim}, i.e. the values of fishing mortality and biomass which are to be avoided. Related to these are quantities such as F_{crash}, F_{MSY} and B_{MSY}. These are better specified mathematically given a stock-recruit function, but it is not clear initially how these relate to the limit reference points nor is it at all clear how they should be computed given the difficult nature of the stock and recruit data.

The following describes the computation of these values based on the data listed above. These computations follow certain conventions which have been assumed along the way. Some of these could no doubt be improved upon for individual stocks, but the point of the present analysis is mainly to obtain initial guidance on the relative merits of different harvest control rules, when viewed broadly rather than in minute detail on a stock-by-stock basis.

The single most important issue is the selection of a stock-recruitment model. The approach taken here is to fit a Ricker stock-recruit curve to each stock. As a generic function, this is preferable to the Beverton-Holt function since a least-squares fit to the latter will attempt to estimate an infinite slope at the origin if much of the data has a negative slope. Naturally, if all of the data has a negative slope, then there is no information on the slope at the origin, but an assumption of an infinite slope is somewhat extreme and hence the Ricker form is assumed. Although not ideal, the blanket use of the Ricker function enabled automation of the analysis, and thus enabling a wider range of stocks than would have otherwise been possible.

Plots of fitted function are given in appendix 1, figures 2-34, for all stocks considered along with the stock and recruitment data used in the fitting process. The CV of recruitment is computed based on the log-scale deviations from the fitted curve. This values is used as an estimate of the likely future variation in recruitment.

Yield per recruit calculations are undertaken, with each set of input data (weight at age, F at age, M at age etc.) being an average over the last three years available. The selection pattern is defined from F at age, scaled so the mean of some ages x through y is unity. x and y are taken as the same values as those used by each Working Group. The reference points are taken from the closest estimate of F to the optimal solution (i.e. selected from a limited range of F values rather than exactly determined through an error minimization routine).

The following information thus provides the basis for the forward simulations for each stock:

1. Current stock size at age. This is the last complete stock size from the ICES data i.e. 1996.
2. Weight at age in both catch and stock.
3. Natural mortality (M) at age, and proportion M before spawning.
4. Selection pattern as determined in the yield per recruit calculation.
5. Proportion mature before spawning.
6. B_{MSY}, F_{MSY}, F_{crash} and $F_{0.1}$, $F_{current}$.

The generic form of HCRs considered here is to assume some base F level as long as the stock is above a precautionary biomass, B_{pa}. Fishing mortality is set to zero if biomass is below the limit biomass, B_{lim}. The fishing mortality declines linearly from the base level to zero between B_{pa} and B_{lim}. B_{pa} is always set to B_{MSY}, B_{lim} is half this value. Use of a lower value indicates more knowledge of the population dynamics. This knowledge must in some way justify reducing B_{lim}. The converse argument does not hold: There is no *a priori* reason to select a lower value for B_{lim} and this is certainly one value which is such that the stock is not capable of producing MSY at this level. Table 1 (see appendix) gives the biological reference points and other results from these preliminary analyses.

The maximum F any HCR will advise the fishery is limited to 1.2. This is a pragmatic bound and assumes a maximum fishing mortality that can be induced by the fleet.

It is expected that any implementation of a PA based HCR will result in reduced catches in the immediate future. The size of reduction acceptable to the fishing community could be crucial in attaining wide acceptance for the implementation of such a strategy. Four levels of acceptable catch reduction (δ) are considered, 100%, 50%, 33% and 25%. This is implemented by a simple choice, if the quota based on the HCR is less than the previous year's catch * (1 - δ), then the advised quota for the year is taken as the previous year's catch * (1 - δ).

Evaluation model

The risk analysis comprises three basic elements, fishery management based on erroneous data, forward projection of the "true" biological stock and a stock recruitment model. Forward projection is based upon the true current stock size and catch as derived from the HCR while fishery management acts on biological measurements with errors in the observed stock size, reflected as errors in the output from the HCR. The remaining stock regenerates after harvesting using the stock recruit function variation in the resulting number of recruits as determined by the CV of recruitment. In addition, the initial stock size in numbers at age is assumed to be uncertain and is drawn at random for each generated trajectory.

Four alternative HCRs based upon the different reference points are considered:

0. Direct use of F_{crash} as a "limit" F by setting $F_t = F_{crash}e^{-2\kappa}$ where κ is chosen to reflect the uncertainty in F_{crash}.
1. Use of F_{MSY} as a "target" F.
2. Use of $F_{0.1}$ as a "target" F.
3. Use of $F_{current}$ as a "target" F.

From a practical point of view, it should be noted that with κ =0.4, the first HCR is equivalent to fishing just under one half of F_{crash}, which will tend to give fairly "reasonable" fishing mortality rates, *i.e.* not excessively low values, yet clearly distinct from the obvious candidate for a limit point.

When a harvest control rule is to be used, estimates of F_{msy} and F_{crash} are needed. These are generated once for each simulated trajectory. This corresponds to an implementation such that these quantities are estimated at the outset and not manipulated from then on. It is quite possible that individual estimates of F_{crash} and F_{msy} can be quite large. Since it is likely that some intervention (i.e. alternative estimation method) will be used if a point estimate of F_{msy} and F_{crash} is very large, the generation of these quantities is truncated to 0.8 and 1.2, respectively in the simulations.

Each simulation projects the stock size and yield forwards 30 years using a fixed HCR throughout. Each HCR (every combination of PA type and δ–level) is tested on each stock for 100 simulations.

The single most important output parameter is the number of occasions in which the fishery is being conducted in a "precautionary manner". This is defined as the percentage of years in which the realised fishing mortality is less that Fpa i.e. lies within the shaded region of figure 1.

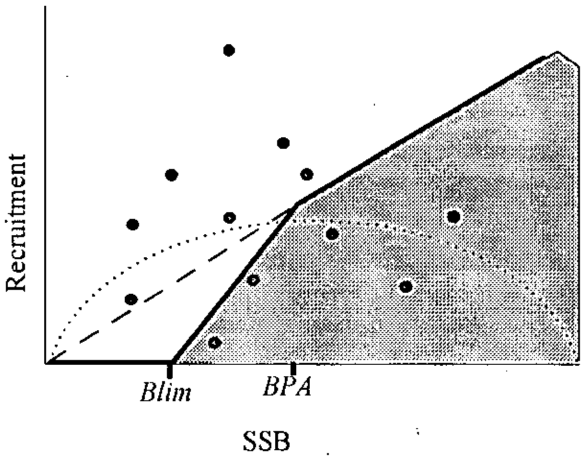


Figure 1. A theoretical SSB-recruitment plot showing the stock-recruit function (....) data(•), replacement line according to Fpa (▬▬). The shaded region defines the bounds for precautionary fishing.

Being in accordance with the precautionary approach.

An appropriate HCR will always be stock specific, and it is quite possible to identify HCRs which are not in accordance with the PA on a stock-specific basis. The use of stochastic processes within the simulations precludes the expectation that an HCR will provide precautionary fishing 100% of the time. For a given stock, therefore, an HCR should satisfy all of the following criteria:

(a) $F < F_{PA}$ in at least 75% of all years

(b) $F < F_{crash}$ in at least 95% of all years

(c) $SSB > B_{PA}$ in at least 75% of all years

(d) $SSB > B_{lim}$ in at least 95% of all years

It is obvious that amongst HCRs which satisfy these safety concerns, other criteria can be used to decide among them. These include long term yield, minimum immediate loss of yield, minimum annual yield variation and so on.

These criteria can be extended to more generic situations. For example, if an HCR "fails" in some sense for most stocks on one of these criteria, then it would not be prudent to use it on very few stocks unless it can be demonstrated that this really is safe and not just due to chance in either the simulations or a biased assessment of some parameters for these few stocks. In accordance with the PA, the following definition will be used to eliminate non-precautionary HCRs.

Definition 2. A HCR will be deemed in accordance with the precautionary approach if the fishing mortality advice to the fishery is less than Fpa at least 75% of the time, and less than Fcrash less than 95% of the time. The SSB must resulting from this HCR must be above Bpa at least 75% of the time and must not fall below Blim on more than 5% of occasions.

Results

The effect of the limitations on catch reduction can be seen in the deterministic case, when comparing the trajectories given in figs 2 and 3 (appendix) corresponding to limiting changes to 25% and not limiting them at all. This example, Faroe Saithe, shows the predicted yield and stock biomass with and without assumed stochasticity. In the deterministic case, it is seen that the catch reduction serves only to delay stock recovery, the equilibrium reached int each case being the same. The stochastic version however, demonstrates that the imposition of a restriction on catch change serves to stabilise the yield and prevents fishery closure.

At each iteration, a stock is assessed as being either precautionary (complying with definition 2) or not over the 30 year projection. Each stock is then examined at each HCR and over all simulations to determine what percentage of simulations are precautionary. The definition of a satisfactory HCR remains unclear. Table 2 presents 3 alternatives for a satisfactory HCR. The 80% level implies that x% of stocks are precautionary for an average of 80% of the time.

Table 2. Percentage of stocks which are precautionary for a set % of the time.

	Delta				
PA Type	0.25	0.33	0.5	1	% time fishing must be precautionary
Fcrash	21	30	30	0	
FMSY	12	15	15	0	80%
F0.1	58	67	64	45	
Fs.q.	12	12	6	3	
Fcrash	48	58	55	9	
FMSY	39	58	64	0	
F0.1	64	73	70	55	75%
Fs.q.	27	21	24	3	
Fcrash	70	76	85	27	
FMSY	76	79	94	0	
F0.1	73	73	73	64	70%
Fs.q.	42	33	55	3	

It is immediately obvious that $F_{0.1}$ is the preferred PA type for high levels of compliance with the PA. If standards are lowered, however, F_{MSY} and F_{crash} can outperform $F_{0.1}$. The case for limiting catch reductions is clearly seen in that a delta of 0.5 or 0.33 always outperforms unlimited catch changes or resticting change to 25%

It can be argued that the chance of dropping below Blim is the most crucial component of being "precautionary", as this indicates that the stock is in real danger, as opposed to exceeding Flim which states that the stock is heading towards danger. Table 3 shows the percentage of stocks which satisfy the Blim criteria outlined above for 95% of simulations. It is apparent that a delta of one is required to miminise the chance of dropping below Blim.

Table 3. Mean percentage of stocks which remain above Blim for at least 95% of simulations.

	Delta			
PA Type	0.25	0.33	0.5	1
Fcrash	45	52	73	82
FMSY	45	55	64	79
F0.1	58	67	70	79
Fs.q.	30	27	36	39

The implications for long term yield are potentially considerable. Table 4 shows the mean yield over the time projection as a percentage of MSY, averaged over all stocks. Fs.q. produces the highest overall yield although much of this is taken early on in the projection with subsequent stock collapse.

Table 5. Mean yield as a percentage of MSY over the projection period, averaged over all stocks.

	Delta			
PA Type	0.25	0.33	0.5	1
Fcrash	62	66	70	88
FMSY	61	65	69	88
F0.1	62	64	68	84
Fs.q.	60	63	66	90

Finally, if the PA type is chosen on a stock my stock basis rather than applying a single PA type over all stocks, the % compliance with the PA is greatly enhanced, and the evidence for a limit on catch changes becomes even more apparent.

Table 6. % Stocks which are precautionary for 75% of simulations when the optimum PA type is chosen on a stock by stock basis.

Delta			
0.25	0.33	0.5	1
82	91	91	61

Discussion

The fact that $F_{0.1}$ is overtaken as the "best" Fpa when the satisfaction criteria are reduced reinforces the need for a stock by stock examination of the data. Quite why F0.1 should not always be the most precautionary is probably due to occasions where F0.1 is actually higher than Fcrash the results based on simulated data sets in (COMFIE, 1997) appear to hold for real data sets as well, i.e. there appear to be instances where an $F_{0.1}$-based strategy is not sufficiently conservative to be sustainable. Although the CV of Fcrash is higher than F0.1 there is no particular reason to believe that F_{crash} is estimated in a biased manner and the results therefore appear to hold regardless of this uncertainty.

In principle, of course, there is no reason why a yield-per-recruit related reference point should perform well in terms of total yield or in terms of sustainability. Hence it would seem appropriate to investigate either combinations of $F_{0.1}$ and F_{med} or alternative methods such as B_{buf}, also designed to alleviate this problem.

The use of Fs.q as the basis for the HCR always returns the lowest accordance with the PA, and the mean yield shows little advantage, probably due to the stock collapsing on a higher number of occasions.

The imposition of a limit on the interanual catch variation is advantageous in two ways. Firstly, when chosen correctly (i.e. 50% or 33%) it enables precautionary fishing, given a suitable F basis for the HCR. Secondly it provides degree of stability to the industry and vastly reduces the need for total fishery closure. The principle drawback, however is the potential loss of long term yield, although the stability arising from this action plan may well negate the economic impact.

The suitability of delta=0.5 and 0.33 is probably due to a combination of factors. A low delta implies that the fleet is restrained from heavily fishing a strong year class thus allowing further recovery of the SSB. The converse, however, is also true, that a very weak year class will get fished relatively heavily, thus increasing the risk of stock collapse. Also, stocks which are already depleted when the restriction comes into force will take many years to improve. Using a high delta, the fishing mortality set by the HCR for a strong year class will be close to or at Fpa. The probability of exceeding Fpa is therefore much larger at higher delta. Delta=0.5 or 0.33 possibly provides a balance between the two. A more detailed examination of delta values may well pinpoint some vaule between the two as optimal.

The choice of PA type, that is the fishing mortality upon which to base the HCR, should be as stock specific as the data allows. If, however, there is insufficient data to make an informed decision between PA types, it would seem wisest to use F0.1 as starting with an $F_{0.1}$-based strategy and including limitations on catch variation appears to be sufficient to make considerable improvements on PA-conformance.

Preliminary work on these HCRs concluded that it is not possible to conform to the PA while imposing a fixed limitation on catch decrease without also resorting to a measure such as (i) also limiting catch increases (ii) putting a ceiling on catches or (iii) increasing assessment precision. In practice it will usually be safe to assume that the assessment precision is fixed and necessary to acknowledge that the catch ceiling will be somewhat arbitrary.

There are quite a few difficulties inherent in the presented simulations and some of these should be addressed if only to tighten the basis for conclusions. One of these difficulties is the narrow-minded approach taken to estimating stock-recruitment functions. There would be considerable benefits in considering a few different functional forms and using whichever seems the most appropriate.

It is not at all clear, however, that any of these proposed additions will change the major conclusions.

Acknowledgments

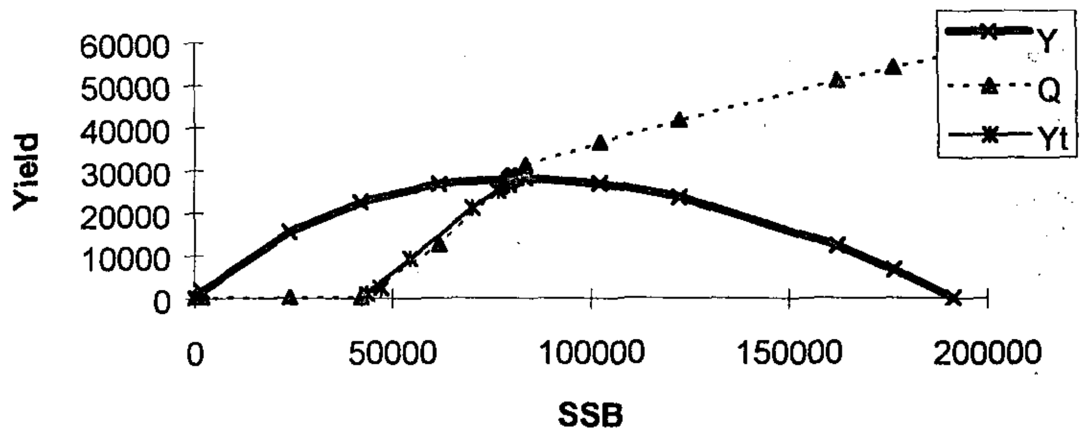
We are grateful to ICES staff for making the ICES stock database available.

Table 1. Some biological reference points for a few stocks.

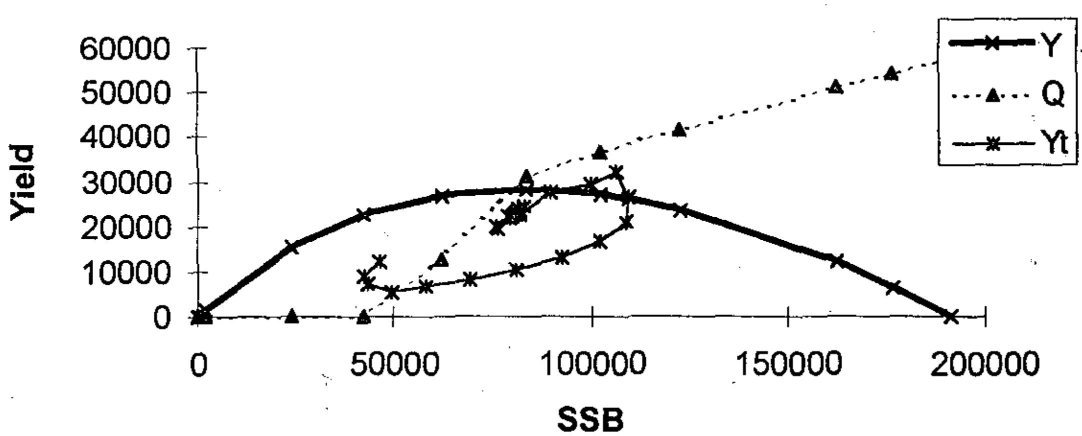
Stock num	Name	F0.1	Fcrash	Fmsy	F97	sigmaF	Bmsy	Blim	Ricker_a	Ricker_K	CV_R	CV_N4
1	cod_arct	0.198	0.8	0.363	0.531641	0.35	788257	394128.5	2.662889	712732.4	0.730244	0.2
2	ghl_arct	0.165	0.363	0.132	0.327704	0.35	62719.86	31359.93	0.865277	84070.12	1.046143	0.2
3	had_arct	0.231	0.363	0.165	0.521113	0.35	133139	66569.52	1.914459	161667.6	1.33042	0.2
4	smn_arct	0.264	0.231	0.099	0.243153	0.35	129643	64821.5	2.344242	275855.2	0.780464	0.2
5	cod_farp	0.297	>1.6	0.561	0.571289	0.35	72699.34	36349.67	0.650265	69989.62	0.563623	0.2
6	had_faro	0.363	0.66	0.297	0.338083	0.35	38872.43	19436.22	0.925831	56203.23	0.989869	0.2
7	sai_faro	0.297	0.594	0.264	0.322947	0.35	83669.62	41834.81	0.561622	104085.6	0.578714	0.2
8	sai_icel	0.231	0.7	0.264	0.324706	0.35	197767.7	98883.83	0.508338	216515.3	0.563553	0.2
9	cod_2224	0.33	1.3	0.627	1.15187	0.35	39365.55	19682.78	5.246397	34912.73	0.725112	0.2
10	cod_2532	0.396	1.4	0.627	0.856435	0.35	301821.2	150910.6	2.648592	322424.5	0.576105	0.2
11	\cod_kat	0.264	1	0.429	1.044535	0.35	25063.64	12531.82	1.615458	22589.12	0.836461	0.2
12	her_riga	0.429	1.4	0.495	0.536756	0.35	50465.02	25232.51	85.08398	66029.97	0.705955	0.2
13	sol_kask	0.264	1.3	0.561	0.394077	0.35	1815.341	907.6704	9.607571	1734.531	0.328885	0.2
14	cod_scow	0.297	0.9	0.396	0.746039	0.35	29594.36	14797.18	0.900721	28206.63	0.510895	0.2
15	had_rock	0.495	0.8	0.363	0.638108	0.35	7614.635	3807.318	3.446252	12148.63	0.896638	0.2
16	ple_iris	0.33	1	0.429	0.585506	0.35	5526.139	2763.07	6.542111	6373.249	0.310637	0.2
17	sai_scrk	0.231	0.528	0.264	0.435359	0.35	42943.32	21471.66	1.774257	42371.48	0.454509	0.2
18	sol_iris	0.297	1.2	0.429	0.423085	0.35	2849.061	1424.531	7.249609	3142.659	0.607341	0.2
19	whg_scow	0.363	1.3	0.495	0.831647	0.35	33062	16531	9.28741	34219	0.569478	0.2
20	cod_347d	0.231	1	0.594	0.7291	0.35	188112.5	94056.23	6.158941	165126.1	0.569581	0.2
21	ple_eche	0.264	0.627	0.33	0.595141	0.35	9917.026	4958.513	6.413887	9762.624	0.39722	0.2
22	ple_kask	0.297	>1.6	0.561	0.796479	0.35	35138.56	17569.28	3.61092	37774.82	0.358954	0.2
23	sol_nsea	0.165	0.462	0.231	0.390293	0.35	55209.68	27604.84	4.409931	65720.59	0.812255	0.2
24	pan_sknd	1	1.6	0.8	0.689817	0.35	9982.356	4991.178	1755.801	13264.88	0.284999	0.2
25	cod_7e_k	0.264	0.9	0.462	0.836433	0.35	15273.52	7636.762	1.078627	12795.25	0.549431	0.2
26	mgb_8c9a	0.462	0.8	0.33	0.351318	0.35	3096.766	1548.383	15.31797	4873.409	0.420259	0.2
27	mgw_8c9a	0.363	0.396	0.165	0.408782	0.35	1542.345	771.1726	5.171346	5255.375	1.02572	0.2
28	mkb_78ab	0.264	0.396	0.165	0.163282	0.35	21222.55	10611.27	1.211402	43663.6	0.08954	0.2
29	ple_celt	0.33	1.1	0.495	0.59429	0.35	1687.759	843.8793	8.92654	1737.319	0.503415	0.2
30	ple_echw	0.264	0.627	0.297	0.55071	0.35	3042.496	1521.248	4.185998	3363.888	0.541813	0.2
31	sol_celt	0.264	0.594	0.297	0.404646	0.35	2375.424	1187.712	4.739838	2777.866	0.255733	0.2
32	sol_echw	0.297	0.264	0.132	0.280254	0.35	3876.114	1938.057	1.896403	9172.202	0.359495	0.2
33	cod_iceg	0.264	1.6	0.66	0.67578	0.35	348334.1	174167	1.440211	321284.6	0.409628	0.2

Appendix I. Stock and recruitment data.

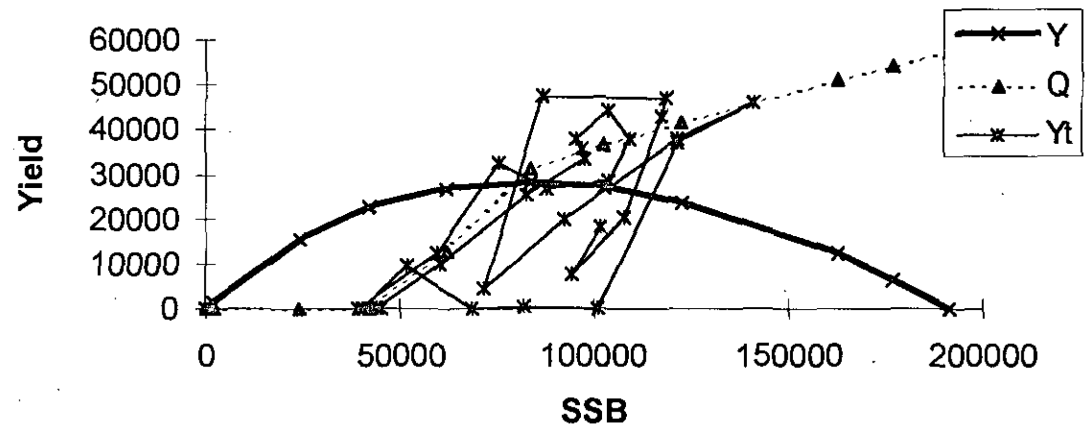
Equilibrium yield vs biomass and quota from CCL based on equilibrium stock Faroe Saithe, delta=1, Fpa=F0.1, Deterministic version



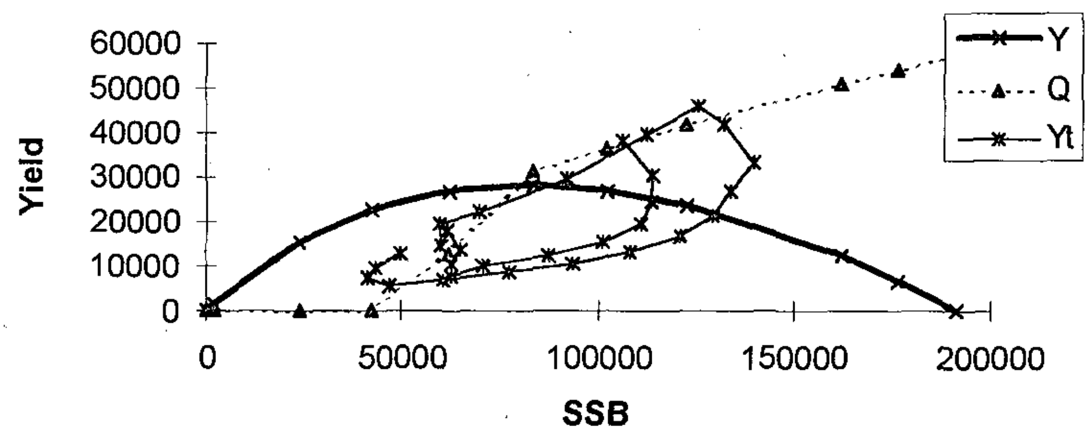
Equilibrium yield vs biomass and quota from CCL based on equilibrium stock Faroe Saithe, delta=0.25, Fpa=F0.1, Deterministic version

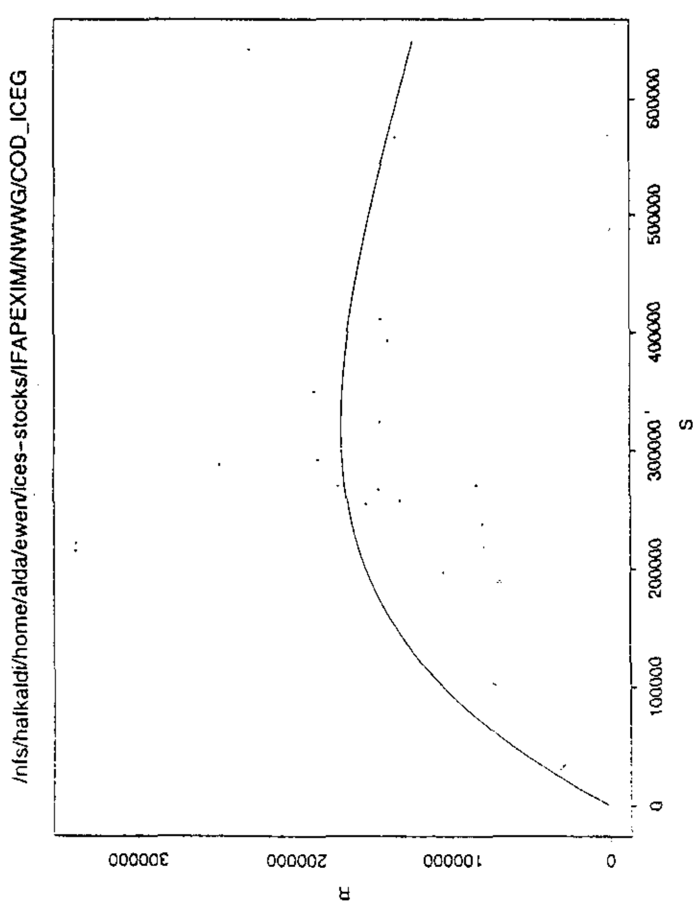


Equilibrium yield vs biomass and quota from CCL based on equilibrium stock: Faroe Saithe, delta=1, Fpa=F0.1, Stochastic version



Equilibrium yield vs biomass and quota from CCL based on equilibrium stock Faroe Saithe, delta=0.25, Fpa=F0.1, Stochastic version

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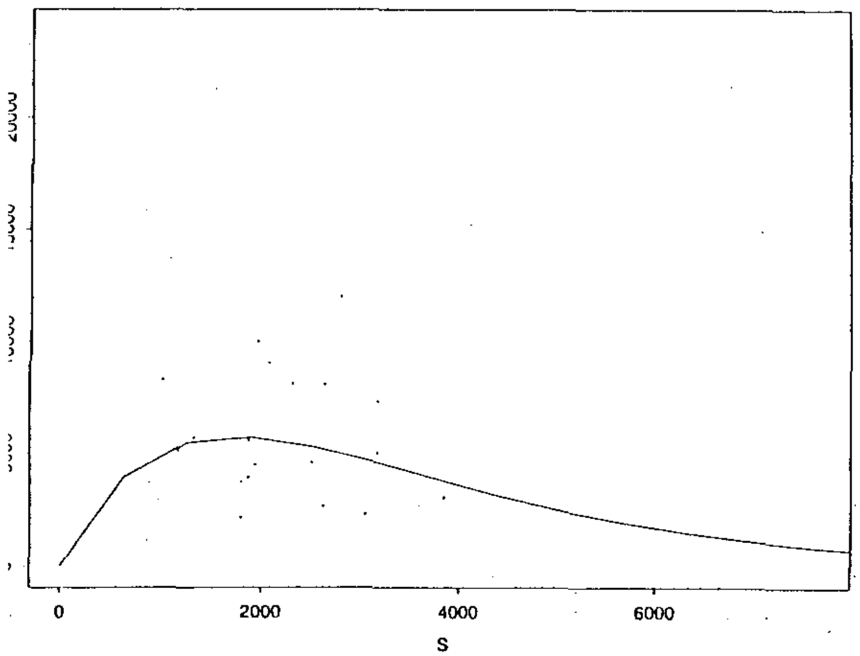

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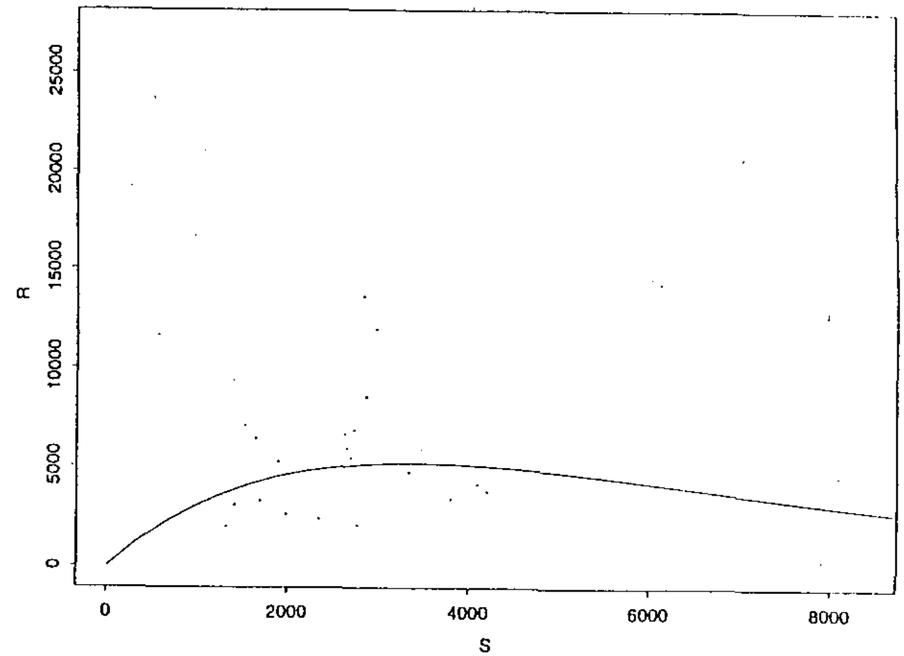

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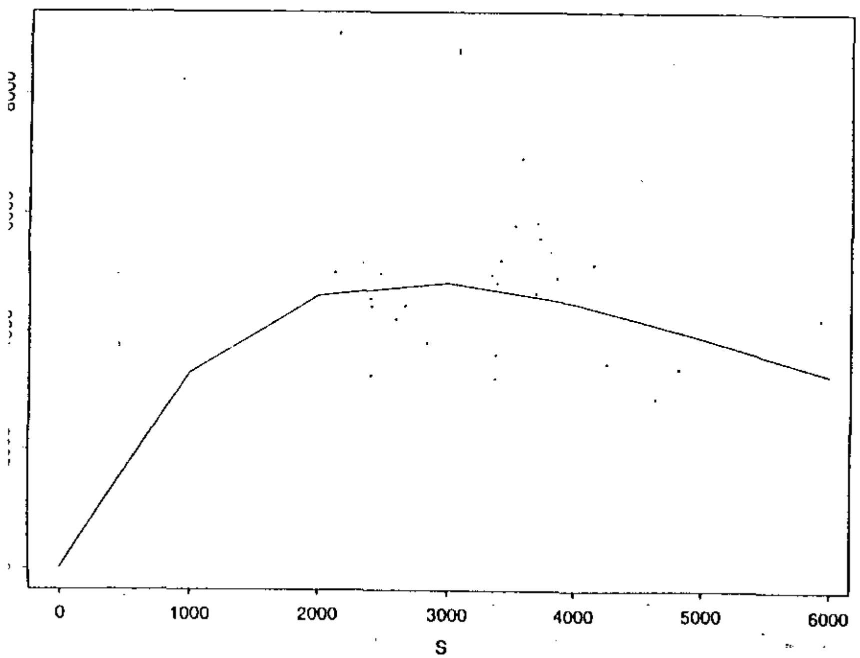

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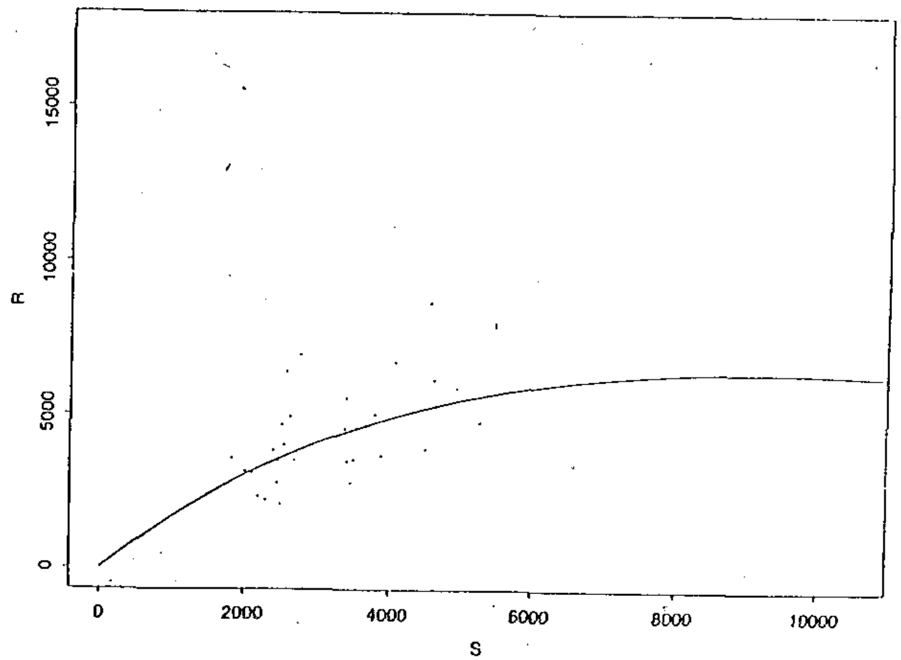

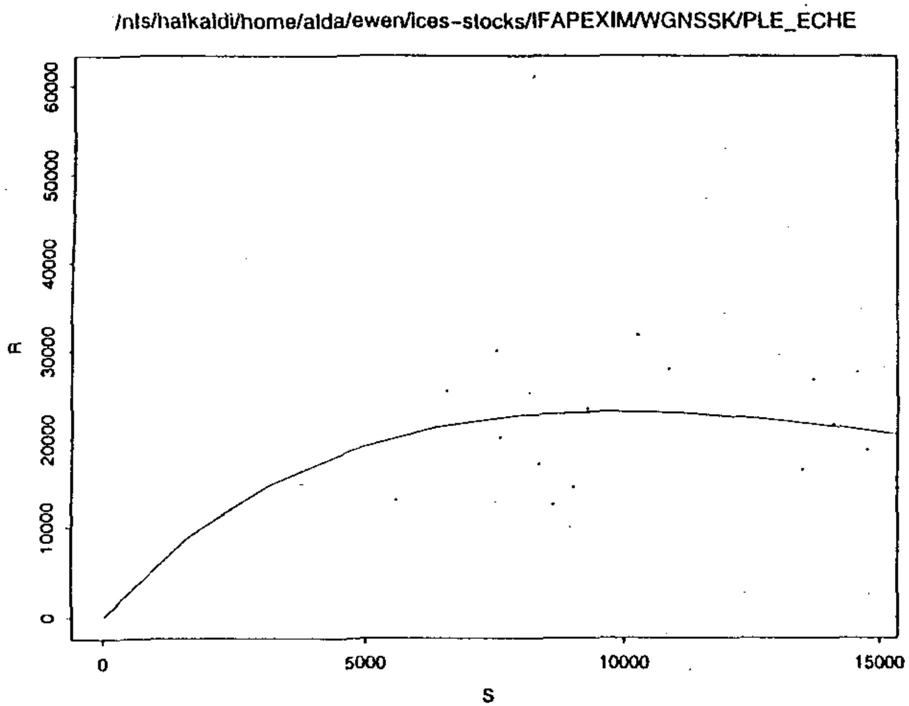
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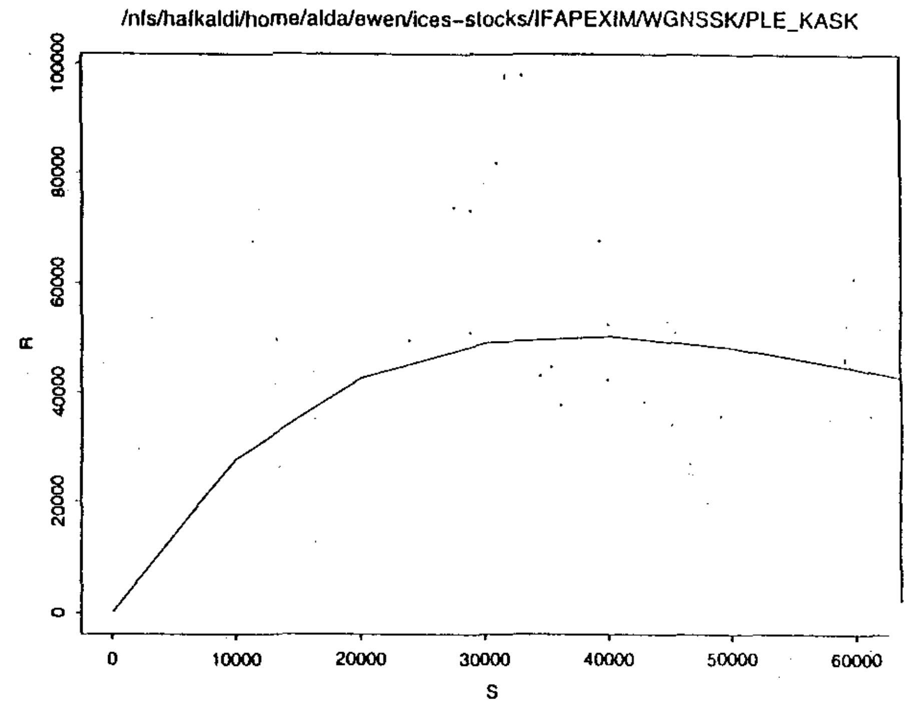
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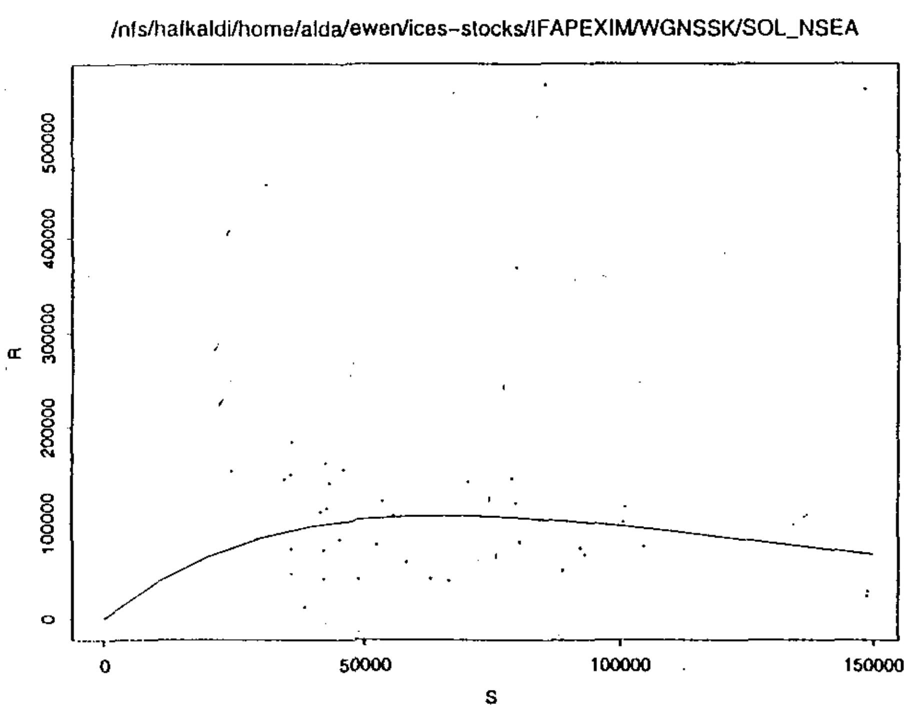
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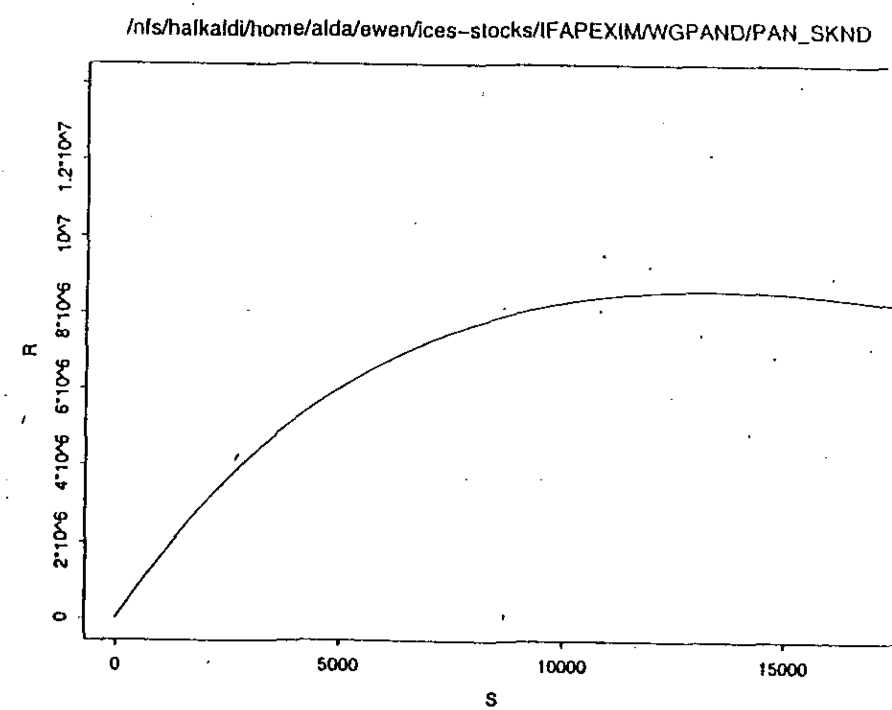
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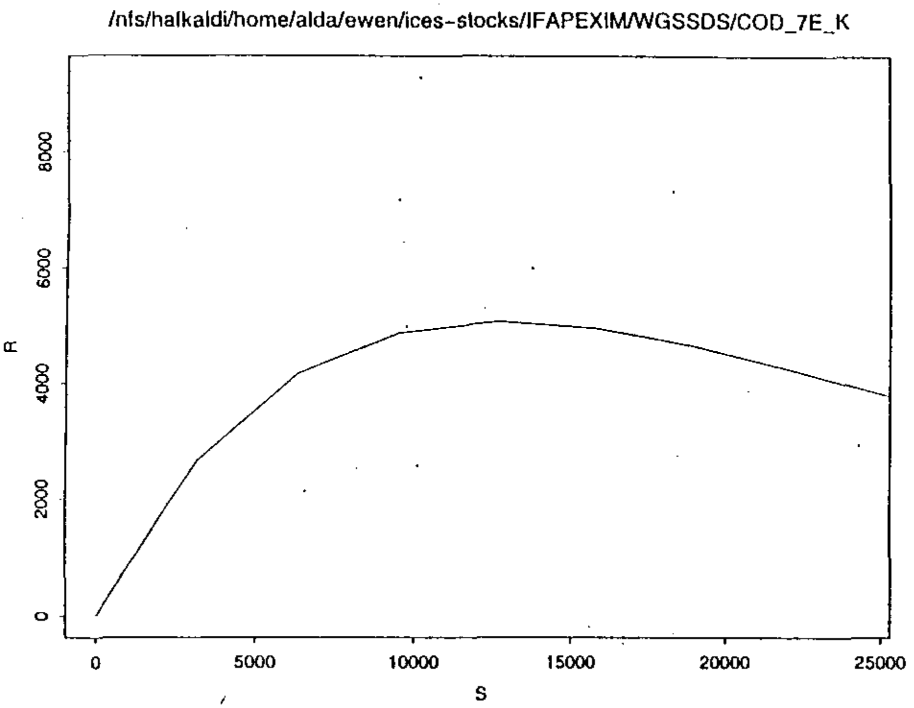
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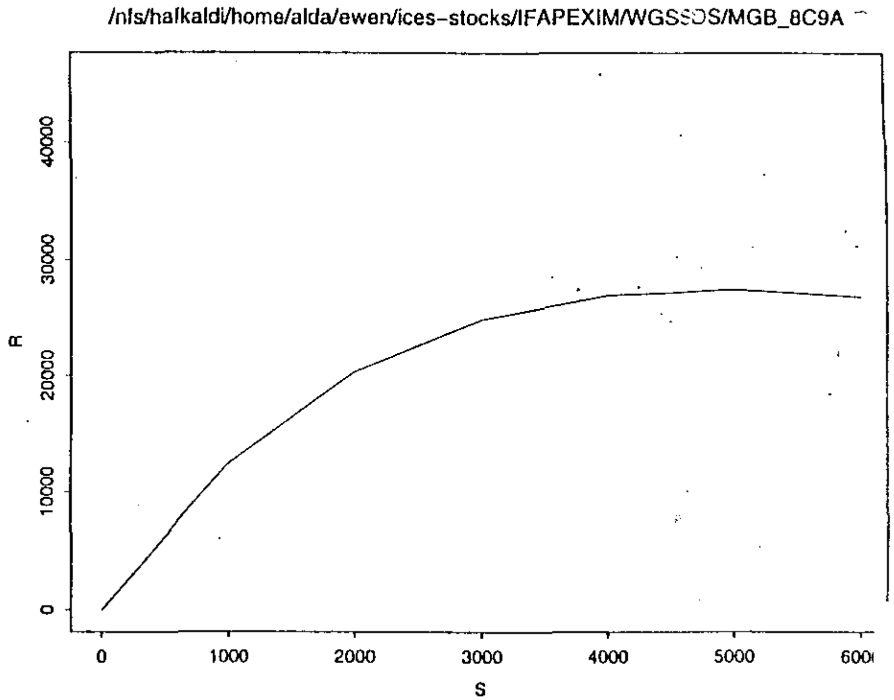
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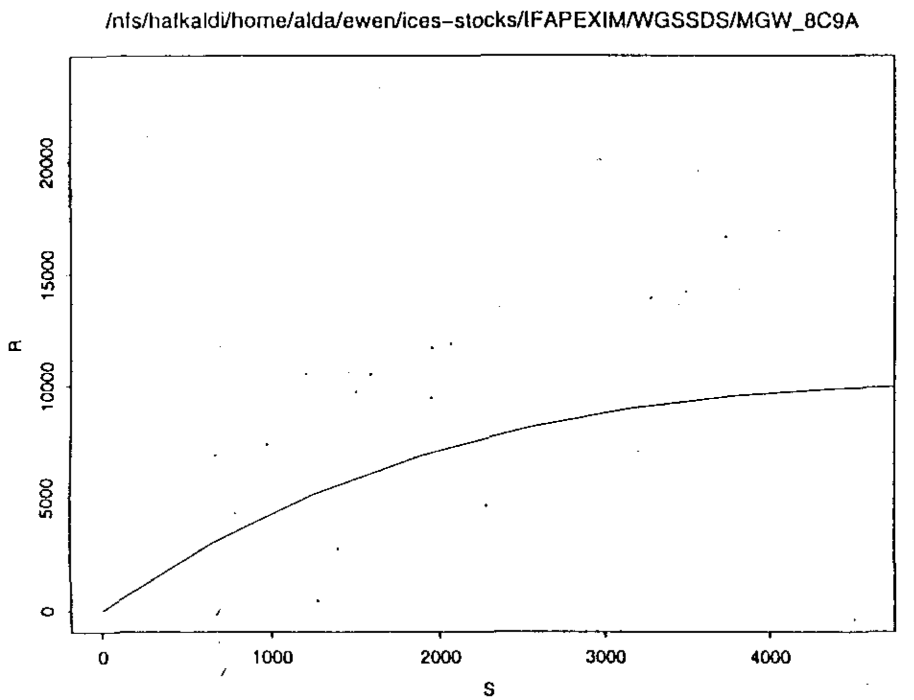
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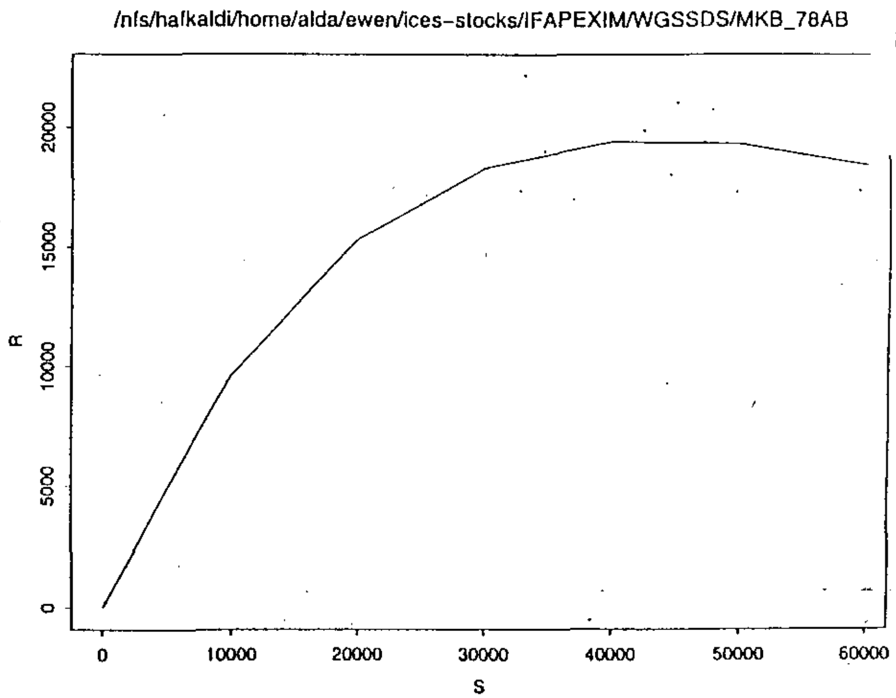
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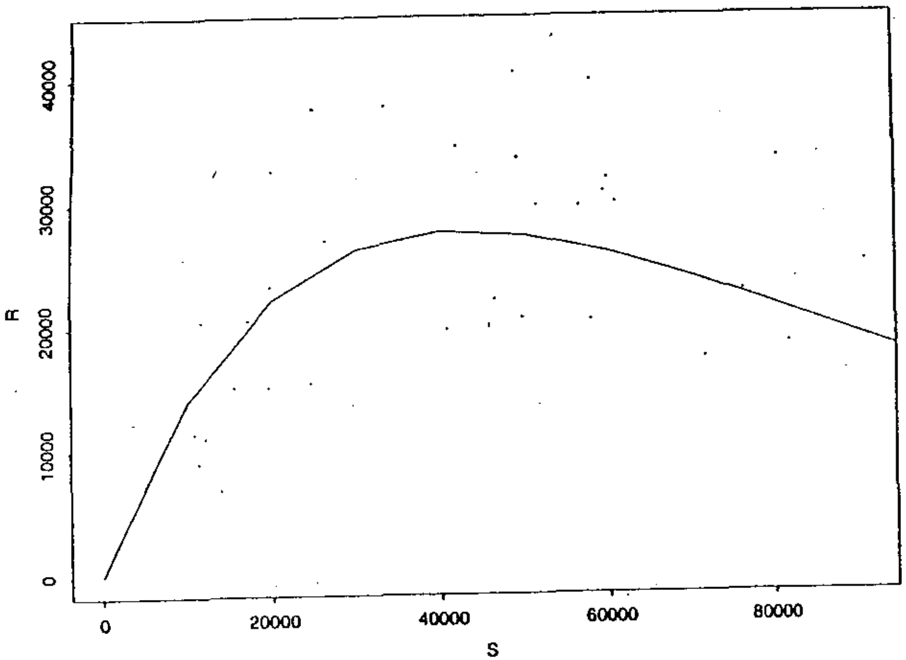

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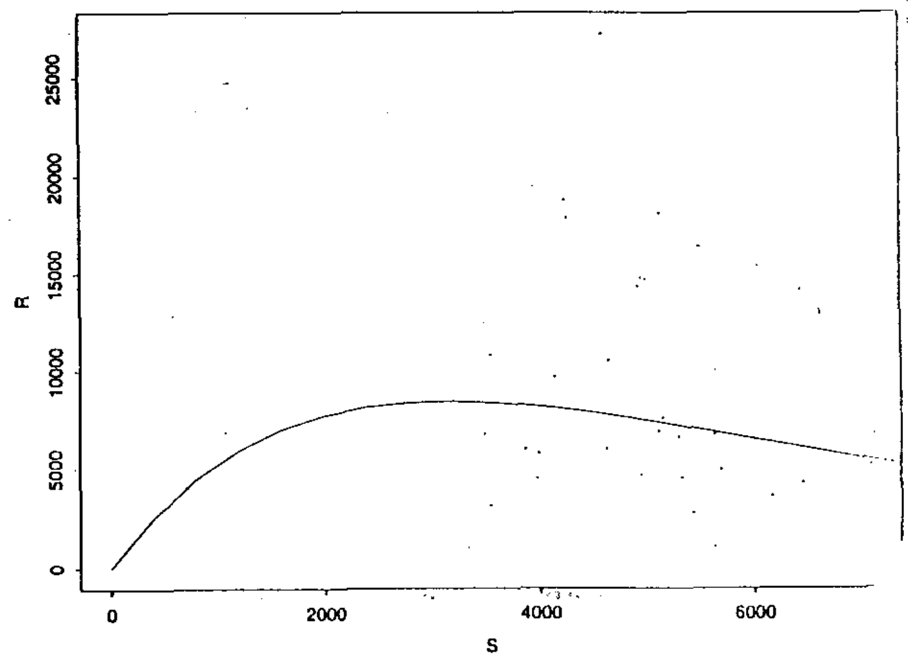

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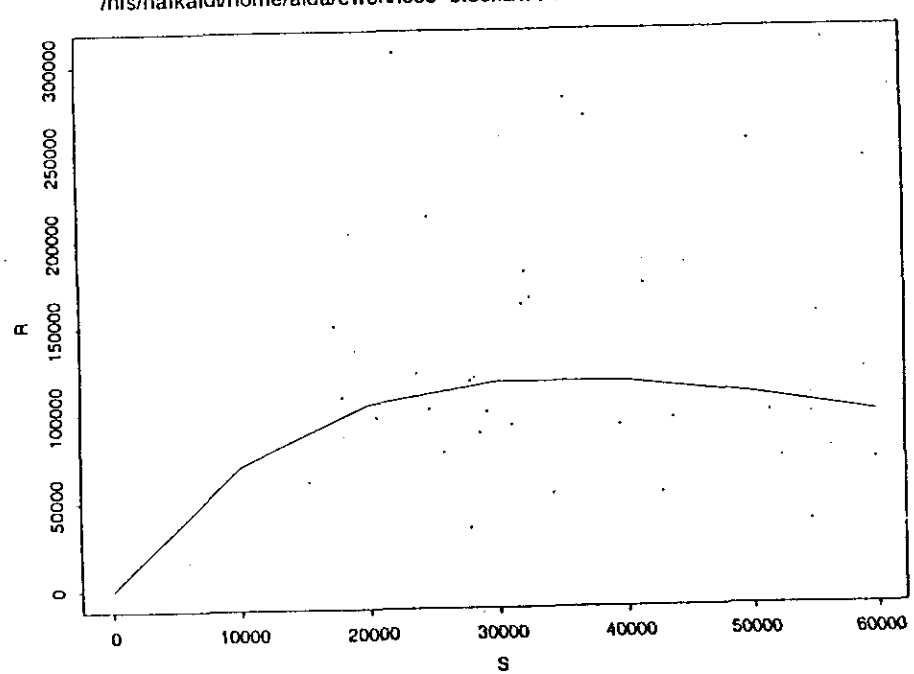

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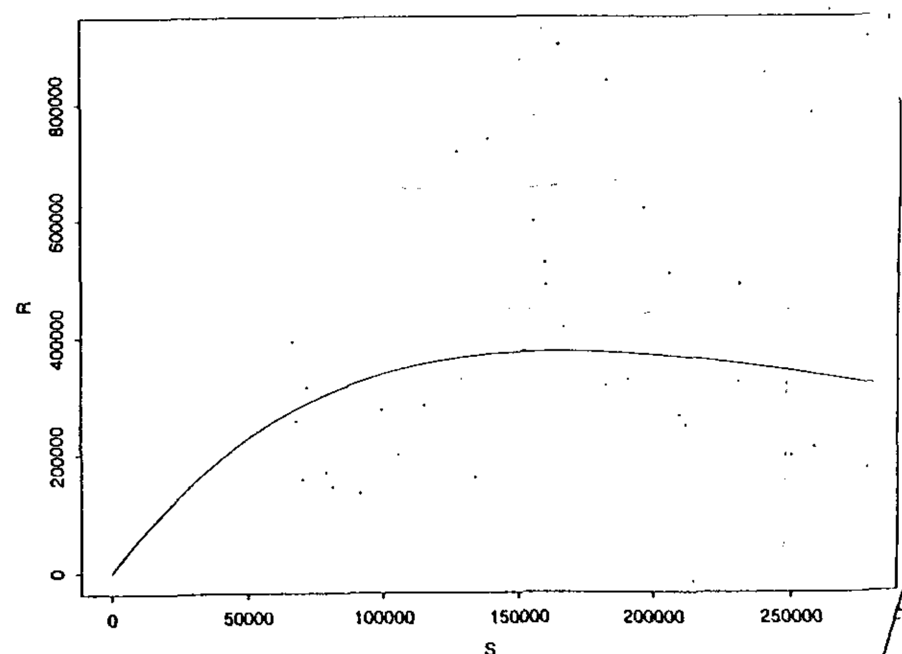

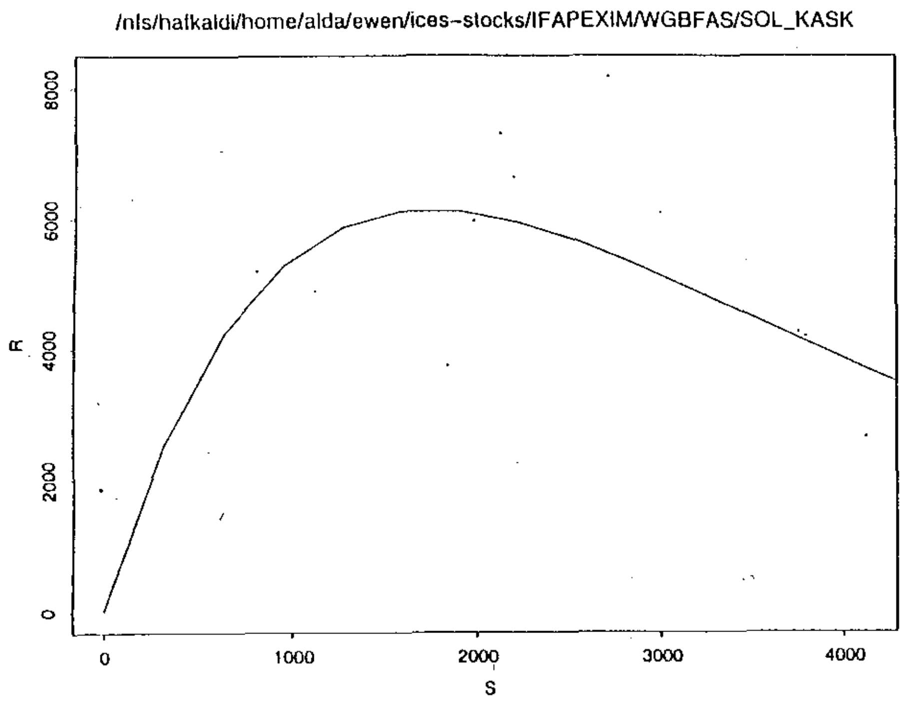
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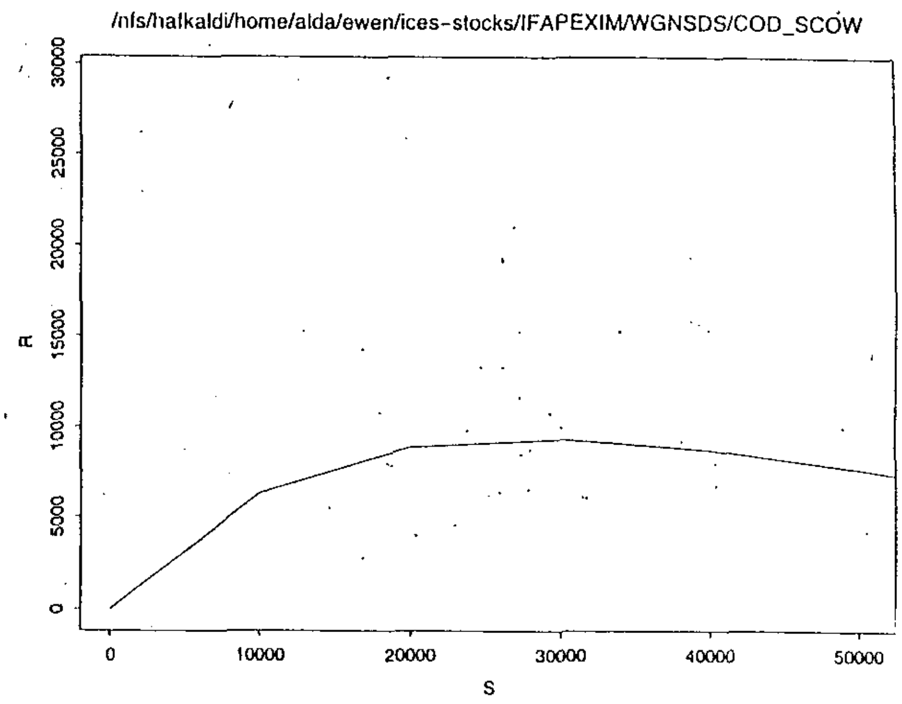
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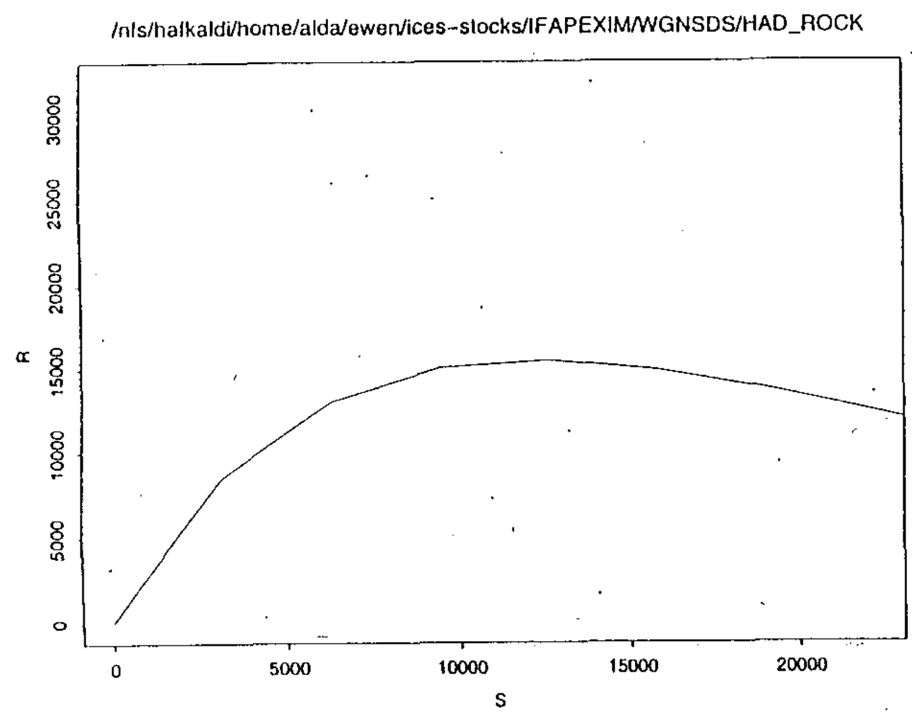
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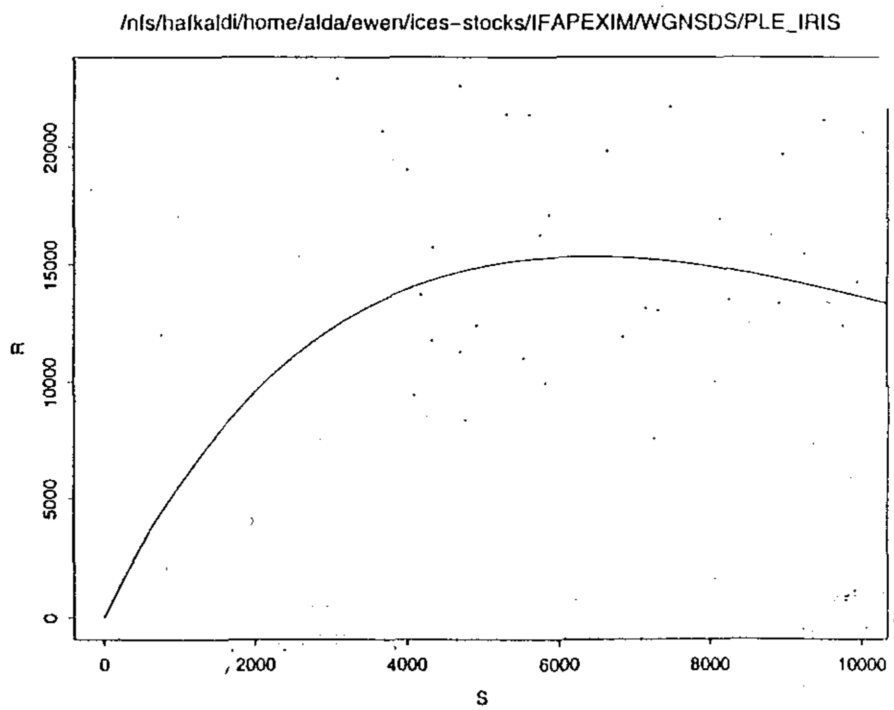
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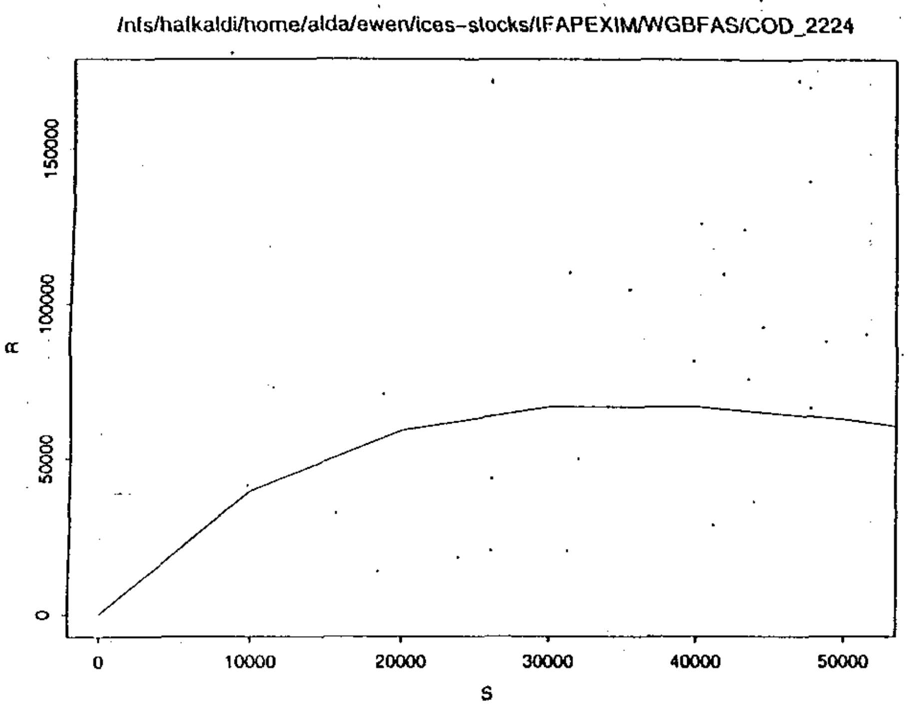
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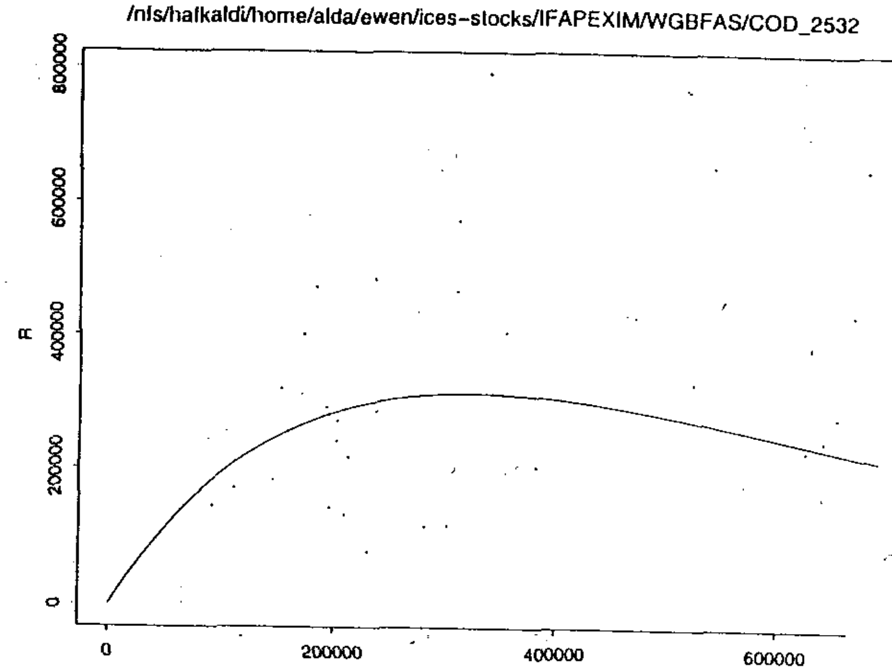
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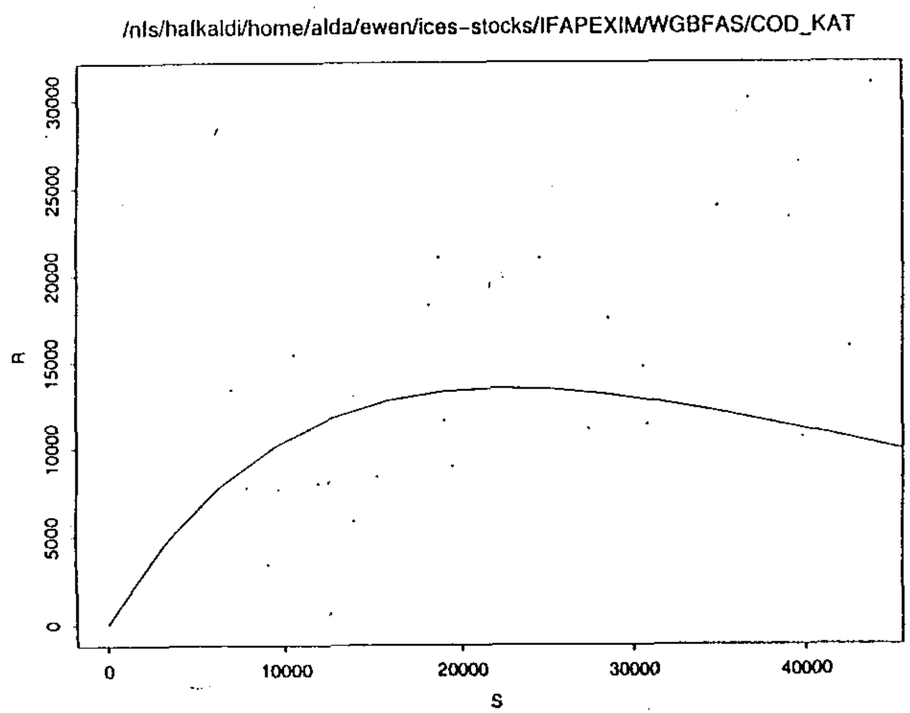
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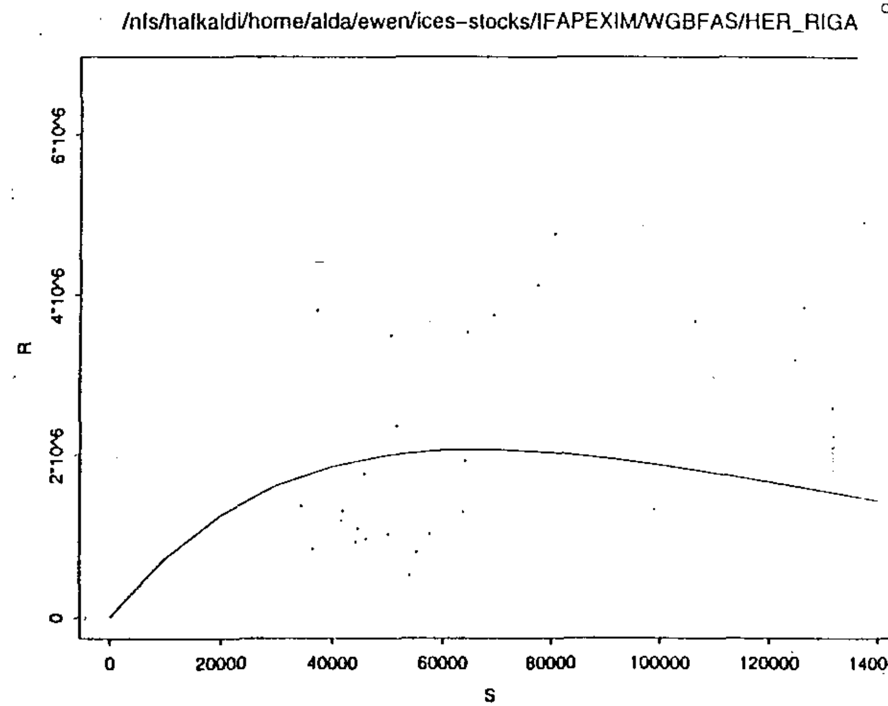
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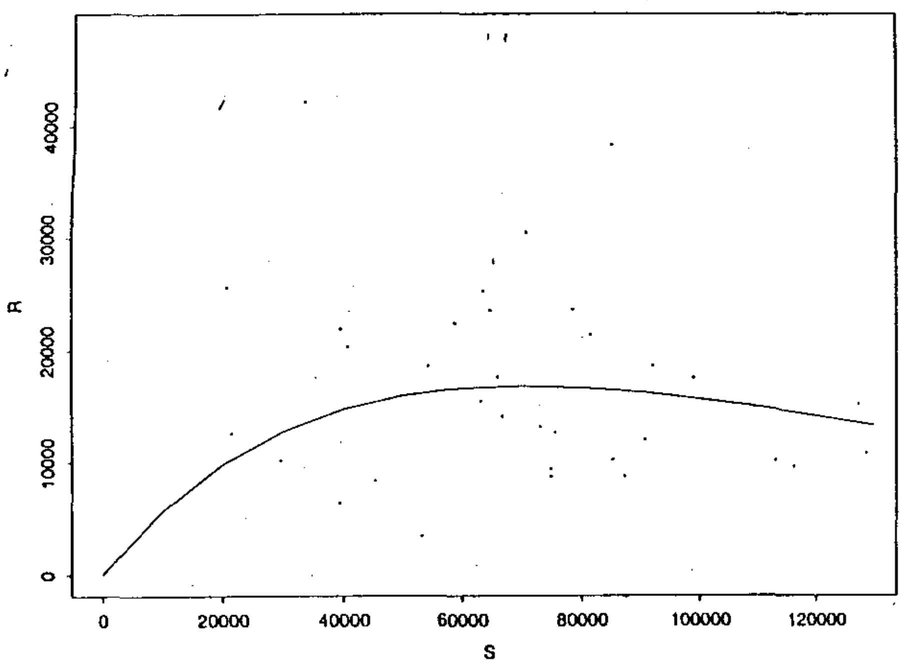

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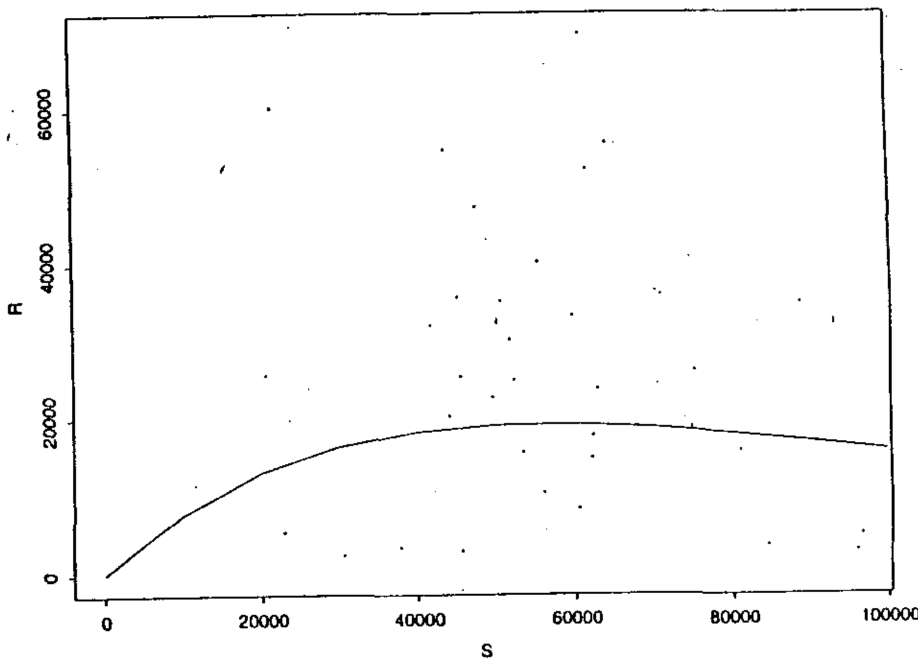

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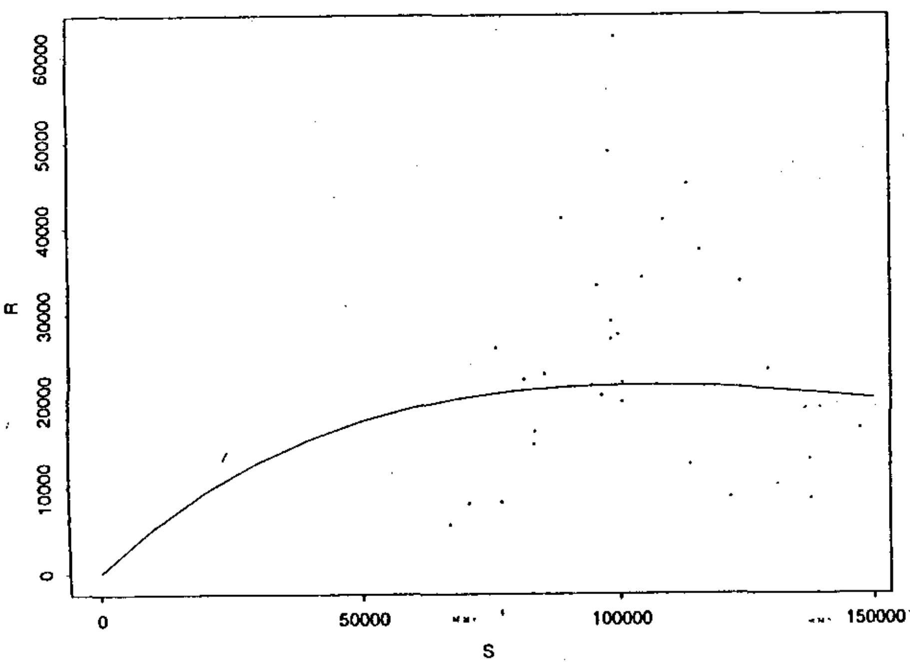

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