APPENDICES

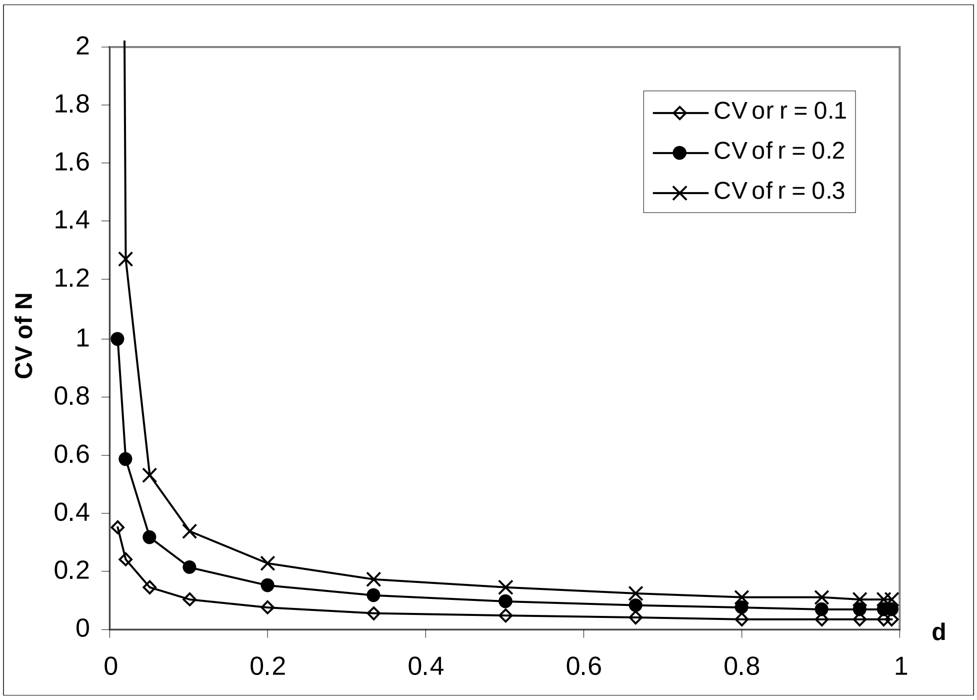
Appendix 2-1: Density dependence and stability

The population model illustrated in figure 2-2 can be represented by:

$$\frac{dN}{dt} = r(t)N - rN(dN + (1 - d))$$

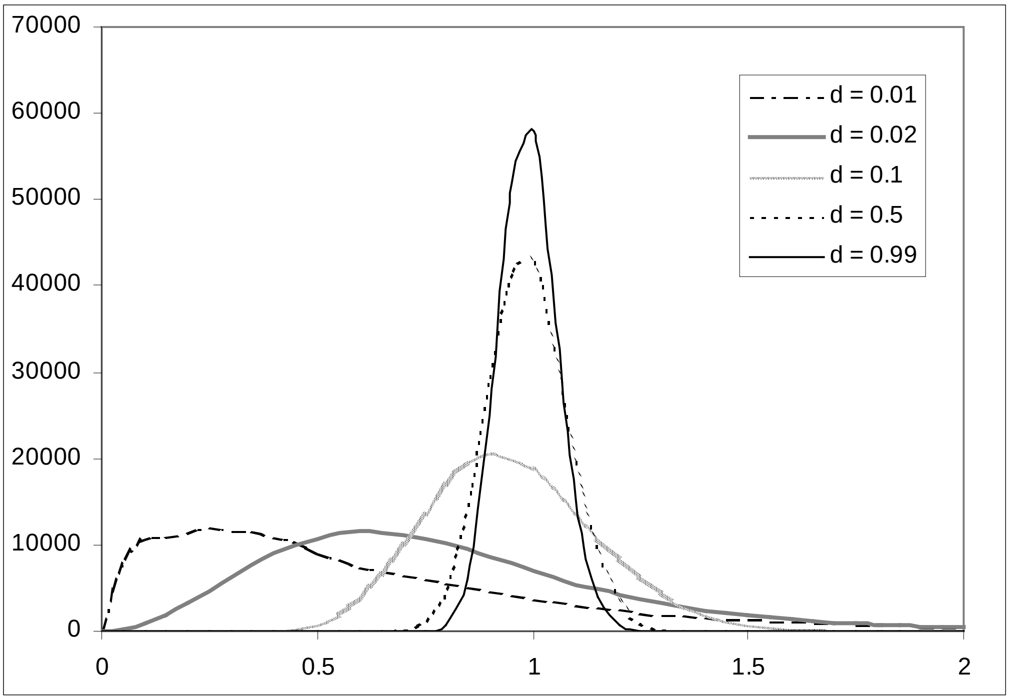
where d is the proportion of d.d. mortality at equilibrium as before,
r is the expected intrinsic growth rate,
and r(t) is its stochastic realisation.

A discrete, Monte Carlo implementation of this model using an annual time step and normal variation in *r*, allows the variation in the actual population density *N* to be examined rather than the variation in the equilibrium density. If we assume that any extinction threshold will occur at a fairly small proportion of any of the mean population sizes considered in this example, then the risk of extinction will be roughly determined by the CV of N alone. As expected, the CV of N increases with d and the CV of *r(t)*.

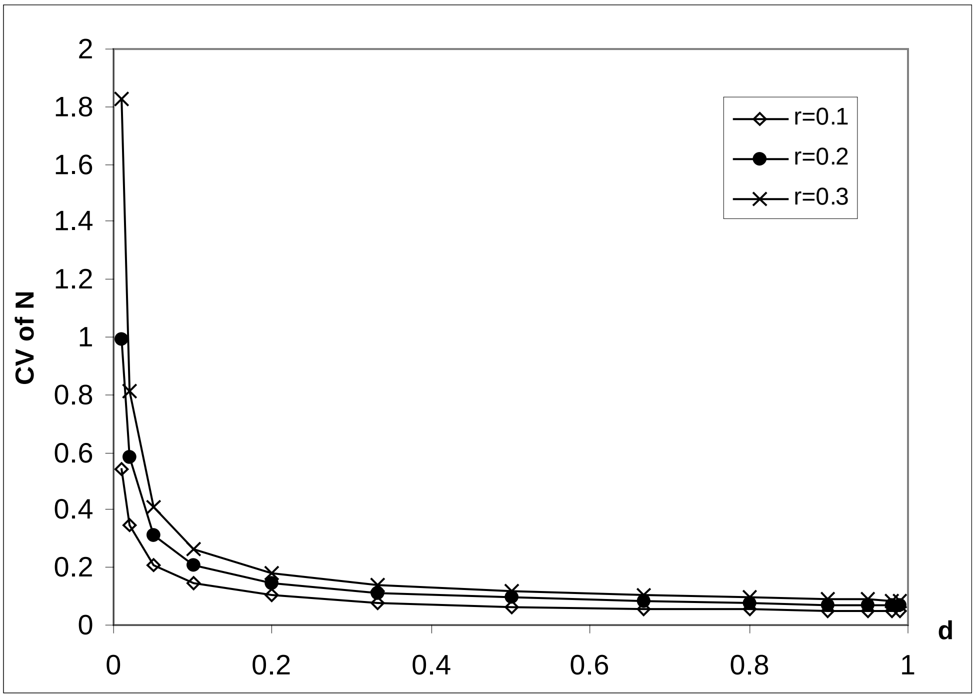


Variation in population density at stochastic equilibrium with proportion of d.d. mortality for different degrees of variability in *r*. Mean *r = 0.2* in all cases. Each data point summarises the results of 1000000 time steps at stochastic equilibrium. Populations which reached zero or negative density (arbitrarily defined as *N<0.000001*) were re-started at deterministic equilibrium (*N=1*).

Unlike the variation in the equilibrium population size, the CV of *N* is not determined solely by *1/d*. The response of *N* to changes the in the transient equilibrium density is related to the rate of population change which means that extinction risk actually increases with *r*, but also that there is an asymmetry of population movement around the equilibrium which produces a skewed stochastic equilibrium population distribution (May 1974) and a non-linear response to *1/d*.



Distribution of population density during 1000000 yrs at stochastic equilibrium, for systems with differing strength of density dependence subject to stochastic variation in r: *r(t) = 𝒩(0.2,0.04)*. In all cases the deterministic equilibrium density is *N=1*.

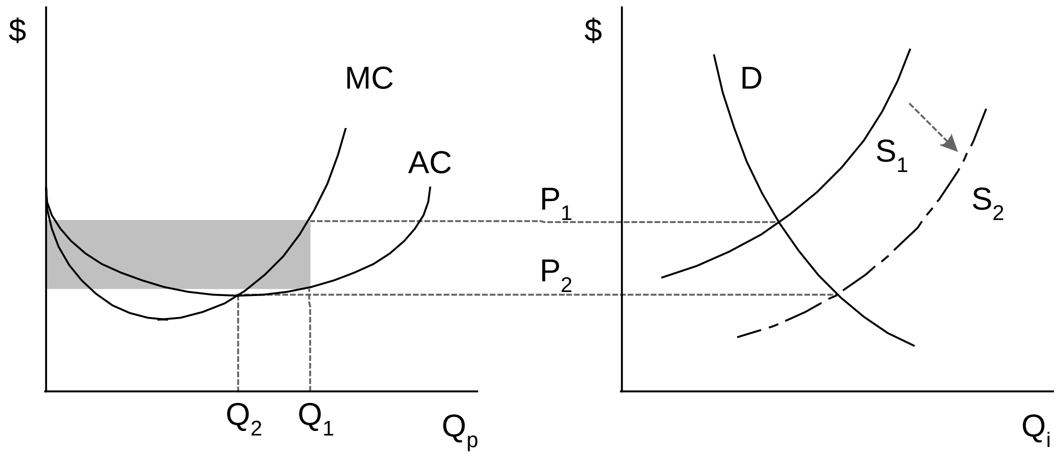


Variation in population density at stochastic equilibrium with proportion of d.d. mortality for different expected values of *r*. CV of *r* = 0.2 in all cases.

Nevertheless, the primacy of density dependence in determining population stability is evident.

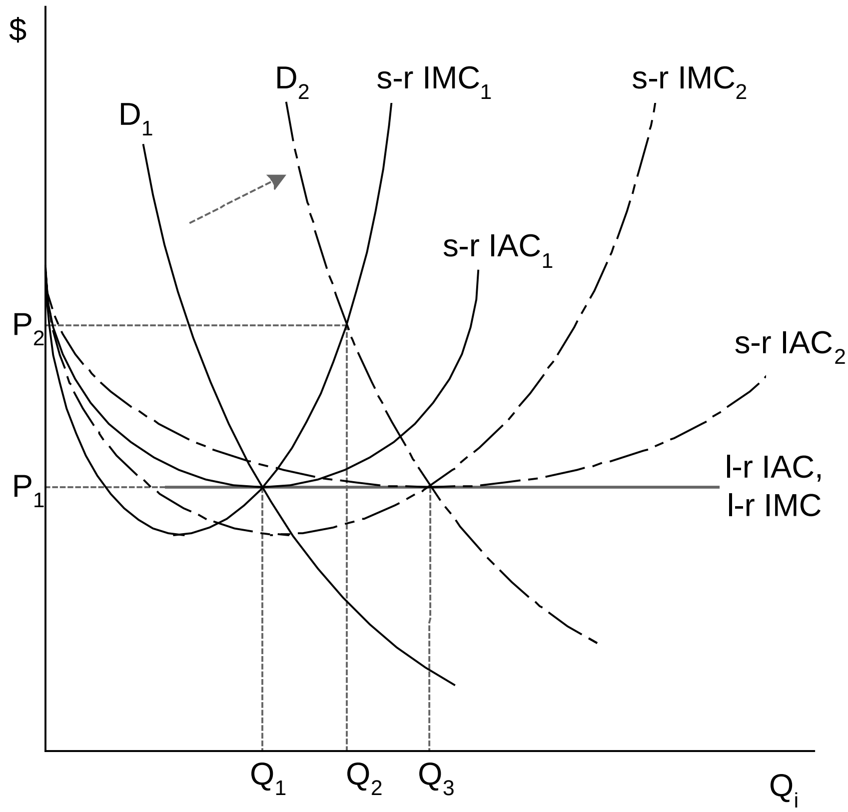
Appendix 2-2: Competitive equilibrium and externalities

In a competitive industry where firms are unable to significantly influence price individually, i.e. are price-takers, each producer will produce at the point where his marginal cost MC is equal to the price. Assuming that each producer has identical costs, if the point of production occurs where MC is above each producer's average cost AC, then the producers will make a profit, encouraging others to join the industry. As more firms enter the industry, supply increases, pushing down price, and reducing the profit margin. Conversely, if the point of production occurs where MC < AC, then producers will make a loss, encouraging exit from the industry and a reduction in supply. Either process will continue until the point at which MC = AC, which by definition must be at the lowest point in the AC curve. Hence at competitive equilibrium no supernormal profit can be made in the industry.



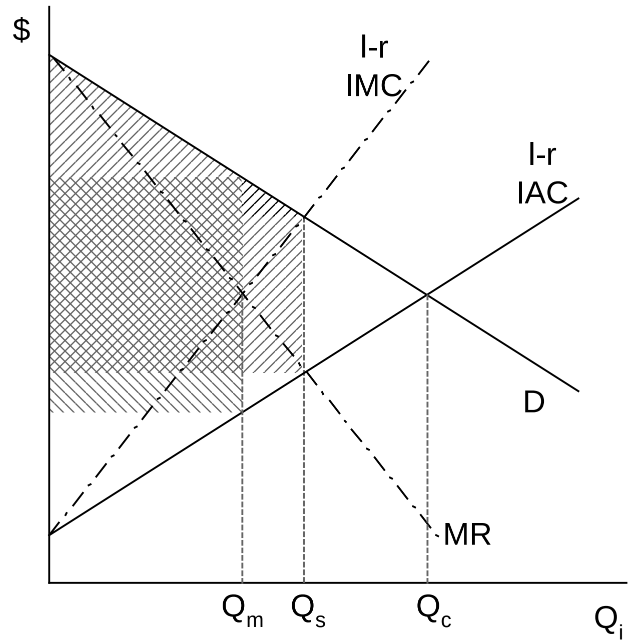
Production by an individual producer Q_p and the industry Q_i in a competitive market. Note that the scale of the unit cost axes is identical for both graphs, but Q_p and Q_i are on very different scales. Each firm produces at the point at which MC = price. At price P_1, this corresponds to an individual output of Q_1, and each producer makes a profit represented by the shaded area. The profitability of the industry encourages new entrants, who increase the supply in the industry. By the time that industry supply has increased from S_1 to S_2, the market price has fallen to P_2, at which MC = AC. At this point no supernormal profit is being made in the industry, and so this represents the competitive market equilibrium.

In the short run, i.e. on a timescale over which the number of firms in the industry is unchanged, under the assumptions that all firms are identical and there are no production externalities, the industry marginal cost and average cost curves are the same as the individual producer marginal cost and average cost curves with the quantity axis multiplied up by the number of firms. The short-run industry marginal cost curve is therefore the same as the short-run supply curve for the industry, represented by S_1 and S_2 in the figure above. As the number of firms in the industry increases, the short-run industry marginal cost s-r IMC and average cost s-r IAC curves are extended along the quantity axis. At competitive equilibrium, however, the firms will always produce at the base of the individual AC curve, which is fixed in the absence of changes in technology or factor prices. So the long-run industry average cost l-r IAC remains constant, and the l-r IAC curve is therefore a horizontal line. If the l-r IAC curve is a flat line, then by definition the long-run industry marginal cost l-r IMC curve must follow the same flat line. Therefore, in the long run, price (which is equivalent to marginal consumer benefit) is equal to the overall marginal cost of production of the industry. This condition defines the point of maximal social efficiency, so the competitive market equilibrium is also a social optimum.



Marginal and average cost curves for a competitive industry. Under demand schedule D_1 a competitive industry has short-run marginal and average cost curves determined by the MC and AC curves of its constituent producers. At equilibrium, the industry therefore produces at the point where s-r IMC_1 = s-r IAC_1, which corresponds to quantity Q_1 at a price P_1. If there is suddenly an increase in demand from D_1 to D_2, then in the short-run production will shift to the new point of intersection of s-r IMC_1 with demand, i.e. Q_2 at price P_2. At this point producers are making a profit, however, encouraging new firms to enter the industry. The increase in the number of firms will push the short-run industry marginal and average cost curves out along the quantity axis. This will continue until they reach s-r IMC_2 and s-r IAC_2 respectively, at which point production will have reached Q_3 and price will have fallen back to P_1 so that firms no longer make any supernormal profit. Because firms always produce where their individual MC = AC at competitive equilibrium, and because their costs are not affected by the number of firms in the industry, the long-run industry marginal cost, average cost and supply curves are all described by the same flat line at price = P_1. Because price is equal to overall marginal cost, the competitive equilibrium therefore describes a social (Pareto) optimum.

If there are production externalities within the industry, so that producers affect each other's costs, then the AC curve experienced by individual producers will change with the general level of productivity in the industry. At competitive equilibrium, firms will still produce at the bottom of their AC curves, so the l-r IAC and the long-run supply price will still occur at the trough of the producer AC curve, but this will now be a function of Q_i. Hence the l-r IAC curve will no longer be a flat line, but will increase with Q_i in the case of a negative production externality. The long-run supply will still follow the l-r IAC curve, but the l-r IMC curve cannot follow it by definition. As supply and marginal cost no longer coincide, the competitive equilibrium is no longer a social optimum. The Pareto optimum still occurs where demand and industry marginal cost coincide, but this is now closer to the monopolist's optimal point of production.



Cost curves (drawn as straight lines for clarity) and supply points for an industry with negative internal production externalities. Industry average costs rise with the total amount of production. Therefore l-r IMC and l-r IAC can no longer coincide. Assuming all firms are identical, each new firm will produce at an AC equal to the l-r IAC. Therefore firms will enter or leave the industry until the point at which l-r IAC = D. Because the industry average cost and marginal cost curves no longer intersect the demand curve D at the same point, the competitive market equilibrium supply Q_c and the socially optimal supply Q_s differ. Q_s occurs where the MC curve intersects the D curve, and maximises social utility (the area hatched bottom-left to top-right). Q_m, the optimal supply point for a monopoly producer, occurs where the MC and marginal revenue MR curves intersect and maximises producer profit (the area hatched top-left to bottom-right). For a renewable resource, Q_s generally occurs much closer to Q_m than to Q_c. If demand is perfectly elastic (i.e. D is flat and so equal to MR) then Q_s and Q_m coincide.

There will of course be a production externality in any industry where increasing production pushes up the price of inputs. If factor markets are competitive, such that the prices of inputs continue to represent their marginal costs, however, then the industry's loss is balanced by the increase in rents accruing to the factor owner. Hence although the industry still produces along the l-r IAC curve, this represents a social MC curve, and the internal increase in costs within the industry actually serves to ensure that factors are employed in their most productive capacity, providing the theoretical underpinning of capitalism. But in the case of a common access resource where CPUE or any other metric of productivity falls with stock density, the increase in cost is a social (not just an industry) cost as a greater quantity of (as opposed to expenditure on) labour/capital/resources is required to achieve the same output. It has long been appreciated that when the benefits of an action accrue to the individual actor, but the costs are born more widely, then Adam Smith's 'invisible hand' (Smith 1776) does not guide us to a socially optimal outcome, and the universality of 'the Tragedy of the Commons' was illuminated by Hardin (1968).

Almost all models of renewable resource production assume that CPUE is a decreasing function of stock density. Additionally, most assume that the unit cost of effort is constant. This does not necessarily imply that harvesters face no incremental costs, as Scott (1955) objected. Rather in more formal terms, it is equivalent to assuming that each producer is identical and produces at the base of his average cost curve. These are acceptable assumptions in a large competitive industry. Under these conditions, the open-access harvesting of renewable resources can be viewed as exhibiting an absolute negative production externality, in that any given producer affects the harvesting costs of all other producers just as much as he affects his own costs.

The earliest bioeconomic models of the fishery highlighted the social loss resulting from open-access harvesting, and the problem has been variously labelled as profit dissipation (e.g. Gordon 1954) and stock externalities (e.g. Smith 1969). Gordon (1954) noted that 'A fisherman . . . does not care for marginal productivity, but for average productivity.' Although recognition of the issue is not new, an appreciation of the difference between individual vs. industry and short- vs. long-term average and marginal cost lends clarification. The figure above provides a much simpler understanding of the relationships between the points of production and how these correspond to harvesting cost curves than is found in a bioeconomic literature peppered with misleading statements and misunderstandings in relation to average and marginal costs. It also reveals at a glance that the implication of many early models, that the sole-owner's optimum is also socially optimal, is dependent on their assumption that demand is perfectly elastic. The results presented here are implied by the solutions of Clark's (1990) linear optimisation problems, but his text is confusing. He states that the 'marginal and average cost of effort are equal', which is obviously true (and entirely trivial) if the unit cost of effort is assumed to be constant, but gives the impression that the marginal and average costs of production are equal, which would imply that open-access harvesting is socially optimal.

Appendix 3-1: Spatial effort distribution and offtake

Imagine n subpopulations each of whose growth is described by a logistic equation with parameters *K* and *r*. If each subpopulation is reduced by a proportion, *a*, then the resulting global population growth will be *(1-a)/(1-na)* times the population growth which would result from removing the same number of animals from a single population. Hence yield is always higher when harvesting is spread evenly.

Considering the distribution of hunting effort rather than harvest, for a population with logistic growth, subject to offtake, $S = qEN$, then for any given value of *E*, the equilibrium population size,

$N^* = K - (K/r)qE$ (Beddington & May 1977)

Therefore the equilibrium yield,

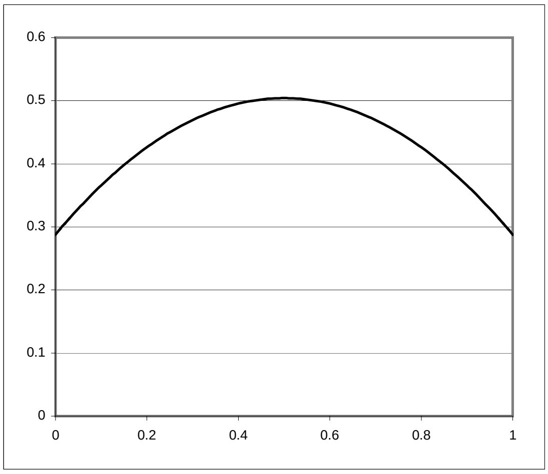
$S^* = qEN^* = KqE - (K/r)(qE)^2$

If there are two identical subpopulations, between which the total hunting effort, E, is divided, then the total equilibrium yield given that a proportion x of the effort is expended on hunting either of the populations,

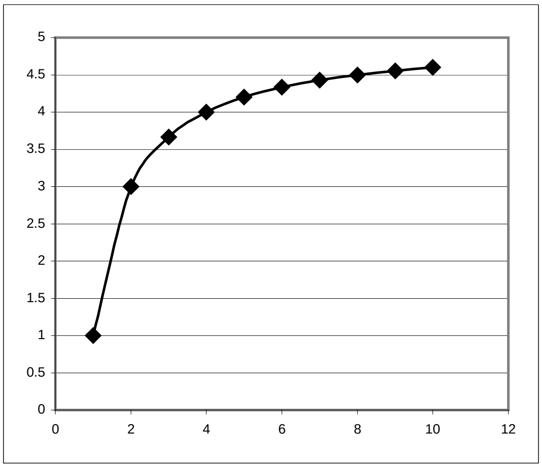
$S_x^* = KqE(1-(qE/r)(2x^2 - 2x + 1))$

Hence maximum offtake occurs at $x = 0.5$, i.e. the optimal harvesting strategy is to divide hunting effort evenly between the two populations. In general the equilibrium yield produced by distributing effort evenly between n subpopulations:

$S_n^* = qEN^* = KqE - (K/r)(qE)^2(1/n)$



Yield (as a proportion of *K*) versus proportion of hunting effort focused on either of two identical prey populations. In this example, *r = 1.2* and *qE = 0.72*. If all hunting effort were focused on one population, its equilibrium level would be *0.4K*.



Yield obtained from spreading hunting effort evenly over *n* populations vs. *n*, relative to yield obtained from focusing effort on a single population. In this example, *r = 1.2* and *qE = 0.96*. If all hunting effort was focused on one population, its equilibrium level would be *0.2K*.

If *r* or *K* vary between populations, then the optimal harvesting strategy will concentrate more effort on the more productive or larger population, but for relatively modest differences the advantage gained over even harvesting is minimal (Milner-Gulland *et al*. 2000). Migration will naturally mitigate the effects of uneven harvesting, but uneven harvesting can still only be optimal where biological parameters vary between subpopulations (Lundberg and Jonzen 1999).

Appendix 3-2: Technology trap

Ignoring at present transport costs, imagine that there are two costs to hunting associated with technology *i*, the capital cost of purchasing the technology H_{Ki} and the recurrent costs of using it H_{Ri} which is equivalent to the *H* used elsewhere. The prey capture rate using technology *i* is Q_iN. Hence the return given by the technology would be:

$(p - H_{Ri}/N).Q_iN = pQ_iN - H_{Ri}Q_i$

where p is the price or gross return for each animal.

Note that the cost function used here is appropriate to a situation where the operating cost of the technology is constant and does not depend on the overall offtake. Consider the introduction of a new hunting technology, which enables more animals to be caught at a lower per capita cost. I.e.

$Q_2 > Q_1$

$H_{R2} < H_{R1}$

Assuming that hunters make decisions based on the current conditions, i.e. the current values of p and N, then hunters would judge it favourable to purchase the new technology if:

$(Q_2 - Q_1)pN - (H_{R2}Q_2 - H_{R1}Q_1) > \delta H_{K2}$

where δ is a (continuous) discount rate based on the opportunity cost of investing the capital elsewhere or the interest payments necessary on a purchase loan.

I.e. the new technology will be purchased if the increase in revenue minus the increase in operating cost is greater than the interest on the capital.

Assume that the industry was originally at competitive equilibrium under the old technology, so that prey stocks were at the level where hunters just break even. As hunters switch to using the new technology, their offtake will increase, and so the prey population will fall. Once the prey population falls below the old equilibrium level, hunting with the old technology is no longer economically viable, and so purchasing the new technology is no longer just advantageous, it is an economic necessity, the only alternative to which is to leave the industry altogether. It might therefore be expected that the rate of switching will accelerate and the prey population will continue to decline. Hunting using the new technology will continue to be profitable until:

$pQ_2N = H_{R2}Q_2 + \delta H_{K2}$

$\therefore \quad N = H_{R2}/p + \delta H_{K2}/Q_2p$

If the industry overshoots this limit, however, and the prey population falls below this value of *N*, then if the capital investment in the new technology is not recoupable, there is no incentive to reduce the amount of hunting, even though the industry is now operating at a loss, because the revenue from hunting is still higher than the operating cost of the new technology, even though not sufficient to cover the initial capital investment. Hunters with the new technology will only start leaving the industry once revenues are even lower than their operating costs, i.e. once the population density falls below

$N = H_{R2}/p$

[Note that from the reciprocal condition for the original technology, the condition for the new technology to totally replace it is: $H_{R1} > H_{R2} + \delta H_{K2}/Q_2$]

Why should the industry overshoot?

1. Some degree of overshooting is likely in any adjustment process where a degree of stochasticity or error is involved, but here there is no mechanism for recovery after the overshoot.
2. Hunters using the old technology are faced with the choice of switching to the new technology or leaving the industry altogether. If there is a tradition of hunting and a general stickiness in

the labour market, then it is likely that *a priori* most hunters will prefer to take up the new technology rather than quit altogether. This preference might be strong enough to encourage hunters to invest in the new technology even after this option has become less profitable than leaving.

3. The fact that there are substantial capital costs involved means that there is a greater incentive to use the technology at its full capacity, so there may also be an increase in effort amongst those who do switch. This would not be the case in a scenario with complete factor markets, but for an individual hunter operating within an imperfect labour market, the increase in his marginal return from labour would induce him to invest more time in hunting.
4. Assuming that the population equilibrium for the new technology lies beyond the point of MSY, the productivity of the industry as a whole will fall, but the offtake of each individual hunter will increase under the new technology. This means that at the new equilibrium the industry may only support a small fraction of the number of hunters that it did previously. Therefore even if the majority of hunters did leave the industry instead of purchasing the new technology, overcapitalization may still occur.
5. In a competitive industry at equilibrium, the only way to make a profit is to be able to operate at lower cost than your competitors, so there is a strong incentive for the first individuals to switch. Within normal economic life, this is the engine that drives efficiency gains, but the negative externality involved in open access harvesting means that individuals' productivities, not just their market shares, are undermined by the actions of others. Hence the necessity to adopt the new technology is greater than normal, and furthermore, if hunters make economic judgements on the basis of current conditions, they will over-estimate their future returns. During the process of population decline to the new equilibrium, it will still appear to be profitable to invest in the new technology. Hence if the rate of uptake is rapid, then most or all hunters may have switched before the prey population falls to the point where it no longer appears profitable to do so.

As soon as the process of switching to the new technology begins, the industry becomes locked into it. It would only make sense to switch back to the old technology at a very low population level, where

$$(Q_2 - Q_1)pN < H_{R2}Q_2 - H_{R1}Q_1$$

Substituting $N = H_{R2}/p$, shows that this condition will never be met above the population level at which operating costs alone are covered.

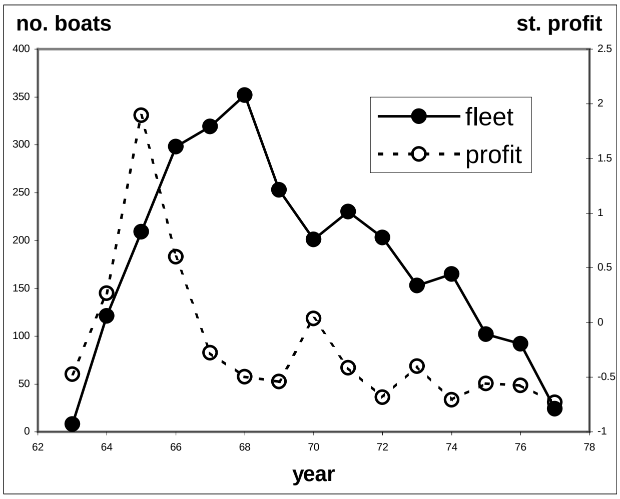
So where the system was already harvested close to or beyond full capacity, the introduction of the new technology reduces production, consumer surplus and the number of hunters supported by the industry, and it is likely that those remaining will be trapped into producing at a loss. In addition, the survival of the resource as a whole may be jeopardized. For an open access renewable resource, the introduction of new technology will not typically increase social welfare.

Price need not be constant for this result to hold. If demand is less then perfectly elastic, then the equilibrium p will rise as N falls, so the new population equilibrium will occur at even lower values. It is possible, though, that production will rise during the period of population decline, causing a reduction in p and so a slowing in the rate of uptake of the new technology.

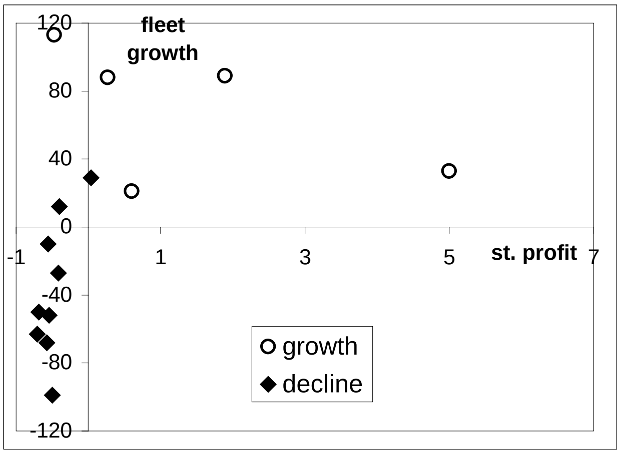
No factor of production lasts forever. Eventually the new technology will wear out and have to be replaced. At this point the industry should readjust to the market equilibrium given at $N = H_{R2}/p + \delta H_{K2}/Q_2p$. Hence over-capitalisation represents a time lag in the adjustment back to equilibrium, rather than permanent state. Hunting equipment such as rifles may remain serviceable for decades, however, which may be far greater than the time span over which a local prey population can be driven to extinction. Hence if the relevant timescales are so divergent, then the new technology can be reasonably treated as a fixed factor of production.

The detrimental effects of new technology have been noted in fisheries. Reviewing technological advances in the British fishing industry between the World Wars, Kensall (1948; quoted in Cunningham *et al.* 1985) remarked that, 'though . . . there had been technical progress in many different ways, fishing was nevertheless less profitable than it had been before the new devices were introduced'. The only renewable resource case for which data on industry uptake and production are available during the establishment of an important new technology is the introduction of the power block to the Norwegian purse seine herring fishery. This 'was recognized as having such a major impact on profitability that it took only six years for it to be adopted by the entire fleet' (Cunningham *et al.* 1985; drawing on Mietle 1969).

In fact, data from Bjorndal and Conrad (1987) show that post-introduction, the Norwegian herring fishery was clearly profitable for only 3 years, with only a single year of very high profits. Furthermore, the increase in the power-block fleet was more rapid than the subsequent decline, and far less sensitive to profit margins. A stable equilibrium was not reached as the fishery was closed before likely extinction of the stock. Hence the one case for which there is data suggests that the uptake of new technology may be rapid, continue past the point at which the industry ceases to be profitable, and be governed by a different process during the expansionary phase to that during the subsequent reduction in capital. This is in line with the suggestion of spiraling, perhaps desperate, uptake precipitating persistent unprofitability or stock collapse.



Size of the power block pure seine fleet and profitability of the fishery 1963-76, based on data from Conrad and Bjorndal (1987). Standardised (st.) profit is profit per boat, divided by operating cost to standardise between years. Note that the fleet continues to increase in size beyond the point at which the fishery ceases to be profitable, but during the decline phase, fleet size is very sensitive to profit, as any small increase in profit brings a subsequent increase in fleet size.



Annual growth of the fleet vs. standardized profit during the growth phase (first 5 years) and subsequent decline phase. Note that during the growth phase, there is no clear relationship between profit and fleet growth, but during the decline phase there is a fairly tight linear relationship.

Appendix 3-3: Hunting and travel combined

Consider a case where hunters continue moving in a straight line from their point of origin through a linear hunting territory until they capture a single prey. The probability of a given hunter capturing an animal at any point in space is λN, where λ is a constant that depends on the detectability of animals, the speed of travel, etc.

By analogy with a temporal decay process, the rate of decrease in hunter activity with distance is given by:

$$\frac{dh}{dx} = -\lambda h N(x)$$

$$\therefore \qquad h = e^{-\lambda \int N(x)dx}$$

In the absence of migration, at equilibrium:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) - \lambda h N = 0$$

$$\therefore \qquad h = \frac{r}{\lambda}\left(1 - \frac{N}{K}\right) = e^{-\lambda \int N dx}$$

$$\therefore \qquad \int N dx = -\frac{1}{\lambda}\ln\left(\frac{r}{\lambda}\left(1 - \frac{N}{K}\right)\right)$$

$$\therefore \qquad N = -\frac{\frac{1}{r}\frac{dN}{dt}}{\left(1 - \frac{N}{K}\right)}$$

$$\therefore \qquad \frac{dN}{dx} = rN\left(1 - \frac{N}{K}\right)$$

I.e. the plot of equilibrium prey density versus distance will be a sigmoidal curve, the steepness of which depends only on *r*. The prey density at $x = 0$ is given by

$$\lambda h_0 N_0 = rN_0\left(1 - \frac{N_0}{K}\right)$$

$$\therefore \qquad N_0 = K\left(1 - \frac{\lambda h_0}{r}\right)$$ *, where h_0 is the total frequency of hunting trips.*

Appendix 4-1: Hunter interview questions

The scope of the interview is explained to potential respondents, before asking whether they are willing to be interviewed. Anonymity is assured. An informal atmosphere is maintained throughout. Questions should always be neutral and no overt reactions shown to answers. Follow-up questions and cross-referencing are routinely used to verify and give context to answers. The following question areas should be covered, but not in any rigid order that might disrupt the flow of the conversation.

1) Species taken. Do you hunt ibex? (Do not continue if the answer to this is 'no.') What other species do you hunt? Do you already have in mind before a trip what you will hunt? Do you always hunt the same things? How do you decide? When you make trips to hunt ibex, do you hunt other things at the same time? What percentage of time is spent hunting other animals? What do you get from these animals – meat, skins, etc? What are their values?

2) Motivation. Why do you hunt? Do you eat, give away or sell meat? How many kg of meat do you get on average from an ibex? How long does it last? Are there any other parts of the animal that have a value? What do you do with these? Why do you hunt to get these benefits instead of doing something else? Do you enjoy hunting? Are there other things you would rather be doing? Would you hunt less if other work was available? If buying a licence was unavoidable, what is the maximum that you would pay?

3) Entry/exit. When did you start hunting? Why? When you began to hunt did you already own the things you needed to hunt, or did you have to buy things especially? Did you have the money already, or did you have to save? Do you think you will ever stop? Why?

4) Material costs. What sort of gun do you use? When did you buy it? What did you pay for it? Did you buy it just for hunting? How much does ammunition cost? On average, how many rounds do you use for each ibex you kill? Does it create a problem if you use horses for hunting, are they needed for other work? Is it possible to borrow horses, guns or hunting equipment or do you need to have your own? What things do you need to buy for each hunting trip? What are the costs per trip?

5) Group size. Do you go with other people when you hunt? How many? Is it always the same number or does it change? Does it make a difference how many people you go with? Why? What is the best number?

6) Location. (On map) Where do you go to hunt? Why there? How long does it take to get there? Where are the ibex located? Does the location vary? Why? How do you know – your own observations, what you hear from others? *Give some hypothetical examples on the map in the form of would you go to location A or B if there were more animals at B, etc.* How far would you go to hunt if you had to?

7) Seasonality. What times of year do you hunt? Why? Where are the ibex at this time? How frequently do you hunt during this period? What do you do for meat, etc. during the rest of the year?

8) Hunt description:

a) search area. How do you decide what area to hunt in / where to make camp? Discuss in light of what was said earlier about ibex distribution.

b) search. Describe in your own words how you search for ibex? How long do you normally spend looking before you find a herd to target? How do you decide when to go for a group? Do you always go after the first you see? How important is the distance, group size, position, lack of alternatives? Typically how many groups do you see before you decide to hunt one?

c) pursuit. Once you have targeted a group, how do you hunt them? How long does it normally take to approach the group? How close do you have to get to have make a kill? Do you select certain animals or just go for whatever is nearest? Typically how many animals do you manage to kill in each group? How often is the hunt successful after you decide to go for a group? Out of 10 attempts, how many times would you expect to succeed? If not successful, at what stage does it usually fail – the animals move off, you miss the shot, etc.? Typically, how many days does it take to catch an ibex?

d) prey reaction. What happens after you have tried hunting a group? The animals flee, but how far? Is it possible to hunt the same group again? Do other groups react? How far away do they have to be? After hunting one group would you continue hunting in the same area, or move to a new one? How far away would you move before hunting again?

9) Trip length. When do you decide to end the hunt? How many days' supplies do you take with you? How long can you stay in the mountains? What is the typical length of a hunt? What is your normal catch of ibex / of other animals?

10) Changes. Have the lengths of the hunts or the catch changed over time? Why? What else has changed? Do you hunt more or less than you used to? Under what circumstances would it not be worth hunting any more? Why?

11) Prevalence. How many people hunt in the community? Why not more or less? What is the trend?

12) Enforcement. Have you ever hunted without a license? Have you ever been caught for poaching? How? What was the penalty? What is the chance of getting caught on a trip? Do you take the chance of being caught seriously? Are there places where you are more likely to be caught? Does this affect where you hunt?

Appendix 4-2: Household survey form and notes

Household surveys are used to relate opportunity costs and meat consumption to income bracket. It is explained to respondents that:

- We are researching incomes, wealth and consumption in the area. The reason is that it is an area with a rich nature, and we are interested in looking at how these factors affect impacts on the local environment. (Hunting is not mentioned directly.)
- We would like to speak to the household members who control the household budget and are responsible for buying food (not just male members).
- Information will be recorded, but kept strictly anonymous. The interview should take about 40 minutes.
- They have been selected for the survey at random, but it is their choice whether or not to take part. If they do not want to answer questions on their financial status and income fully, then please say so now.
- Please ask any questions you have at any time during the discussion.

Visual methods are used wherever respondents might have problems dealing with abstract quantities; i.e. cards with names of meats are used for the ordination exercises and *ad hoc* pie charts can be created with a circle and matchsticks to aid in deciding proportions of various quantities.

1) Members of household.
All the people who live the majority of time within the household, and with whom meals are shared. Start with the head of the household. Relationship refers to the relationship to him/her. Asterisk the people who were the main respondents during the interview

2) Wealth.
'Description' is for information relevant to the value of items; for houses, it refers to the type, number of rooms and location. 'Others' refers to any items that might be volunteered and seem relevant. For assets such as livestock and real estate, price refers to the current sale value. For consumer durables, the original purchase price and date of purchase should be recorded.

3) Occupations of males aged 17-65.
Take names from the list of household members. This table should include all productive occupations, including household work and education, and not just paid employment. If there is seasonal variation in activities, then try to estimate the percentage of time spent in each occupation in each season. Use a new line for each occupation of each individual. It may be necessary to use extra lines for seasonal differences. Record all agricultural work as a single item. Only for agricultural work, estimate the percentage of the family's total agricultural labour that is contributed by that person.

4) Incomes.
'% labour' refers to the percentage of all the household agricultural labour which is involved in producing that product. Sources of cash income should account for all the occupations listed above, employment of other household members, state benefits and any other sources of income, such as gifts, returns on investments, etc. Remember to ask the family about all these possibilities, including cash sources which may only occasionally be received. For occupations, the 'Source' column should include the name of the household member who generates the income.

5) Employees and inputs.
This should include anyone helping to work land, or money paid to shepherds to tend livestock, or specific seasonal inputs such as the hire of a tractor for ploughing.

6) Meat consumption.
Start by asking what meats and fish are consumed, then produce cards and let the informant put them in order based on their preference. Ask specifically whether any wild meat, is eaten. Determine values equivalent to mutton, by asking if the person would rather take 10kg of mutton or 10kg of the other meat, imagining that there is no opportunity to re-sell meat. Increase or decrease the amount of the other meat offered as an alternative to the 10kg mutton until the point of equivalence is reached. Check that these preferences accord with the ordination exercise. Re-order cards by consumption. Run

through quantity and frequency of consumption for each one – e.g. how many days a week/month, how much does the family consume in a day.

Questionnaire no:	**Village:**
Date:	**Household identifier:**
Address:	**Ethnicity:**
Surname:	

1) Members of household.

Name	Relationship	Sex	Age

2) Wealth.

Item	Description	Price	Quantity
Houses			
Garden			
Grazing land			
Sheep			
Goats			
Cattle			
Horses			
Pigs			
Fowl			
Motor vehicles			
Carts			
Farm machinery			
TV			
Fridge			
Stereo			
Radio			
Rifles, shotguns			
Savings			
Others			

3) Occupations of males aged 17-65.

Name	Occupation	% labour (agr prod.)	% time	Seasonality

4) Incomes:

a) agricultural products.

Product	% labour	Production	% sold	Price

b) cash.

Source	Income	Time period

5) Employees and inputs.

Job	No. people	Time	Pay

6) Meat consumption.

Meat	Equiv value	Consum.	Frequency	Quantity

Appendix 5-1: Herds sighted during Chong Kemin field survey

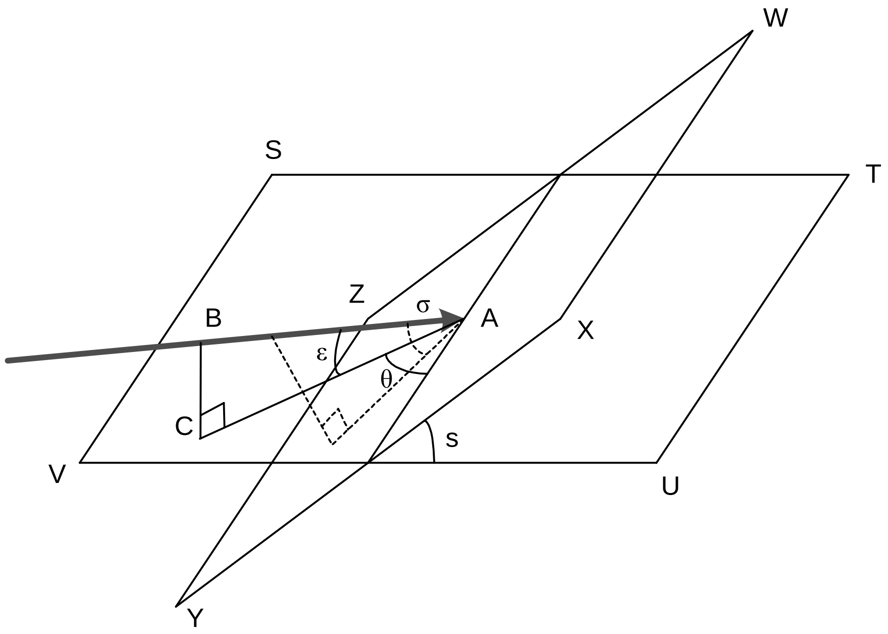
Date and time of each sighting, approximate horizontal distance of the herd from the observer and approximate altitude of the herd are recorded alongside the number of animals in each class; lambs, yearlings, adult males, adult females and unidentified individuals.

Date	Time	Dist. (m)	lambs	yrlings	ad. ♂	ad. ♀	unid.	Alt. (masl)
29/5	13:10	1500		3	5			3400
30/5	16:30	600	2		3			3300
	16:30	1500					16	3400
	16:50	800	5		19			3200
	17:10	1000					6	3400
	17:50	200			2	1		3000
	17:50	2000				2	16	3000
	19:00	4000					8-10	>3500
31/5	13:30	3000				34		3100
	13:40	500				24		2750
	18:30	3500					4	3400
	18:30	3500					≈30	3400
1/6	12:00	3000					≈45	3400
	14:30	4000					15	3400
	20:10	2000					4	3400
2/6	08:55	1000				15		3300
	09:30	1200	3		8			3300
	10:15	1700					2	3400
	11:50	2000					27	3100
3/6	09:00	1000		10		12	16	3300
	18:05	3000					≈50	3400

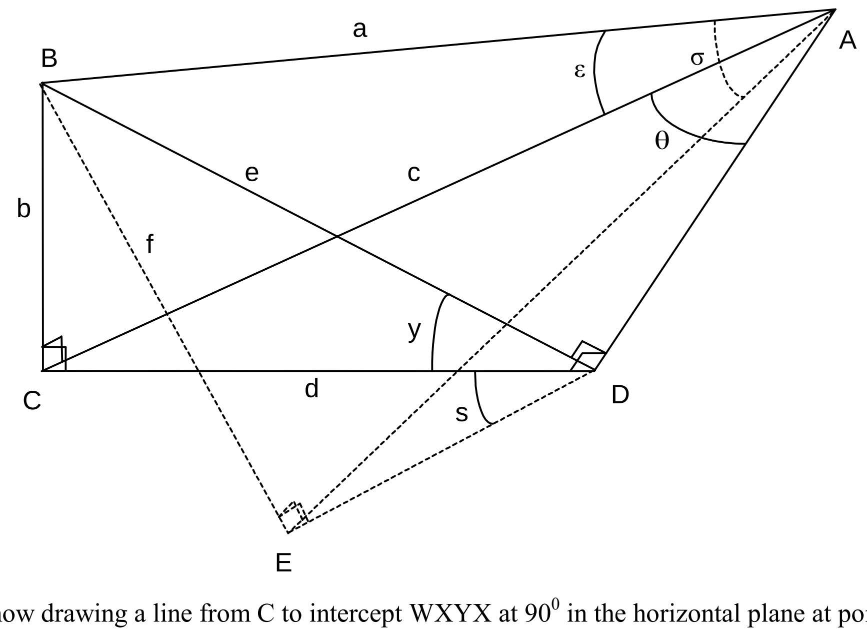
General notes:

- No detailed observations were made whilst walking on 3/6.
- Apart from during the approach to the valley, all observations were made from the bottom of the Chong Kemin valley. Ibex were located considerably higher and on steeper slopes at distances of typically a couple of km from observers.
- Although fewer animals were seen on southern slopes, this may in part be because less suitable habitat was visible form the valley floor. Tracks were seen along north-facing slopes.

Appendix 5-2: Derivation of sighting angle according to basic principles of geometry



Imagine a sighting line in the direction BA, intercepting a cell whose surface is orientated in the plane WXYZ. STUV is a horizontal plane that intersects WXYZ at the same point as the sighting line. The slope of WXYZ is s. If a perpendicular is dropped from an arbitrary point, B, along the sighting line, reaching the horizontal plane at C, then θ is the angle between CA and the surface of the cell in the horizontal plane. The sighting angle, σ, is the minimum angle between the sighting line and the plane WXYZ. It has the same relationship to WXYZ as ε does to STUV, i.e. it is the angle between BA and a line extending from A to the base of a perpendicular from WXYZ extending to the sighting line.



Imagine now drawing a line from C to intercept WXYX at 90^0 in the horizontal plane at point D, creating the shape ABCD. As BC is perpendicular to the horizontal, angle BCD must be 90^0, and by rotation about AD, it can also be seen that angle BDA is 90^0.

The shape ABED is analogous to ABCD, except that its base lies on the plane WXYZ, instead of the horizontal plane. By analogy, it must have the same properties as ABCD, and again by rotation about AD, it can be seen that the face BED lies in the same (vertical) plane as BCD.

Hence, by simple trigonometry, the sighting angle is given by:

$$sin(\sigma) = sin(y+s) \,.\, sin(\varepsilon) / sin(y) \qquad \textbf{(1)}$$

$$where\ tan(y) = tan(\varepsilon)/sin(\theta) \qquad \textbf{(2)}$$

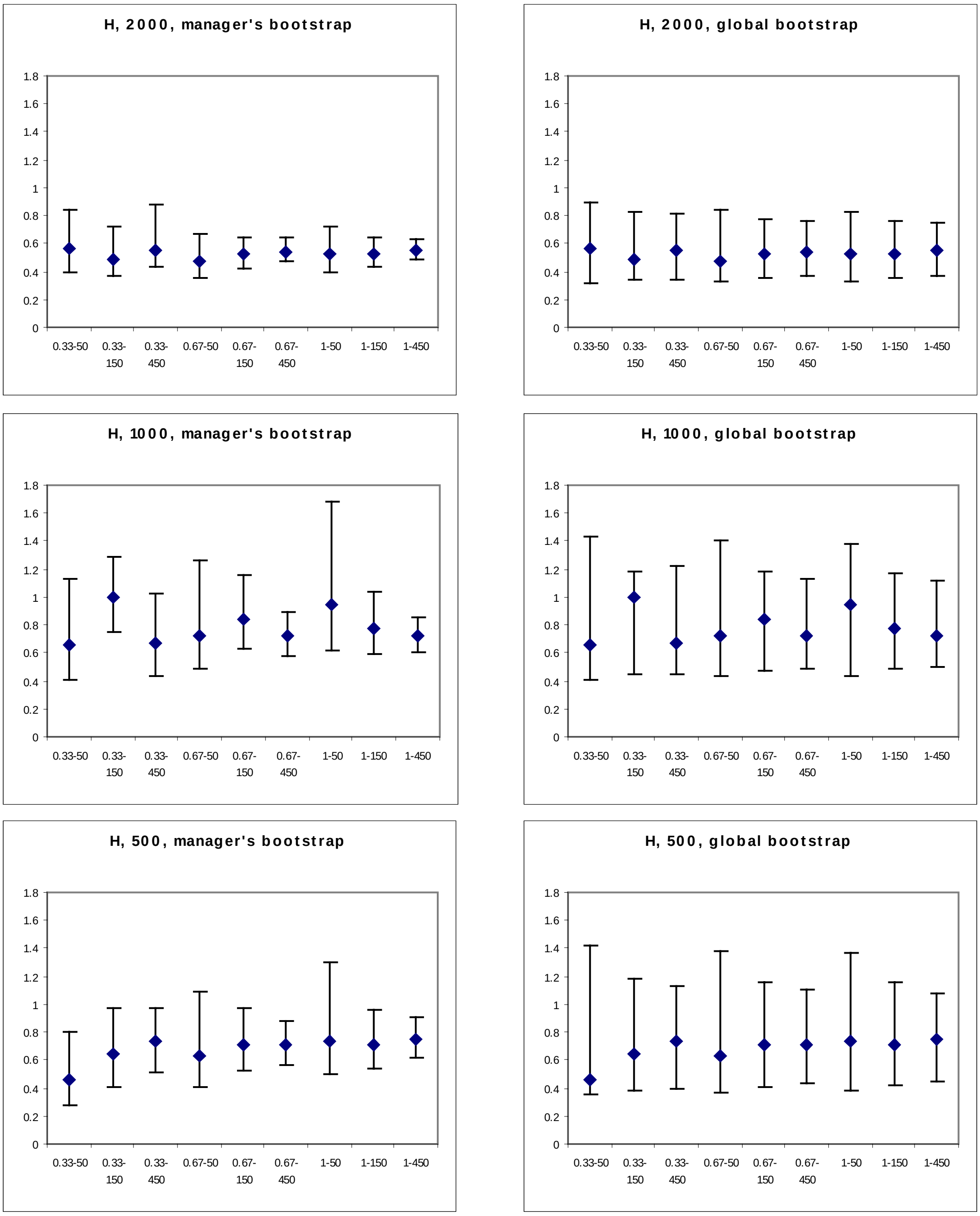
This can be verified by substituting the ratios of the vertices, i.e.

(1): $g/a = (g/e \,.\, d/a) / d/e$

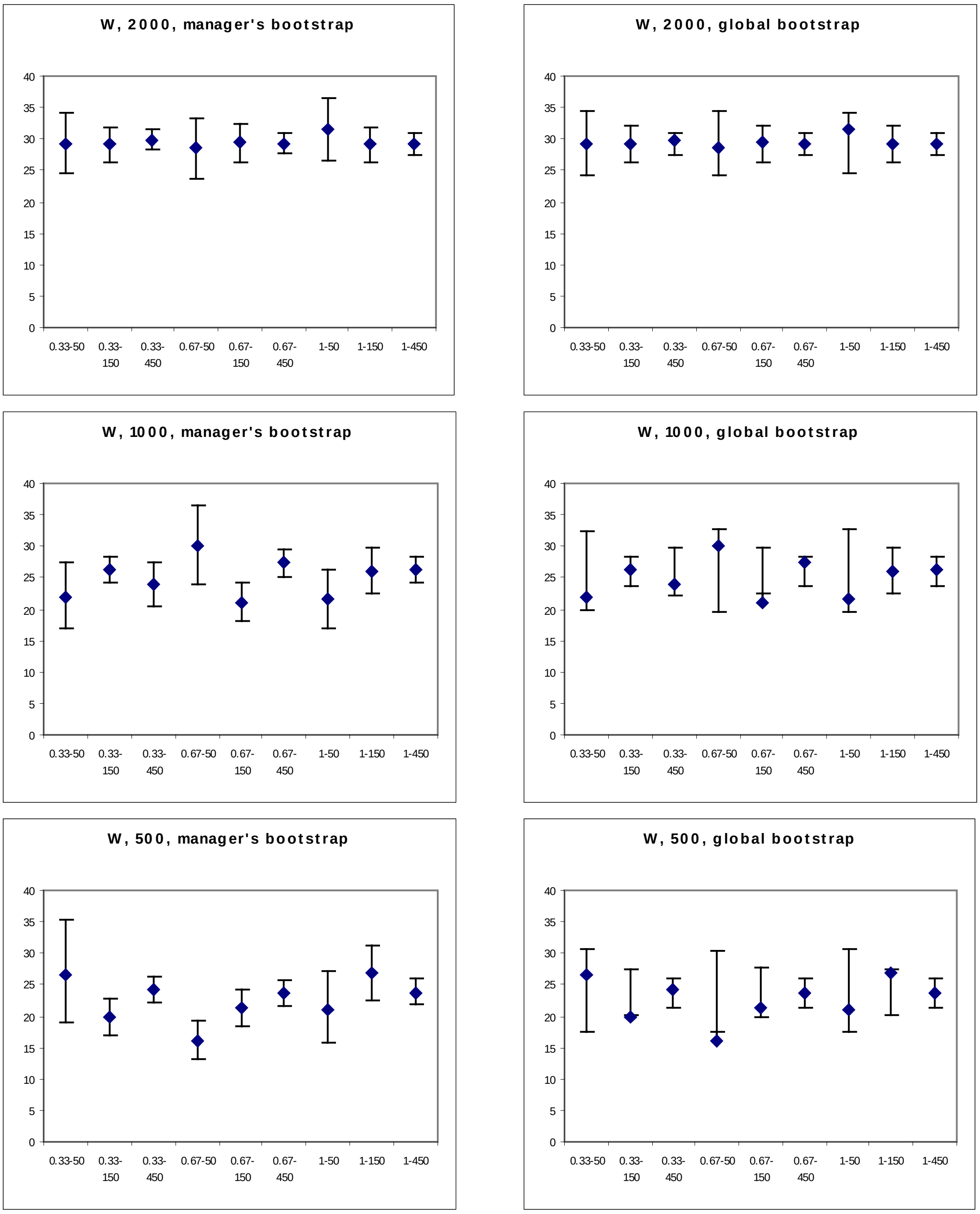
(2): $d/f = d/b / f/b$

Appendix 6-1: Parameter estimates and bootstrap CIs in the sampled models.

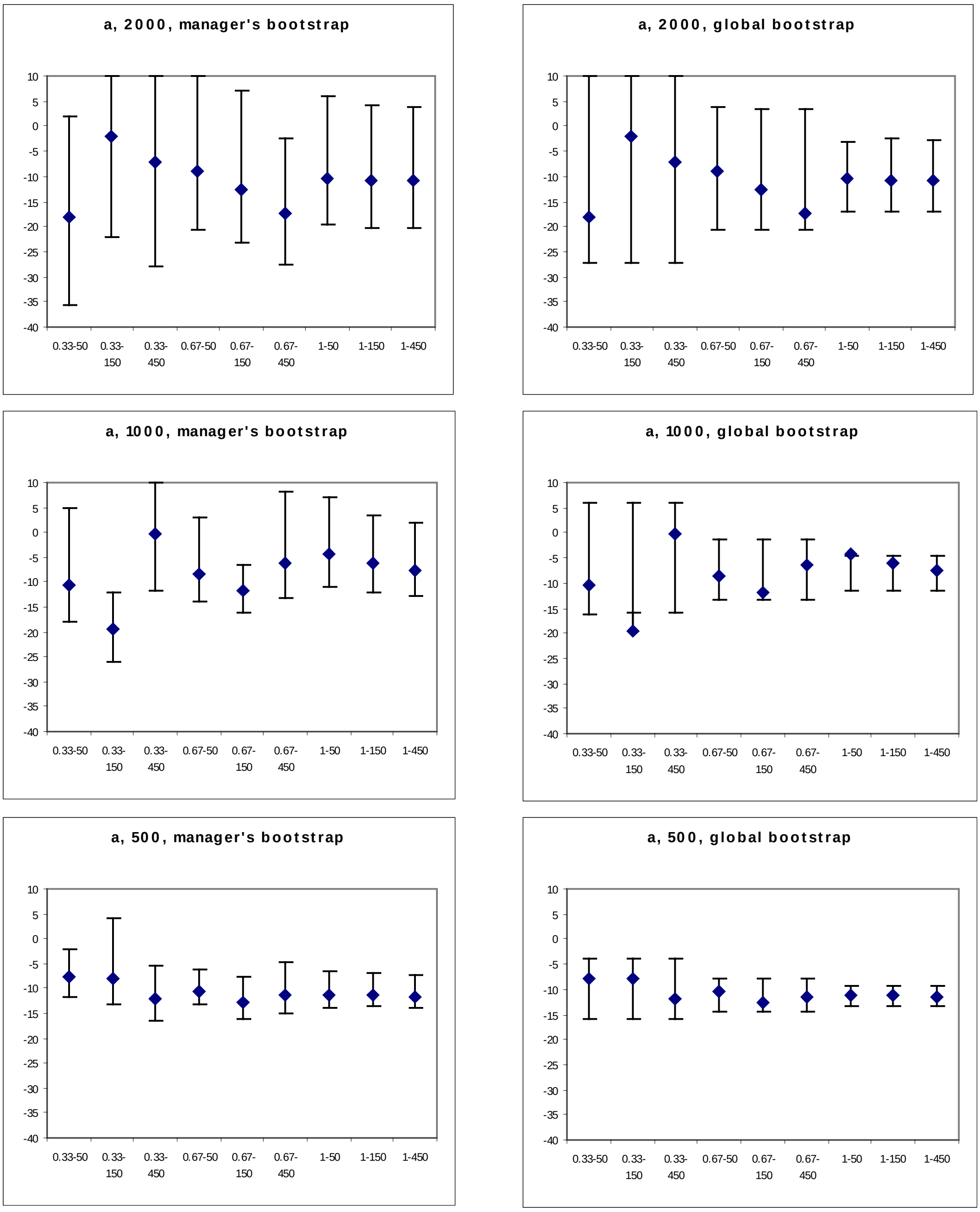
Note that in roughly 1 in 20 cases the parameter estimate lies outside the bounds of the global bootstrap CI, as would be expected.



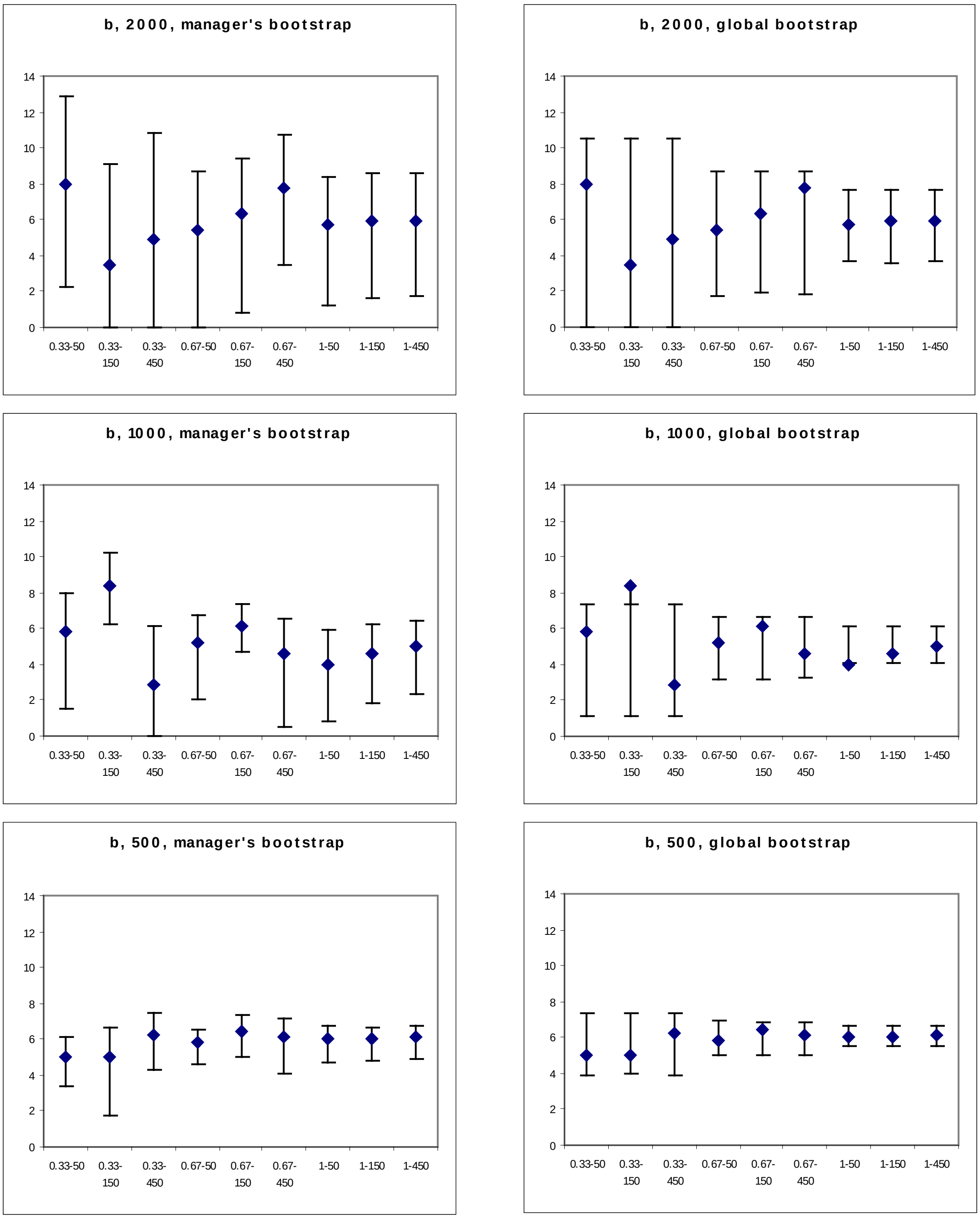
Estimates of *H* for sampling exercises carried out at different population sizes, ~2000, ~1000 and ~500 from top to bottom respectively, and 95% CIs determined by the manager's and global bootstrap methods (see 6.3.3.1), left and right respectively. Each of the 9 different levels of sampling intensity are represented within a single plot and described by the codes along the category axis; i.e. 0.33-50 – a third of the habitat was surveyed for ibex and 50 hunts were followed. In each plot, the 3 leftmost points show results from the lowest level of biological survey intensity and increasing levels of hunt survey intensity. The next 3 represent the next level of biological intensity and so on. Hence the effects of biological survey intensity can be judged by comparing between block of 3, and the effects of hunt survey intensity by comparing within them.



Estimates and CIs for average meat weight, *W* (kg).



Estimates and CIs for the herd size parameter *a* (see eqn. 6-13). Note that a cannot exceed 10, as it will take its maximum value when *b=0*, and hence a is the mean herd size at carrying capacity.



Estimates and CIs for the herd size parameter *b* (see eqn. 6-13). Note that *b* cannot be lower than 0 as average herd size cannot decrease with population size.