

# Fish Stock Assessment: an Inductive Science with the Logical Form of “Primitive Magic”: Replacing an Inductive View with a Critical Rational One.

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**Abstract.** A logical analysis of the common fisheries models used in stock assessment has shown that they produce specific predictions with the logical form of existential statements, fail Karl Popper’s falsifiability criterion, and so cannot be falsified or tested by the empirical evidence. By contrast, the theoretical models of fisheries economics make predictions, not in the form of existential statements, but in the form of universal patterns that exclude possibilities. These economic models meet Karl Popper’s falsifiability criterion, since, from the logical point of view, the excluded possibilities represent potential falsifications or tests of the model. Management decisions are presently guided by specific quantified predictions produced by those fisheries models best supported by the facts or data; a pragmatic approach to prediction that involves an inference from past experience and so makes the inductive assumption that we are entitled to argue from the past to the future. This inductive approach should be replaced by a **critical rational approach** in which management decisions are based, not on those non-falsifiable “metaphysical” models best supported by the facts, but on those falsifiable models that have been the best tested by the facts. A critical rational thesis illustrated, in this paper, by the bold falsifiable Gordon-Schaefer model of fisheries economics, in which bioeconomic optima (such as the maximum economic yield) are not interpreted in terms of specific quantified predictions but are seen as “aims” or “ends” and interpreted as normative laws; norms that are indirectly incorporated into a social engineering by way of the methodological rule of concomitance.

**Keywords:** Karl Popper, falsifiability, fisheries, stock assessment, Schaefer, introduction.

## 1. INTRODUCTION

Finding a distinction between the discipline of science on the one hand from the disciplines of mathematics and logic on the other, was solved in 1919 by Popper (1959a: 311, 1959b: 34) in terms of a logical criterion rather than a conceptual definition. Under Sir Karl Popper’s falsifiability criterion, declarative sentences or statements belong to the empirical sciences if they possess a logical form that would permit them to be refuted, an example would be “it will rain here tomorrow” or “it rained here two weeks ago”. These singular historical-type statements exhibit “falsifiability” since they are falsifiable in principle and can be answered with a “Yes-Or-No-Answer” (Popper, 1970: 57). By

contrast, the tautological statement “it will or will not rain here tomorrow” and the existential proposition “The Devil exists” cannot be answered with a “Yes-Or-No-Answer” and so, under Popper’s falsifiability criterion, these examples, while being perfectly meaningful statements, would be regarded as being “metaphysical” ones rather than scientific ones. As far as meaningless nonsense is concerned, Popper (1959a; 312) does not pretend his criterion is applicable to it.

Stock assessment is presently conducted under a form of instrumentalism that aims is to base management decisions upon specific model predictions, for although a model’s predictions can never be regarded as accurate, they are still able to “establish the scale of regulation that would

be required to get the best results” (Beverton and Holt, 1957: 448). This approach to pragmatism incorporates a “principle of induction” since it involves an inference from past experience and makes the implicit assumption that the future will be largely like the past. The central thesis of my present research program is that the instrumental and inductive approach of stock assessment represents a pseudo-methodology that is to be held responsible for the collapse of so many of our fish stocks.

This paper explores the suggestion that the pseudo-methodology of stock assessment should be replaced by a **critical rational approach** in which management decisions would be based, not on those “metaphysical” non-falsifiable fisheries models *best supported* by the facts, but on those models that meet the falsifiability criterion and have been the *best tested* by the facts; a non-inductive thesis illustrated by employing the Gordon-Schaefer model of fisheries economics.

## 2. THE ECONOMIC APPROACH TO MODELING

Economic models, like natural laws, are guesses or conjectures derived by commonsense, logical or mathematical argument, and while these models can be expressed in the form of equations, these equations, unlike the laws of physics, usually remain in algebraic form since “the parameters are themselves in the most important cases quickly changing variables” (Lord Robbins, quoted by Popper 1961: 143). The view that the parameters of

economic models should be interpreted as variables leads to model predictions that, unlike the *specific* predictions deducible from initial conditions and the laws of physics, are *non-specific* and are referred to by Frederick von Hayek, N. L. as “pattern predictions” or “predictions of the principle” (Hayek, 1994: 142).

## 2.1 The bold Gordon-Schaefer model

The Gordon-Schaefer model is named after the economist H. Scott Gordon and the biologist Milner B. Schaefer. Gordon (1952) applied the economic law of Diminishing Returns to the fisheries by, firstly correcting Alfred Marshall’s earlier application of the law and then by arguing diminishing returns to effort applies to the fishing industry utilizing a logical argument referred to as a *reductio ad absurdum*. (Gordon, 1953). On the assumption that diminishing returns to *population* does not exist sustainable yield ( $Y_s$ ) is related to nominal fishing effort ( $f$ ) by equation (1) where the exponent  $\beta$  reflects variable returns to nominal effort,  $a$  is the intrinsic growth rate,  $K$  is the Ecological Carrying Capacity (ECC) and  $q$  is the catchability coefficient, which is implicitly assumed to be less than half the value for  $a$  (see Cunningham *et al.*, 1985 for further details).

$$(1) \quad Y_s = Kqf^\beta [(a - qf^\beta) / a]$$

When diminishing returns to effort are present (that is,  $0 < \beta < 1$  in equation [1]) the sustainable yield curve takes longer to reach the maximum sustainable yield (MSY) and declines more slowly beyond it. The greater the diminishing returns (that is, the nearer the value of  $\beta$  to 0 in equation [1]) the longer it will take to reach MSY, and the longer it will take to decline afterwards (Fig. 1a, right). In the absence of diminishing returns ( $\beta = 1$  in equation [1]) sustainable yield is a simple quadratic function of effort and forms mirror image of the biological productivity curve (Fig. 1a, left) in which growth ( $G$ ) is a function of the population ( $P$ ) described by equation (2) with constants  $a$  and  $K$  as in equation (1).

$$(2) \quad G = aP [(K - P) / K]$$

From the perspective of *population growth* the origin of the biological productivity curve is at 0 on the population axis (Fig. 1a, centre) and an outward move along this axis represents an increase in the size of the population, but from the perspective of *fish yield*, the origin of the biological productivity curve is at EEC on the population axis (Fig. 1a, left) representing an unexploited population at its Ecological Carrying Capacity. The mirror image relationship between the sustainable yield curve in the absence of diminishing returns (Fig. 1 a, right) and the biological productivity curve

(Fig. 1 a, left) means that “an outward move along the effort axis implicitly indicates a fall in the size of the fish population” (Cunningham *et al.*, 1985: 36). In turn, a fall in the size of the fish stock implies an increase in population growth until a maximum is reached at EEC/2 on the population axis, a point corresponding to a maximum potential fish yield and referred to by Schaefer (1954: 32) as the “maximum equilibrium catch”.

## 2.2 Falsification and the bold approach

The models of economics, like the laws of the natural sciences, make conditional predictions of the form: “If this occurs, *then* such and such will follow” (Lipsey *et al.*, 1997: 33, their emphasis). For example, the supposition of values for the parameter  $\beta$  in equation (1) leads to conditional pattern predictions of the form: *if* no diminishing returns to effort are present *then*, other things being equal, the attainment of MSY will be achieved faster and the decline from the MSY more pronounced, than when large diminishing returns are present (Fig. 1a, far right); further, equations (1) and (2) can be said to be “bold” and “falsifiable” since they exclude possibilities by asserting certain patterns do not exist. For example, equation (1) logically excludes possible patterns of the form: (i) *The attainment of the MSY will not be slow and the decline from it fast* and (ii) *The attainment of the MSY will not be fast and the decline from it slow*.

Under Popper’s non-inductive method one argues *negatively* by way of refutation and criticism, but in order for a theory to be refutable or falsifiable it must possess “deductive consequence”; that is, it must be bold and “stick-its-neck-out” enabling it to “clash with reality”. In logical terms, the economic Gordon-Schaefer model, by excluding possible patterns, can be said to be falsifiable via it’s “deductive consequence” in the same way that the universal-non-existential statement ‘white ravens do not exist’ is a deductive consequence of the universal theory ‘all ravens are black’; that is, “The theory ‘All ravens are black’ rules out the existence of white ravens; and observation of a white raven refutes the theory” (Popper, 1999: 19). In more general terms, the logical notion of falsifiability can be described as a capacity for *riskyness* or *boldness* in which the laws and models of an empirical science open up new possibilities for falsification by “sticking-their-neck-out”. In contrast to positivistic notions of the real-world in terms of a visual image at different levels of abstraction (for example Skellam, 1969, his Fig. 1). Popper (1979a: 360, his emphasis) compares his interpretation of the scientific enterprise to a blind man “who touches, or runs into, an obstacle, and so becomes aware of its existence. *It is through the falsification of our suppositions that we actually get in touch with ‘reality’*. It is the discovery and elimination of our errors which alone constitute that ‘positive’ experience

which we gain from reality”.

**2.3 Recommendation one**

The non-falsifiable “metaphysical” models of stock assessment should be replaced by the bold falsifiable models of fisheries economics.

**3. THE INDUCTIVE APPROACH OF STOCK ASSESSMENT**

Unlike a bold falsificationist’s tradition, stock assessment looks for factual support for fisheries models, and, since one seeks to make arguments of this kind positively rather than negatively, there is no logical requirement for models to have “deductive consequence” so they are able to “clash with reality”. The models of stock assessment are formed by

a process that starts from the collection of fisheries data or facts or measurements; a process that can be described after Popper (1961: 98) as a “process of generalization or induction” in which, characteristically, the models of stock assessment have *specific values* assigned to their equation and model parameters and so make *specific quantified predictions*; the pragmatic use of which involves an inductive inference from past experience (see 3. 4).

**3.1 The non-falsifiable Graham (not Gordon) Schaefer model version one**

Fig. 1 (b) illustrates Ricker’s (1975: 319-322) version of the biological productivity curve for an exploited Pacific halibut

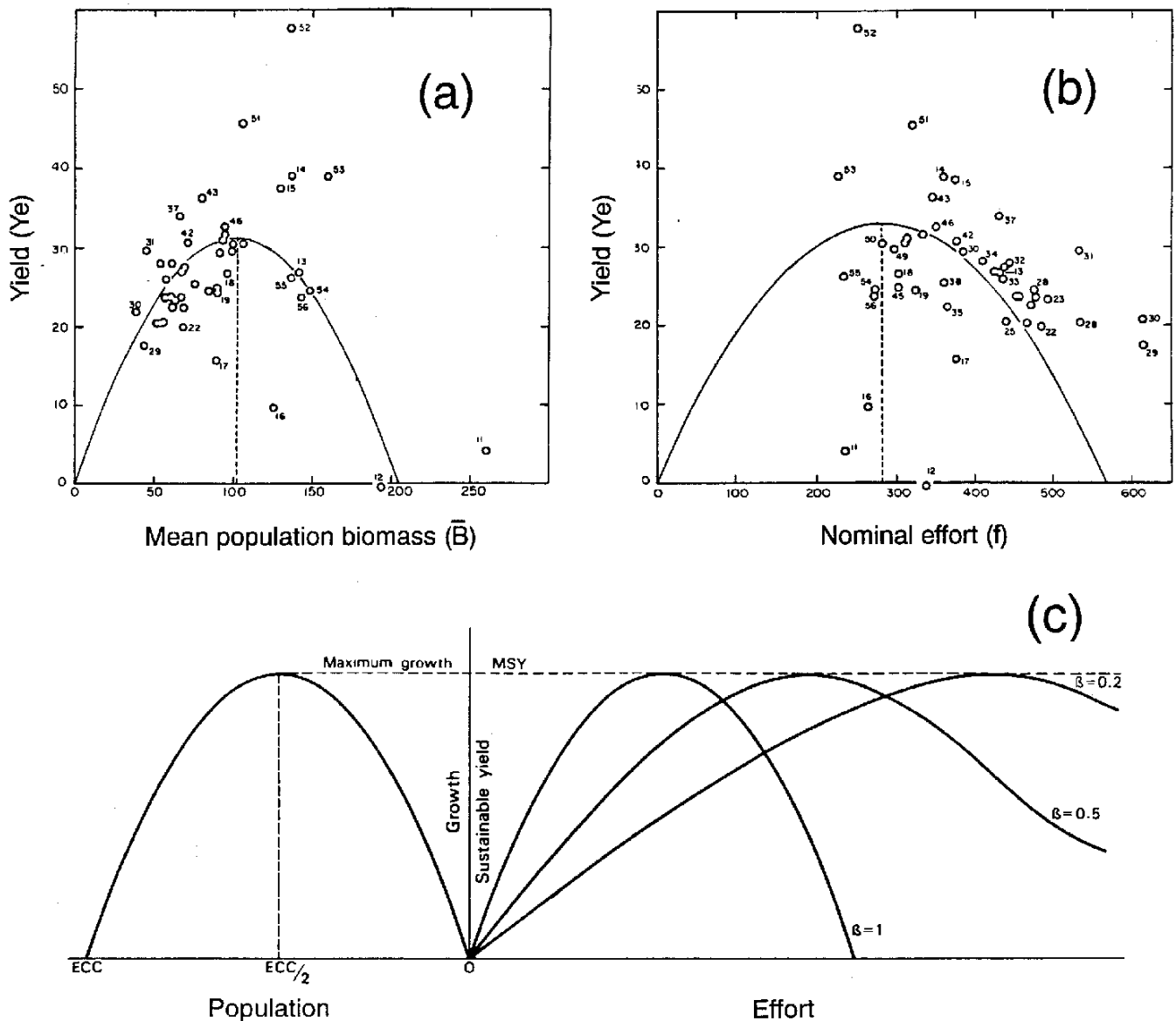


Figure 1. Schaefer-like models that are falsifiable in principle (a) and cannot be falsified (b and c).

(a) The bold Gordon-Schaefer model in which the biological productivity curve on the left is a mirror image of the sustainable yield curve in the absence of diminishing returns to effort on the right. The greater the diminishing returns the longer it will take to reach the MSY, and the longer it will take to decline afterwards (illustrated by the supposition of values 0.5 and 0.2 for parameter  $\beta$  in equation [1]) (from Cunningham *et al.*, 1985).

(b) The Graham-Schaefer model (first variant) for an exploited Area 2 stock of Pacific halibut showing the plot in yield (millions of pounds) with the mean population biomass (millions of pounds) for the same year. The data covers the period 1910 to 1957 (data points marked 10,11 represent years 1910, 1911 etc.) and were obtained from the International Pacific Halibut Commission (from Ricker, 1975).

(c) The Graham-Schaefer model (second variant) for an exploited Area 2 stock of Pacific halibut showing the plot in yield (millions of pounds) with observed fishing effort (thousands of skates) for the period 1910 to 1957 (data points marked as in (b), from Ricker, 1975).

Area 2 stock. In which a surplus production maximum or maximum equilibrium catch or maximum equilibrium yield near 30 million pounds was found by fitting a parabolic curve to data from 1910 to 1957 obtained from fishermen's logs analyzed by the International Pacific Halibut Commission (see Ricker, 1957, his Table 13.1).

### 3.2 The non-falsifiable Graham (not Gordon) Schaefer model version two

Fig. 1 (c) illustrates Ricker's (1975: 322-323) version (modified from Schaefer, 1957) of the sustainable yield curve (described by equation [1] with parameter  $\beta = 1$  in 2.1.) In which a maximum sustainable yield or maximum equilibrium yield near 35 million pounds was found for Pacific halibut from 1910 to 1957. The parabolic curve describes the relationship between surplus production or yield (a derived statistic) and fishing effort (an observed statistic). This curve was formed by fitting a GM regression line (see Ricker, 1975: 351, his Appendix IV) to data obtained from the International Pacific Halibut Commission.

### 3.3 A verificationist's view of fisheries science

There are logical reasons why the specific predictions of stock assessment cannot be falsified and so may be said to be "metaphysical" in Popper's terms. These specific predictions, such as "there exists a MSY of 30,000 million pounds for stock X", have the logical form of an existential statement ("there exists at least one white swan" or "white swans exist"). Existential statements can, in principle, be verified by a singular statement describing "observable" facts (there is a white swan flying here and now) but, since they cannot be falsified, a valid negative argument cannot be made against them. The non-falsifiable nature of a specific MSY prediction formed by fitting a Schaefer-like model to data, can be illustrated, after Popper (1961: 128, n. 2) and in a way superior to that attempted by Corkett (1997: 162) by the following hypothetical example. Say, a Rickerian Graham-Schaefer model (version two) is fitted to data and gives a MSY of 30,000 million pounds, then any deviation from this (such as more recent data suggest, say, a MSY of 45 million

pounds) could not disprove this prediction; for it remains logically possible (or we can always hope) that, in the long run, deviations in the opposite direction (suggesting, for example, say, a MSY of 25 million pounds) will "set matters right again". *Note bene*: This hypothetical example illustrates the unfalsifiable nature of an existential model's specific prediction in terms of argumentative invalidity. This invalidity can only be improved upon by increasing the logical strength (not the empirical strength, see 5. ) of the deductive logic underlying Popper's non-inductive method (see 2.2 ); a minimum requirement for which, is, that all scientific theories and models meet his falsifiability or demarcation criterion. Specific predictions with the logical form of existential statements, although non-falsifiable, are still verifiable, so they could be said to form the basis for a verificationist's view of science and Corkett (1997) claimed "all models of stock assessment are constructed according to the verificationist's view of science".

### 3.4 Specific quantified predictions and their inductive assumption

The aim of quantitative stock assessment is to produce specific quantified predictions upon which management decisions may be based (Hilborn and Walters, 1992). But basing management decisions on specific quantified predictions makes the inductive assumption that we are entitled to infer the future use of predictions from facts or data. This inductive assumption, can, in terms of stock assessment, be stated, after Popper (1979b: 4, his emphasis), in the following terms: "Why ... do all reasonable people expect, and *believe*, that instances of which we have no experience [the future value (y2) for a MSY for stock X] will conform to those of which we have experience [the MSY for stock X was (y1) in the past]? That is; Why do we have expectations in which we have great confidence?". As Popper (1979c: 363, his appendix 2 with his emphasis) points out his own interpretation of the scientific method requires no inductive assumption since, in his view, an inference from past experience is not based on data or facts or measurements alone, but is based "upon observational

experience (formulated by statements of ‘initial conditions’) plus some *universal theories*. The presence of these theories (such as Newton’s theory of gravitation) is essential for arguing from the past to the future. But *these universal theories are not in their turn inferred* from past. They are, rather, *guesses*: they are *conjectures*.”

### 3.5 Aims and targets: the instrumental approach

The dynamic predictions of bioeconomic models, such as static maximum economic yield (SMEY) and Maximum Economic Yield (MEY), together with the MSY, are, under a fisheries economic tradition, often interpreted as constituting an aim or “target level of fishing that the management authority is attempting to achieve” (Cunningham *et al.*, 1985: 83). Unlike the normative approach to pragmatism (see 4.2); an instrumental approach to pragmatism would involve managing fishing activity so that this activity proceeds at, or near, a particular specified target level, a specified level that would require quantified specific predictions similar to those sought under a stock assessment tradition (see 3. ). For example, Padilla and Charles (1994, their Figs. 1a and 1b) found that a small pelagic fishery in the Philippines needed an effort level of  $260 \times 10^6$  fleet horse power to achieve an MSY of  $550 \times 10^3$  million tons of catch but that a lower effort level of  $160 \times 10^6$  fleet horsepower was sufficient to achieve the MEY.

## 4. THE NON-INDUCTIVE APPROACH OF CRITICAL RATIONALISM

Since pragmatic decisions are guided by theory choice has to be made, and, under a criticist’s or falsificationist’s view of science, it will be rational to chose the *best tested* or *best criticized* theory; an argument that MAKES NO INDUCTIVE ASSUMPTION and underlies a branch of philosophy known as critical rationalism (Andersson, 1984, Miller, 1994 ). For, while a highly tested fisheries model gives no indication about how it will, or will not, perform in the *future*, the critical rationalist points out, that we are still able to base our policies and management decisions on the most highly tested model, that is, the one that best survives a critical discussion “and I [Popper] do not know of anything more ‘rational’ than a well conducted critical discussion” (Popper, 1979a: 22).

### 4.1 Recommendation two

Stock assessment’s inductive view of pragmatism should be replaced by a critical rational approach in which no inference is made from past experience.

### 4.2 Aims and targets: the normative approach

Unlike an instrumental approach to pragmatism (see 3.5), a critical rational approach to fisheries management would view targets (such as the MSY and MEY) as aims or

objectives; that is, as normative laws or norms in which all that a fisheries management or fisheries science may say about them is “whether or not they are compatible with each other or realizable” (Popper, 1961: 64). While, under a normative approach such targets, aims and objectives, remain beyond the domain of a social technology, they may still be incorporated *indirectly* into management decisions via a methodological rule of the form: “You cannot achieve such-and-such ends [targets] without such-and-such concomitant effects” (Popper, 1961: 61). An example, making use of Corkett’s (1997) illustration of social engineering involving technological change, would be: You cannot attain the target MSY in a stock fished with high technological efficiency without running the risk of subjecting this stock to an earlier and more pronounced decline than a stock fished with lower technological efficiency.

### 4.3 Recommendation three

Stock assessment’s instrumental approach to “ends” should be replaced by an normative approach in which targets, aims and objectives are viewed as normative laws.

### 4.4 Social engineering: the “blind man” approach to pragmatism

It is important to distinguish Popper’s technological social theory, involving a cautious trial and error approach to pragmatism in the form of social engineering, from his non-inductive scientific method. Whereas his scientific method is “risky” and may be said to be “revolutionary” since it aims for the replacement of theory, his pragmatic social technology starts with the institutional *status quo* and then proceeds with modifications by a “piecemeal” social engineering (see examples for fisheries management in Corkett, 1997). Under Popper’s social theory it is important to distinguish between two categories of prediction; as Karl Popper (1961: 42) explains: “From the point of view of the pragmatic value of science, the significance of scientific predictions is clear enough. It has not always been realized, however, that two different kinds of prediction can be distinguished in science, and accordingly two different ways of being practical. We may predict (a) the coming of a typhoon, a prediction which may be of the greatest practical value because it may enable people to take shelter in time; but we may also predict (b) that if a certain shelter is to stand up to a typhoon, it must be constructed in a certain way, for instance, with ferro-concrete buttresses on its north side”.

Corkett (1997) labeled the pragmatic appeal of specific predictions to stock assessment as an example of instrumentalism; an instrumental approach based on the naive assumption that effective pragmatism had to be based

on *positive* specific predictions analogous to those predictions deducible from initial conditions and advanced physical theory (prediction [a] in the above quote) whereas it is the *negative* deducible predictions of physical theory in the absence of initial conditions (involving prediction [b] in the above quote) that are involved in the falsifiability or empirical content of scientific laws. That is, in terms of *physical laws* AND *fisheries models* the falsifiability content represents possible falsifications that open up opportunities for the testing of laws and models (see 2.2 ), but, in terms of *physical engineering* AND *social engineering*, the same possible falsifications are to be interpreted as technological predictions that inform the Popperian fisheries manager or social engineer, in a *negative* “blind man” kind of way, what cannot be achieved and should not therefore be attempted. Thus, unlike the existential view of pragmatism based on a positivistic inductive tradition, a critical rationalist’s view of pragmatism follows a “natural science” tradition by informing us what cannot be achieved, thus placing us “in a better position to *take* those political and ethical decisions upon which the future management of our resources will depend” (Corkett, 1997, emphasis added).

#### 4.5 Recommendation four

Stock assessment’s positivistic approach to pragmatism, in which management decisions are based on specific *positive* predictions, should be replaced by a social engineering “blind man” approach, in which *negative* predictions guide institutional adjustments by trial and error.

### 5. DISCUSSION

The falsification of theory cannot take place unless the scientific enterprise involves a bold and risky approach; an approach that the logico-technical concept of falsifiability interprets in terms of the *logical strength* of a negative argument; that is, a valid argument in which “the falsity of the conclusion (if it is false) is invariably retransmitted to at least one of the premises” (Popper, 1974a: 114). One of the more common misrepresentations of the falsificationist’s view of science (sometimes referred to as naive falsificationism) seeks to understand the logical criterion of falsifiability in terms relevant to the *empirical strength* of an argument. An example of this kind of misrepresentation is given by Sir Isaiah Berlin who writes: “Karl Popper...suggests that a proposition is significant if and only if it can be *conclusively falsified* by the conclusive verification of a singular proposition which contradicts it - as when a law is refuted by the occurrence of one negative instance” (Berlin, 1978: 20 my emphasis). In fact, Popper has always maintained that all falsifications remain problematic, but that, in the case of competing theories - competing in the sense of attempting to solve the same problem of explanation - the refutation of competitors can

lead to the *corroboration* of the theory that remains. For, while we can never know, in such a competition, that the “winning theory” is a true theory - describes the real-world truly - it is, from the perspective of a falsificationist’s view of science, rational to focus on this *provisional* “winner” as a subject for further attempted criticisms.

Corkett (1997) asserted that while the Gordon-Schaefer model in the *presence* of diminishing returns met the postulate of boldness; in the *absence* of diminishing returns, or on the assumption that diminishing returns need not be deployed, the Gordon-Schaefer was emptied of empirical content, failed to meet the postulate of boldness and supplied no empirical information about the real-world. This assertion was based on an understand of population growth in terms of specific predictions rather than conditional ones and needs modification since the population growth curve of the Gordon-Schaefer model is a mirror image of the sustainable yield curve, in the absence of diminishing returns (Fig. 1a). Both curves are to be described by parabolic equations and both make conditional predictions (not specific ones) of the form: *if* the specific growth rate (parameter  $\alpha$  in equation [1] and [2]) is large *then*, other things being equal, the approach to the maximum growth rate and the MSY will be faster and the decline from the maximum growth rate and the MSY will be more pronounced than if the specific growth rate is small. Further, the Gordon-Schaefer model in the absence of diminishing returns, is able to meet the falsifiability criterion (meet the postulate of boldness) since it is able to exclude possibilities (potential falsifications) similar to those excluded by the supposition of values for  $\beta$  in equation (1) (see 2.2 )

A qualification should be made to Corkett’s claim that “all models of stock assessment are constructed according to a verificationist’s view of science” (see 3.3) since it is advisable to distinguish - something Corkett (1997) did not do - between “strong verification” (in the sense that an existential statement of the form ‘white swans exist’ can be said to have been verified) from “weak verification” where the unverified statement ‘pink swans exist’ and the verified statement ‘white swans exist’ can both be said to be *verifiable in principle*, since, in all logically possible worlds, both ‘pink swans’ and a ‘white swans’ can be said to exist. While this distinction only remains relevant under a verificationist’s view of science, it does, I believe, point the way to an analogous mistake often perpetuated under the banner of falsificationism. For, if we label Popper’s approach to both the testability (falsifiability) of theory and the engineering application of theory, as “soft”, since it involves a *falsification in principle*, then this “soft” approach can, perhaps, be more clearly seen as differing from a “hard” inductive approach involving *conclusive*

*falsification*. For example, Sokal and Bricmont (1998: 63) state: “Popper thinks he has solved Hume’s problem....Clearly, this ‘solution’ is unsatisfactory from a scientific point of view. In particular, at least one of the roles of science is to make predictions on which other people (engineers, doctors...) can reliably base their activities, and all such predictions rely on some form of induction”. Sokal and Bricmont (1998) largely base their positivistic assessment of Popper’s scientific view on a critical account of his non-inductive theory by Hilary Putnam. In my judgement these criticisms of Putnam have been answered clearly, unambiguously and in full by Popper (1974b). Contrary to Sokal and Bricmont’s (1998:68) naive criticisms of Popper’s epistemology based on a positivistic inductive tradition, I assert that Popper’s arguments against induction are indeed to be taken seriously in a literate sense, that is, in terms of this paper, a critical rational approach to fisheries management would indeed involve a “blanket rejection of induction”. While Popper’s arguments against induction are beyond the scope of this paper, the assertion that the models of stock assessment fail Popper’s demarcation criterion, and so *by definition* possess the logical form of meaningful “primitive magic” can be illustrated with Popper’s (1972: 249) own example of a purely existential theory. “There exists a finite sequence of Latin elegiac couplets such that, if it is pronounced in an appropriate manner at a certain time and place, this is immediately followed by the appearance of the Devil - that is to say, of a man-like creature with two small horns and one cloven hoof.” Whereas this proposition, like the existential predictions made by the models of stock assessment, is verifiable in principle, since it is logically possible to find a Latin chant which, when pronounced appropriately, would produce the Devil, the evaluation of this spell cannot be made in terms of a Yes-Or-No answer since the application of such a spell cannot be falsified, for, if a repetition of the elegiac couplets failed to achieve the expected result “that would be no falsification, for perhaps an unnoticed yet essential aspect of the correct ceremony was omitted” (Popper, 1983: xxi).

## 6. CONCLUSIONS AND RECOMMENDATIONS

1. The bold theoretical models of fisheries economics meet Karl Popper’s criterion for empirical science and should replace the non-falsifiable “metaphysical” models of stock assessment.

2. A critical rational approach to pragmatism, in which management decisions are based on those bold models that best survive a critical discussion, should replace an inductive approach in which management decisions, based on specific quantified predictions, make the inductive assumption that one is entitled to argue from the past to the future.

3. A normative approach to “ends”, in which targets and aims are approached indirectly via the methodological rule of concomitance, should replace an instrumental approach in which models are fitted to data so that targets and aims may be viewed quantitatively.

4. A social engineering approach to pragmatism, in which negative predictions guide institutional adjustments by trial and error, should replace a positivistic approach to pragmatism in which management decisions are based on positive specific predictions.

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