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# An empirical equation to predict annual increases in fishing efficiency

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## Abstract

This contribution presents a meta-analysis of estimates of the slow increase of technological efficiency, or ‘creep’, obtained by various authors for a number of demersal and pelagic fisheries. This factor is used in fisheries science to adjust for the gradual increase in the effectiveness of fishing gear resulting from the successive introduction of technological improvement to fishing gear and vessels. Altogether, 39 estimates of this creep factor, mostly around 2-4% per year, and covering periods from 6 to 120 years, were assembled or newly calculated from secondary data, and shown to decrease as the period covered increased. This finding is compatible with the hypothesis that creep factors are usually estimated and published to correct for the introduction of a very effective new technology over a shorter period of time. We suggest that estimates obtained in this fashion cannot be applied to long-term analyses and propose instead an empirical relationship derived from estimates of creep factor and number of years covered in a study. Also, this study confirms that technology creep must be included in all analyses involving time series of fishing effort, particularly if they exceed a decade in temporal coverage.

## Introduction

People have been fishing for millennia and they have always tried to improve the methods they use (von Brandt 1964), both in order to increase their catch, and to compensate for the declining catch per effort due to decline of the underlying resources. Since the late 19th Century, following the introduction of steam trawlers in England, which marks the start of industrialized fishing, the improvement of technology has been relentless, and present vessels are much more powerful than the steam vessels of similar tonnage (Engelhard 2008; Thurstan et al., 2010).

The relationship between fishing mortality and fishing effort is:

$$F = q \cdot f \qquad \ldots 1)$$

where $F$, of dimension of time$^{-1}$ (conventionally a year), is the fraction of the fish population that dies from fishing; $f$ is a measure of fishing effort (e.g., number of boats or fishing hours·days$^{-1}$ of a certain type of fishing vessel); and $q$ is the catchability coefficient (Beverton and Holt 1957).

Technological creep can be conceived as either a change in catchability ($q$) or a change in the definition of nominal effort (Gulland 1956; Sanders and Morgan 1976). Either way, it will affect fishing mortality. Conversely, if $F$ is to be kept at a given level, effective effort will be affected by technological creep, and nominal effort must be reduced accordingly.

Technological improvement can be conceptually separated into two groups:

1. Major improvements in gear design, fish finding and/or catch handling resulting in massive increase in effective fishing effort when they are implemented throughout a fleet within a few years;
2. Small background alterations in rigging of a vessel, the skill of skippers at handling new technology or at applying information technology, etc.

Technology creep factors receive far too little attention by fisheries scientists and even less by fisheries managers, for example when the attempt to freeze the amount of fishing effort at a certain level, but fail to account for the increase in effective effort of the vessels whose number is frozen, or when subsidizing fleet retirement programs that allow for the funds for the purchase of new, more efficient vessels (Pauly et al., 2002; Munro and Sumaila 2002 and references therein).

Most of the studies on creep factor refer to cases in (1) because the effect is strong and visible and thus justifiably attracts scientific and management attention. However, because of the cumulative effect, the changes in (2) are also important, because they occur relentlessly, even when no major technology improvements appear to be taking place.

This contribution therefore aims at presenting a number of estimates of this creep factor (both previously published and newly estimated), and based thereon, to propose an empirical plot derived to allow inference on long-term creep factors combining items in (1) and (2), as in Figure 1.

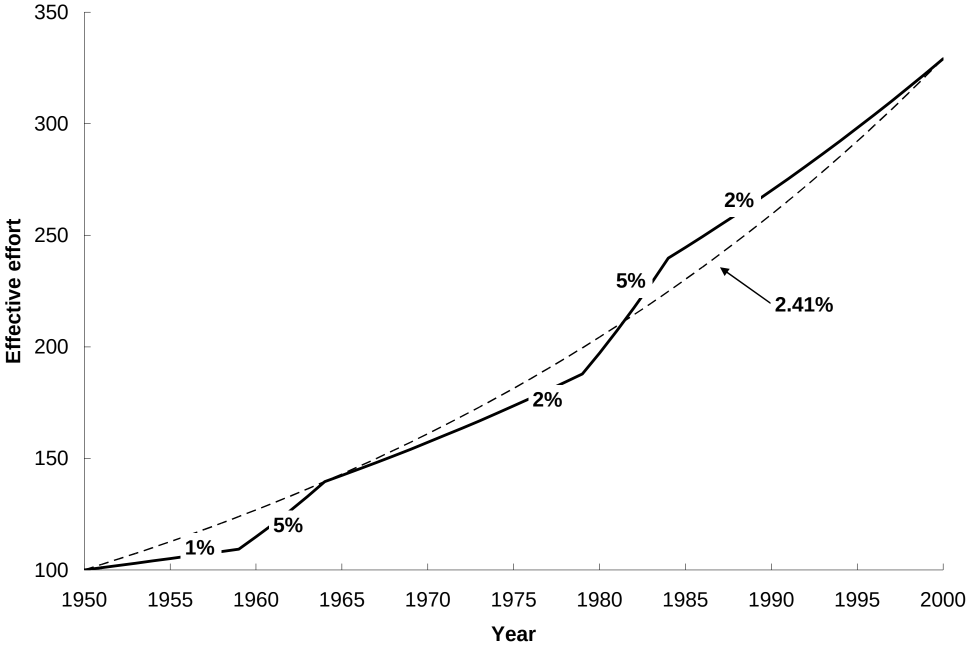

**Figure 1**. Simulation of increase in effective effort over a 50 year period consisting of a mixture of background rates (C% = 1 and 2%) and rapid increases (5%) due to technological improvements. The average rate (2.41%; dotted line) is obtained by comparison of the beginning and end estimates of effective effort, but can be approximated by an average rate of increase weighted by the number of years (2.42%).

## Material and Methods

A literature search was conducted targeting estimates of time series trends of fishing power or fishing efficiency available from online resources (Aquatic Sciences and Fisheries Abstracts, Web of Science, Google Scholar) using the search terms "fishing power" and "fishing efficiency". This yielded 113, 106, and 70 hits for fishing power and 65, 53 and 60 hits for fishing efficiency in ASFA, WS and GS, respectively. Of these, 13 contributions contained usable time series data of fishing power (39 case studies; see Appendix 1) from which estimates of the annual increase of 'fishing power' or 'fishing efficiency' were obtained. In some cases, published data on comparisons of fishing power/efficiency from different vessel types fishing in parallel were used to estimate the instantaneous rate of technological creep (*C*; year$^{-1}$), and the corresponding annual increase, in % (C%).

## Results and Discussion

The first result we obtained is a series of estimates of *C* (Appendix 1), some of which need to be commented upon in some detail; we then continue with a joint analysis.

Figure 2 presents estimates of *C* in English trawl fisheries for cod and plaice based on the classical method for fishing power estimates (Gulland 1956), for trawlers fishing in parallel. This time series extending from 1880 to 2005 was reported in Table 1 of Engelhard (2008). Here, all ranges were replaced by mid-ranges and a few points were identified as outliers (e.g., those representing sailing vessels; see Figure 2). The resulting slopes of the plot (Figure 2; see also Appendix 1) provide relatively low estimates of *C* for cod and plaice, respectively), pertaining to an extraordinarily long time series of 120 years.

Our second case are the result of an informal workshop reported upon by Fitzpatrick (1996; see Table 1), whose main result was that, over a period of 30 years, the skippers of a wide range of vessels perceived an increase of the efficiency of fishing gears, i.e., fishing power, equivalent to C% = 4.43% year$^{-1}$ +/- 0.00255. Details on this exercise are not available which would enable for the results from the different fisheries included therein to be discussed separately.

**Table 1.** Estimated technology coefficients of fishing vessels by vessel type (data from Fitzpatrick 1996), as reported by Gelchu and Pauly (2007, Table 2.5).

| **Vessel type** | **Length (m)** | **Technology coefficient** | | |
|---|---|---|---|---|
| | | 1965 | 1980 | 1995 |
| Super trawler | 120 | 0.6 | 1 | 2.5 |
| Tuna seiner | 65 | n.a. | 1 | 1.6 |
| Freeze trawler | 50 | 0.7 | 1 | 2.0 |
| Tuna longliner | 65 | 0.5 | 1 | 2.3 |
| Purse seiner | 45 | 0.6 | 1 | 2.0 |
| Stern trawler | 35 | 0.6 | 1 | 1.9 |
| Longliner | 35 | 0.4 | 1 | 2.8 |
| Multi-purpose vessel | 25 | 0.6 | 1 | 2.5 |
| Shrimp trawler | 25 | 0.5 | 1 | 2.2 |
| Gillnetter | 15 | 0.4 | 1 | 1.5 |
| Trawler | 13 | 0.5 | 1 | 1.8 |
| Fast potter | 10 | 0.3 | 1 | 1.4 |
| Pirogue (canoe) | 10 | 0.6 | 1 | 1.3 |
| Mean (± 2*s.d.) | - | 0.53±0.23 | 1 | 1.98±0.93 |

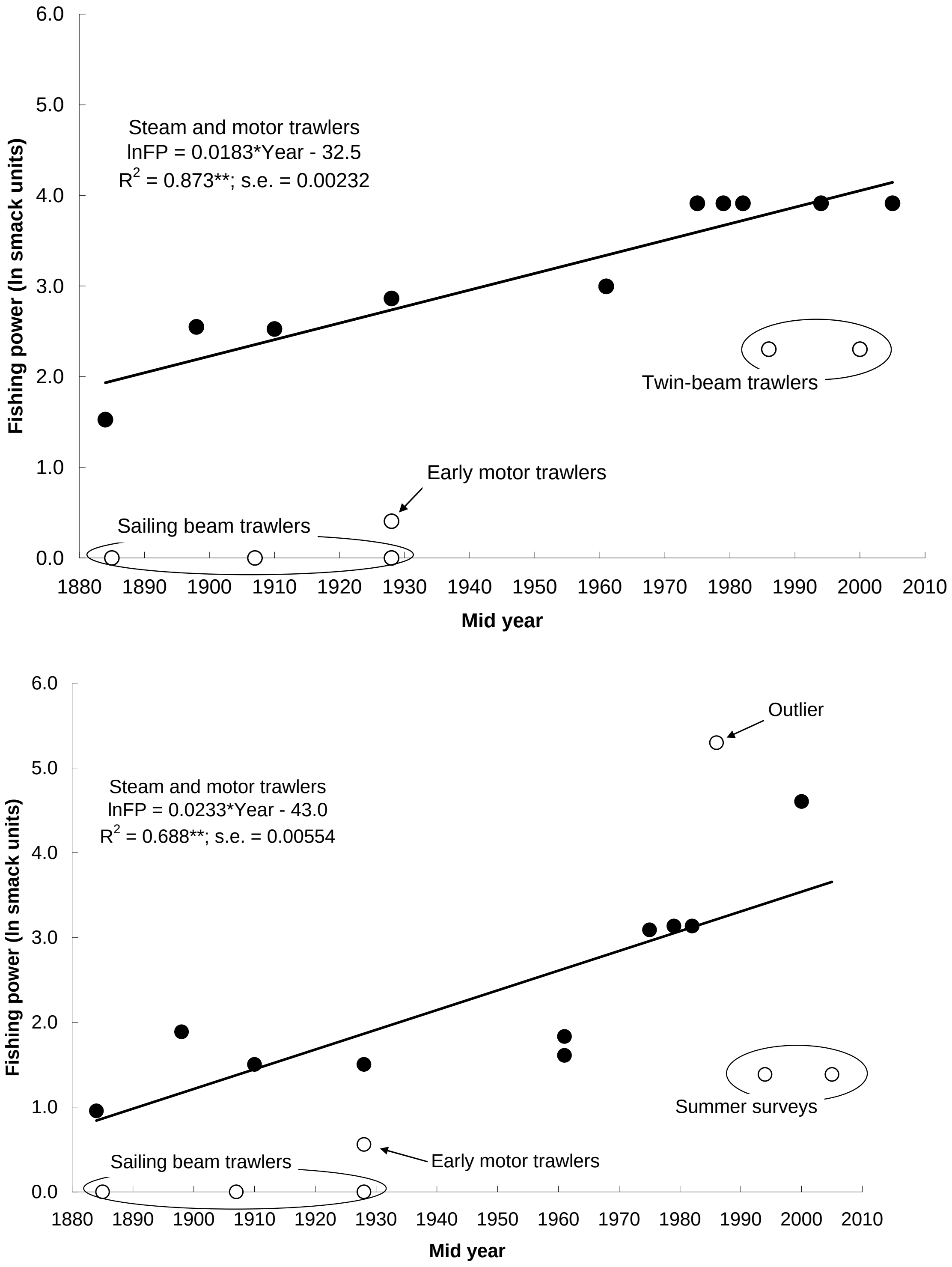

**Figure** 2. Increase of fishing power in English demersal trawl fisheries for cod (above) and plaice (below) based on data in Engelhard (2008, Table 1).

Other estimates that were obtained from secondary data are documented in the rightmost column of Appendix 1. Overall, the estimates of *C* in Appendix 1 range from 0.0049 to 0.201 year$^{-1}$ with a group of suspiciously low values (0.0049-0.0245 year$^{-1}$) published by O'Neill et al., (2003) and O'Neill and Leigh (2007) who studied fishing power on various Australian invertebrate fisheries, When the estimates of *C* in Appendix 1 (excepts for the estimates O'Neill and collaborators) are converted to lnC% and plotted against the logarithm of the number of years for which they were estimated, the result is the significantly negative relationship shown in Figure 3.

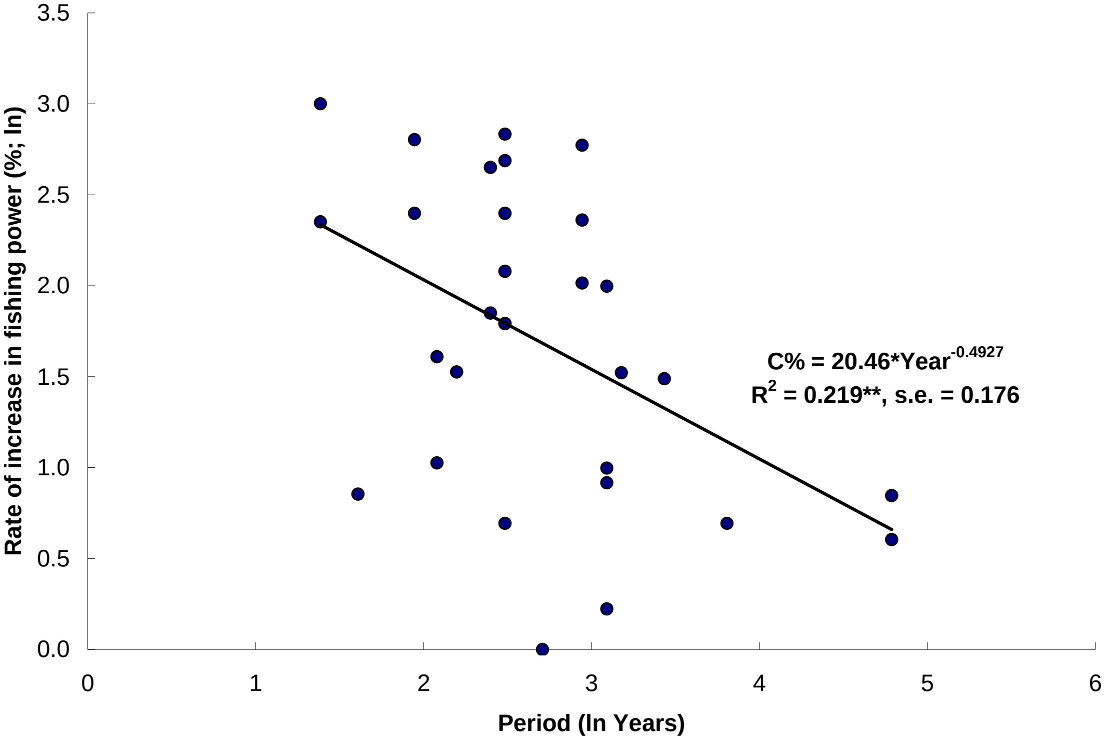

Figure 3. Relationship between technological creep (C%) *vs.* the period (in years) to which the estimate applies ($\ln C\% = 3.018 - 0.4927 \cdot \ln Year$; $R^2 = 0.219$, $R = 0.468$; the low estimates of O'Neill and collaborators are omitted, and hence df = 29, $P<0.01$).

This relationship is not very tight, but given the heterogeneous nature of the data that went into the point estimates and of the underlying models (General Linear Models, chains of comparisons of successive trawler type, subjective assessments, etc.), a better fit can probably not be expected.

The relationship linking C% to the duration of the period (Y) for which C% was estimated can be expressed as:

$$C\% = 20.46 \cdot Y^{-0.4927} \qquad \ldots 2)$$

For a period of 100 years, this equation gives C% values of 2.12%, 2.98% for 50, 6.58% for 10 and 9.26% for 5 years. No pattern could be identified for the data in Appendix 1 that would have allowed for specific fisheries (pelagic *vs*. demersal, large-scale *vs*. small-scale) to be identified (except for the low values of O'Neill and collaborators). Thus, we suggest that equation (2) can be used for all fisheries for which no other estimate of technological creep is available.

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**Appendix 1**. Technological creep (*C*) estimates for various fisheries and periods, with method of estimation and source (see also text).

| **Fishery/species** | **Period** | **Creep (*C*; year$^{-1}$)** | **St. err. of *C*** | **Remarks/Source** |
|---|---|---|---|---|
| British North Sea Atlantic cod (*Gadus morhua*, Gadidae) trawl fishery | 1886-2005 | 0.0183 | 0.00232 | Change in fishing power (FP; smack units); based on data in Engelhard (2008, Table 1) with lnFP= 0.0183·Year-32.5 (see Fig. 2) |
| British North Sea European plaice (*Pleuronectes platessa*), trawl fishery | 1886-2005 | 0.0233 | 0.00554 | FP (smack units); based on data in Engelhard (2008, Table 1) with lnFP = 0.0233·Year-43.0, $r^2$ = 0.688**, df=8 (see Fig. 2) |
| Japan distant water pelagic long liners | 1954-1998 | 0.02 | 0.0155 | Annual mean rate of change for mako shark, blue marlin, bigeye, yellowfin and skipjack tunas; based on Ward (2008, Table 2) |
| Wide range of vessel types | 1965-1995 | 0.0443 | 0.00255 | Change in technology coefficient; based on data in Gelchu and Pauly (2007, Table 2.5) based on Fitzpatrick (1996; see Table 2 in this contribution) with lnTC=0.0443·Year-87.7, $r^2$=0.893**, df=36 |
| Pacific ocean perch (*Sebastes alutus*, Sebastidae) trawl fishery, Vancouver Isd. | 1953-1976 | 0.0458 | – | Based on 2% increase reported by Kimura (1981) |
| Thread herring (*Opisthonema libertate*, *O. bulleri*, *O. medirastre*) fishery, Mexico | 1972-1993 | 0.0737 | 0.0125 | Index of FP based on data in Ruiz-Luna et al., (1997, Table 1; CPUE=a·lc$^b$; l.c. loading capacity); result was lnFP=0.0737·Year-0.786, $r^2$=0.684**, df=16 |
| Western rock lobster (*Panulirus cygnus*, Palinuridae) shallow water fishery, Austr. | 1971-1992 | 0.0125 | – | Mean of FP increase: 0.005-0.02; Brown et al., (1993) |
| Western rock lobster deep water fishery, Western Australia | 1971-1992 | 0.025 | – | Mean of FP increase 0.01-0.04; Brown et al., (1993) |
| Pacific cod (*Gadus rnacrocephalus*,), Butterwort ground fishery, Canada | 1960-1981 | 0.0271 | .009649 | FP increase based on data in Westrheim and Foucher (1985, Table 6), with lnRFP=0.0271·Year-53.0, $r^2$=0.282*, df=20 |
| Norwegian gillnet fishery, North Sea | 1980-1998 | 0.075 | 0.0457 | Mean trend in FP indices for cod, haddock and saithe; based on data in Marchal et al., (2002, Table 6) |
| Norwegian longline fishery, North Sea | 1980-1998 | 0.16 | 0.01 | Mean trend in FP indices for cod, haddock and saithe; based on data in Marchal et al., (2002, Table 6) |
| Norwegian otter trawl fishery, North Sea | 1980-1998 | 0.106 | 0.0438 | Mean trend in FP indices for cod, haddock and saithe; based on data in Marchal et al., (2002, Table 6) |
| European fisheries | 1985-1999 | 0.01 | – | Technology coefficient; Banks et al., (2001) and Kirkley et al., (2001) |
| Danish cod gillnet fishery, Baltic Sea | 1987-1998 | 0.06 | – | Increase of index of FP; Marchal et al., (2001, Table 3) |
| Danish cod trawl fishery, Baltic Sea | 1987-1998 | 0.02 | – | Increase of index of FP; Marchal et al., (2001, Table 3) |

| | | | | |
|---|---|---|---|---|
| Danish gillnet fishery, North Sea | 1987-1998 | 0.147 | 0.0788 | Mean trend in FP indices for cod, plaice and sole; based on data in Marchal et al., (2002, Table 6) |
| Danish otter trawl fishery, North Sea | 1987-1998 | 0.08 | 0.04 | Mean trend in FP indices for cod and plaice; based on data in Marchal et al., (2002, Table 6) |
| Danish seine fishery, North Sea | 1987-1998 | 0.11 | 0.02 | Mean trend in FP indices for cod and plaice; based on data in Marchal et al., (2002, Table 6) |
| French hake (*Merluccius merluccius*, Merlucciidae) fixed net fishery | 1986-1997 | 0.06 | – | Mean rate of change in FP; Morizur and Carn (2000) |
| French sole (*Solea vulgaris*, Soleidae) fixed net fishery | 1986-1997 | 0.17 | – | Annual rate of change in FP; Morizur and Carn (2000) |
| French-Ivoirian-Senegalese yellowfin (*Thunnus albacares*, Scombridae) fishery, Eastern Atlantic | 1980-1990 | 0.1416 | 0.0334 | FP; based on data in Gascuel et al., (1993, Figure 5a) with lnFP=0.1416·Year-12, $r^2$=0.666**, df=9 |
| Spanish purse seine yellowfin fishery; Eastern Atlantic | 1980-1990 | 0.0636 | 0.0178 | FP; based on data in Gascuel et al., (1993, Figure 5b) with lnFP=0.0636·Year-5.746, $r^2$=0.586**, df=9 |
| Pacific Coast ground fish trawl fishery | 1981-1989 | 0.0460 | 0.0139 | Tornqvist chain of total factor productivity; based on data in Squires (1994, Table 3) with lnTFP=0.0460·Year-91.3, $r^2$=0.610*, df=7 |
| Dutch beam trawl fishery, North Sea | 1991-1998 | 0.05 | 0.0785 | Mean trend in FP indices for cod, plaice and sole; based on data in Marchal et al., (2002, Table 6) |
| Pacific Coast ground fish trawl fishery | 1982-1989 | 0.0279 | – | TFP; Squires (1994, Table 1) |
| French spider crab (*Maja squinado*, Majidae) fixed net fishery | 1992-1998 | 0.11 | – | Mean rate of increase; Morizur and Carn (2000) |
| Western rock lobster fishery, Australia | 1983-1989 | 0.165 | 0.0512 | Catch rate increase by period testing 4 technology factors for legal-size lobsters; Fernandez et al., (1997, Table 2) |
| Australian northern prawn (*Penaeus esculentus*, *P. semisulcatus*, Penaeidae) fishery | 1988-1992 | 0.0235 | 0.00230 | Annual estimates of FP; based on data in Robins et al., (1998, Figure 3), with lnFP=0.02352·Year-46.75, $r^2$=0.972**, df=3 |
| Western rock lobster fishery, Australia | 1989-1992 | 0.105 | 0.0298 | Catch rate increase by period testing 4 technology factors for legal-size lobsters; Fernandez et al., (1997, Table 2) |
| Brixham demersal trawl fishery, England | 1965-1968 | 0.201 | – | Annual change in FP; Houghton (1977) |
| Eastern king prawn (*Melicertus plebejus*,) (all depths) trawl fishery, Qld, Australia | 1988-2004 | 0.0225 | 0.00154 | Annual change in FP; based on O'Neill and Leigh (2007, Table 2) with lnFP=0.02249·Year-44.73, $r^2$=0.934**, df=15 |
| Eastern king prawn (shallow) trawl fishery, Queensland, Australia | 1988-2004 | 0.0245 | 0.00130 | Annual change in FP; based on O'Neill and Leigh (2007, Table 2) with lnFP=0.02452·Year-48.75, $r^2$=0.960**, df=15 |

| | | | | |
|---|---|---|---|---|
| Eastern king prawn (deep) trawl fishery, Queensland, Australia | 1988-2004 | 0.0195 | 0.00261 | Annual change FP; based on O’Neill and Leigh (2007, Table 2) with lnFP=0.01948·Year-38.79, $r^2$=0.789**, df=15 |
| Red spot king prawn (*M. longistylus*, Penaeidae) trawl fishery, Australia | 1988-2004 | 0.00583 | 0.00202 | Annual change FP; based on O’Neill and Leigh (2007, Table 2) with lnFP=0.005831·Year-11.55, $r^2$=0.356*, df=15 |
| North Queensland tiger prawn (*Penaeus esculentus*, Penaeidae) trawl fishery, Austr. | 1988-2004 | 0.00715 | 0.000928 | Annual change FP; based on O’Neill and Leigh (2007, Table 2) with lnFP=0.007154·Year-14.28, $r^2$=0.798**, df=15 |
| Southern Queensland tiger prawn trawl fishery, Australia | 1988-2004 | 0.00703 | 0.00185 | Annual change FP; based on O’Neill and Leigh (2007, Table 2) with lnFP=0.007034·Year-13.98, $r^2$=0.491**, df=15 |
| Endeavour prawn trawl fishery, Australia | 1988-2004 | 0.00957 | 0.00168 | Annual change FP; based on O’Neill and Leigh (2007, Table 2) with lnFP=0.009573·Year-19.08, $r^2$=0.685**, df=15 |
| Torres Strait tiger prawn trawl fishery | 1989-1999 | 0.01872 | – | FP increase; O’Neill et al., (2003, Table 3) |
| Saucer scallop (*Amusium balloti*, Pectinidae) trawl fishery, QLD, Australia | 1988-2004 | 0.0049 | 0.00138 | Annual change in FP; based on O’Neill and Leigh (2007, Table 2) with lnFP=0.004788·Year-9.515, $r^2$=0.444**, df=15 |