SC/68C/HIM/14

Sub-committees/working group name: HIM

An updated assessment of historical impact of setnet fisheries on Maui's dolphin

D.I. MacKenzie

Fisheries New Zealand

Tini a Tangaroa

An updated assessment of historical impact of setnet fisheries on Maui's dolphin

New Zealand Aquatic Environment and Biodiversity Report No.XXX

D.I. MacKenzie

ISSN 1176-9440 (print)
ISSN 1179-6480 (online)
ISBN XXXX (online)

March 2021

New Zealand Government

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-and-resources/publications
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

MacKenzie, D.I. (2020). An updated assessment of historical impact of setnet fisheries on Maui's dolphin. ***New Zealand Aquatic Environment and Biodiversity Report No. XX.*** **XX p.**

Previous assessments of the historical impact of setnet fisheries on Maui's dolphin have varied in their conclusions about the level of depletion of the population since 1970. A key component is determination of catch rates (proportion of population captured), that have been calculated from observed setnet fishing effort, and captures of Hector's dolphins, along the ECSI, particularly in Fisheries Statistical Areas 020 and 022. Calculation of a catch rate requires an estimate of the at risk population size, which previously have been based on abundance estimates calculated from boat-based surveys that estimated <2000 Hector's dolphins along ECSI (Dawson et al. 2004). Abundance estimates from aerial surveys conducted in 2012 and 2013 were 2-2.5 times greater for the same areas (MacKenzie and Clement 2016). Higher abundance estimates indicate that catch rates will be lower than previously assumed. This research evaluates how the updated abundance estimates affect our understanding of historical impacts of setnet fisheries on Maui's dolphin.

Based on observed setnet fishing effort during the 1998, 2000 and 2001 fishing seasons in Statistical Areas 020 and 022, an entanglement rate of 0.000238 (proportion of dolphins per m of setnet, per km^2) was calculated using abundance estimates from Davies et al. (2008). This reduced to 0.000078 or 0.000072 using abundance estimates of MacKenzie and Clement (2016), i.e., a decrease of approximately 67%. If the offshore strata are combined, while maintaining alongshore strata, estimated entanglement rates reduce by a further 10%.

Repeating the deterministic KRG8_1.5% analyses of Davies et al. (2008) with the updated abundance estimates changes their estimated catchability coefficient from 0.000150 to 0.000044-0.000048 (proportion of vulnerable dolphins captured per m of setnet, per nmi^2) depending on how the offshore strata used by MacKenzie and Clement (2016; 0-4, 4-12 and 12-20 nmi) are allocated to the strata used by Davies et al. (2008; 0-4 and 4-15 nmi). However, the estimated carrying capacity only changes from 227 to 199-201 Maui's dolphins due to the low level of overlap between setnet fishing effort and dolphin distribution assumed by Davies et al. (2008). Subsequent additional work has identified a possible error in the code used by Davies et al. (2008) that if confirmed would lead to a further reduction in the estimated carry capacity. Furthermore, it has been found that even if the catchability coefficient is set to 0 the population is projected to decline from 1970 to 2004, possibly due to the assumed age distribution not being at the equilibrium level implied by the population structure. Hence the apparent level of depletion is due to other sources besides set net fishery catch.

Slooten and Dawson (2010) provide insufficient details of their key assumptions and input values to enable the exact reproduction and verification of their results using a surplus production model, which suggested the Maui's dolphin population in 1970 was numbered in the 1000's. A decline of the magnitude they reported can be obtained assuming an entanglement rate of 0.000500 (proportion of dolphins captured per m of setnet, per km^2), where all setnet fishing effort and dolphins were assigned to the same offshore strata within each Statistical Area, and setnet fishing effort was constant (on average) from 1970-1982. The corresponding simulations suggest that 100's of dolphins were captured each year during the 1970s, and that the Maui's dolphin population size in 2009 was at <10% of the 1970 level. Repeating the simulations with entanglement rates that were rescaled by a factor of 0.15 to 0.35 (to be comparable to observed recalculated values) resulted in lower population sizes for 1970, and 2009 population sizes that were at a level that were generally >50% of the 1970 level (depending on simulation scenario).

Simulation scenarios were also conducted were setnet fishing effort was assumed to linearly increase between 1970 and 1982 (as per Davies et al. 2008), within an entanglement rate of 0.000078 (i.e., using the updated ECSI abundance estimates). Maximum population growth rate was assumed to have the same distribution as that used by Slooten and Dawson (2010), or a slightly higher distribution based on

Roberts et al. (2019). Both scenarios give similar results, suggesting the Maui's dolphin population size in 2009 was at >75% (approximately) of the 1970 level.

In summary, how the updated estimates of ECSI Hector's dolphin abundance affect our understanding of the historical impact of setnet fishing effort on Maui's dolphin depends on assumptions of dolphin and fishing effort overlap, and level of capture rates. Davies et al. (2008) assumed little overlap hence the population status in 2004 changed little (0.59 vs 0.67 of carrying capacity) despite their catchability coefficient decreasing by over two-thirds when the updated abundance estimates are incorporated. Whereas, Slooten and Dawson (2010) assumed a much greater level of overlap and the 2009 population size changed from being at <10%, to approximately 50%, of the 1970 value for a similar proportional decline in entanglement rate (i.e., two-thirds). Using the entanglement rates calculated here, and assuming setnet fishing effort increased from 1970-1982, the 2009 population size was found by simulation to be at >75% of the 1970 value.

The updated ECSI Hector's dolphin abundance estimates will also have repercussions on our understanding of the historical impact of setnet fishing effort on Hector's dolphins.

1. INTRODUCTION

Previous assessments of the historical impact of setnet fisheries on Maui's dolphin have varied in their conclusions regarding the level of depletion of the population since 1970 that may be due to setnet fisheries (Martien, et al., 1999; Burkhart & Slooten, 2003; Slooten, 2007; Davies, et al., 2008; Slooten & Dawson, 2010) (Table 1). Each of these previous assessments have used similar methods to back-calculate Maui's dolphin abundance in 1970, but with different data sets and assumptions about historical fishing effort. Key to these assessments has been the determination of catch rates (proportion of individuals in population caught per unit of fishing effort) that have been derived from captures of Hector's dolphin in observed sets along the east coast South Island (ECSI), particularly in Fisheries Statistical Areas 020 and 022.

Table 1: Summary of previous assessments of historical impacts of setnet fishing on Maui's dolphin. $\hat{N}_{1970}$ is the estimated 1970 population size, and is the estimated population size used (with year of data collection). Note these values are point estimates and each may involve substantial uncertainty.

Source	$\hat{N}_{1970}$	$\hat{N}$ (year)	Notes
Martien, et al. (1999)	437, 448, 524	140 (1985)	λ_{max} = 1.049, 1.044, 1.018, respectively.
Burkhart and Slooten (2003)	577	146 (1985)	Sum of population units 1, 2, 3 and 4. λ_{max} = 1.023.
Slooten (2007)	1729	111 (2004)	λ_{max} random value between 1.018 and 1.049 (uniform distribution).
Davies et al. (2008)	227, 254, 208	134 (2004)	Maximum annual growth rate (as implemented in their model) = 2.0%, 1.5%, 0.8%, respectively.
Slooten and Dawson (2010)	2200	111 (2004)	Approx. median from their Fig. 2. λ_{max} random value between 1.018 and 1.049 (uniform distribution).

A key component for calculating a catch rate is the number of individuals at risk of capture within the area of the fishing effort (e.g., local abundance), and the previous catch rates used in published assessments have been based on Hector's dolphin abundance estimates from boat-based surveys conducted in the summers of 1998-2000 , which estimated there were less than < 2000 individuals along the ECSI within 4 nmi of the coast (e.g., Dawson et al. 2004). Aerial line-transect surveys for Hector's dolphin were conducted within 20 nmi of the ECSI coast in the 2012/2013 summer, and winter 2013, to estimate their abundance and distribution. The resulting summer-time estimate was circa 9500 dolphins within the entire survey area (MacKenzie and Clement 2016), with approximately half of the dolphins estimated to be within 4 nmi. The summer-time abundance estimates from MacKenzie and Clement (2016) are therefore approximately 2-2.5 times greater than the previous estimates for the 0-4 nmi coastal zone. This is highly unlikely to be the result of natural population growth during a 13-15 year time span, but could be the result of fundamental differences in using boat-based verses aerial platforms for estimating Hector's dolphin abundance, which also occurred in abundance surveys for the west coast South Island (WCSI) population (Slooten, et al., 2006)

The result of the more recent abundance estimates would suggest that the local population size at the time of the observed setnet fishing was higher than what pervious impact assessments have assumed, and that the setnet catch rate was lower than previously calculated. The purpose of this work is to re-evaluate the potential historical impact of setnet fisheries on the Maui's dolphin population in light of a greater abundance estimate for ECSI Hector's dolphins, focusing particularly on the assessments of Davies et al. (2008) and Slooten et al. (2010) as they are the most recent published assessments and represent the extreme cases.

2. METHODS

2.1 Entanglement rate calculation from observed catch.

Baird and Bradford (2000) present results for observed setnet fishing effort in the 1997/98 fishing year, for Statistical Areas 018, 020 and 022. They quantify fishing effort in terms of number of sets (rather than net length), and estimated a total of 16 dolphins were caught in areas 020 and 022. Their catch rate of 0.037 has units of dolphins caught per set.

Davies et al. (2008) provides details on the number of dolphin captures in observed setnet fishing events in Statistical Area 020 and 022, for the 1997/98, 1999/2000 and 2000/2001 fishing year. They do not provide a numerical summary of the total length of setnet fishing effort observed, but it can be approximated from their Figure 9 (and also Figure 22). In combination with abundance estimates ($\hat{N}$), these values can be used to calculate an entanglement rate as:

$$\hat{M} = \frac{\sum_{j=1}^{n} C_j}{\sum_{j=1}^{n} \frac{E_j^* \hat{N}_j}{A_j}}$$

where j denotes spatial or temporal strata with observed fishing effort (E_j^*), and C_j is the observed number of captures. This calculation the entanglement rate is constant across space and time, and is derived from considered the total number of observed captures ($\sum_{j=1}^{n} C_j$), is the sum of the strata-specific captures ($C_j = \frac{ME_j^* \hat{N}_j}{A_j}$). Comparing the calculated entanglement rate using older and updated abundance estimates will give some indication of how our understand of the historical impact of setnet fishing on Maui's dolphin may change. For the purpose of the calculation, abundance estimates from Davies et al. (2008) and MacKenzie and Clement (2016) were used. Both groups defined a 0-4 nmi offshore strata, with Davies et al. (2008) defining a single 4-15nmi while MacKenzie and Clement (2016) used 4-12 nmi and 12-20 nmi offshore strata. A simple approach has been used to resolve this issue where either the abundance estimates for the 4-12 nmi strata were assigned to the 4-15 nmi strata (MCa), or the estimated abundance from the 4-12 and 12-20 nmi strata was assigned to the 4-15 nmi strata (MC_a and MC_b in Table 2, respectively). This approach will provide an indication of the results sensitivity to the assumed offshore abundance.

For the purpose of an entanglement rate calculation, the offshore strata could be considered as separate strata, or combined into a single stratum to recognise that offshore movement is possible so individuals that are within the 0-4 stratum are potentially at risk of capture from fishing effort further offshore that is still within the distribution of Hector's dolphin. Note that using separate offshore strata does not assume no-movement of dolphins, but abundance estimates represent the average number of dolphins are risk with that area.

Table 2: Summary of observed captures, observed setnet fishing effort, stratum area and abundance estimates given by Davies et al. (2008) and MacKenzie and Clements (2016; MC_a = 4-12nmi attributed to 4-15 nmi; MC_b 4-20 attributed to 4-15 nmi).

Year	Stat Area	Sanctuary	Offshore	Captures	Observed Effort	Area (km^2)	Abundance source		
							Davies	MC_a	MC_b
1998	020	Outside	0-4	0	13.25	1083.54	138	469	469
			4-15	1	44.75	2722.93	37	336	634
		Inside	0-4	0	0.00	495.93	91	969	969
			4-15	0	7.25	1146.51	20	1030	1584
	022	Inside	0-4	0	0.00	1072.53	795	1704	1704
			4-15	2	33.25	2790.84	275	1034	1034
		Outside	0-4	4	68.25	1845.29	392	658	658

			4-15	0	83.75	4743.48	229	1004	1004
2000	020	Outside	0-4	0	4.63	1083.54	138	469	469
			4-15	0	0	2722.93	37	336	336
		Inside	0-4	0	0	495.93	91	969	969
			4-15	0	1.63	1146.51	20	1030	1584
	022	Outside	0-4	1	19.13	1845.29	392	658	658
			4-15	0	53.00	4743.48	229	1004	1004
2001	022	Outside	0-4	0	2.17	1845.29	392	658	658
			4-15	0	35.58	4743.48	229	1004	1004

2.2 Reanalysis of Davies et al. (2008)

Davies et al. (2008) took a two-step approach in their assessment where they first conducted an integrated modelling analysis of different data sources (e.g., observed catch, absolute and relative abundance estimates, age and sexual maturity data from caught and beach-cast individuals) to estimate parameters of a population model which included setnet fishing impacts. They estimate a ‘catchability coefficient’ (q) that is on the scale of proportion of vulnerable dolphins per metre of setnet, per square nautical mile (nmi^2). That is, the expected catch in area j (C_j) would be:

$$C_j = q\frac{N_{v,j}E_j}{A_j}$$

where N_v is the number of vulnerable dolphins, E is the metres of setnet fishing effort in the area, and A is the size of the area measure in nmi^2. Note that the number of vulnerable dolphins will be less than the total number of dolphins in an area as the model allowed for an age-specific vulnerability (younger dolphins estimated to be more vulnerable than older individuals). The value for q will therefore be higher when using the number of vulnerable dolphins compared to using the total number of dolphins in an area.

Their second step involved using the estimated population model parameters based on observations from statistical areas 020 and 022, to back-calculate Hector’s and Maui’s dolphin abundance to 1970 (which was regarded as pre-setnet carrying capacity, K) for each of the four sub-population areas. The number of captures each year was calculated from assumed and recorded annual setnet fishing effort in each area, in combination with the estimated value of q. Their modelling then projected the population forward 200 years under different possible scenarios for managing fishing effort. See Davies et al. (2008) for more details. Davies et al. (2008) assumed a Maui’s dolphin population size of 134 individuals in 2004.

The source code used by Davies et al. (2008) was supplied by New Zealand’s National Institute for Water and Atmosphere (NIWA) that enabled a direct re-running of their assessment, but using the updated abundance estimates for statistical areas 020 and 022 (Table 3). Note that the areas defined by MacKenzie and Clement (2016) do not match exactly with those used by Davies et al. (2008), but the along-shore definitions are very similar and will have relatively little impact on the overall results.

The specific model that has been used in the reanalysis was denoted as KRG8_1.5% by Davies et al. (2008), which considered all 8 dolphin captures be regarded as setnet-related deaths, and an approximate maximum population growth rate of $\lambda_{max} = 1.033$. This a mid-range value for population growth rate according to Slooten and Dawson (2010), although at the lower end according to Roberts et al. (2019).

Table 3: Summer abundance estimates for each strata from Davies et al. (2008), and as estimated by MacKenzie and Clement (2016) for summer and winter. Only the point estimates have been used.

				Summer			Winter	
S.A.	Sanc.	Offshore	MC Strata	Davies	MC_a	MC_b	MC_a	MC_b

020	Outside	0-4	Pegasus Bay	138	469	469	67	67
020	Outside	4-15	Pegasus Bay	37	336	634	553	942
020	Inside	0-4	Banks Pen. Nth.	91	969	969	354	354
020	Inside	4-15	Banks Pen. Nth.	20	1030	1584	502	986
022	Inside	0-4	Banks Pen. Sth.	795	1704	1704	449	449
022	Inside	4-15	Banks Pen. Sth.	275	1034	1034	256	347
022	Outside	0-4	Timaru	392	658	658	224	224
022	Outside	4-15	Timaru	229	1004	1004	1765	2817

Addendum on Davies et al. (2008)

Following the initial presentation of updated results using the Davies et al. (2008) model and code, questions were raised regarding that apparent lack of sensitivity of K to changes in the catchability coefficient (q), and the implied level of depletion of the population. A closer inspection of the model code was conducted to confirm how K was calculated and should be interpreted. Additional results were also extracted from the modelling procedure to provide further context for the results, including the calculated level of catch in each year using the original and updated value for q, and for the scenario when $q \approx 0$.

2.3 Approximation of Slooten and Dawson (2010)

Slooten and Dawson (2010) applied a surplus production model (Eqn. 1) to back-calculate the abundance of Hector's and Maui's dolphins in 16 defined areas in 1970; an approach they have previously along with other co-authors (Martien, et al., 1999; Burkhart & Slooten, 2003; Slooten, 2007). N_t is abundance at time t, λ_{max} is maximum annual growth rate, K is 1970 abundance and c_t is the proportion of the local dolphin population caught (and presumed killed) by entanglement in setnets in year t (note they use C_t to denote this parameter).

$$N_{t+1} = N_t[1 + (\lambda_{max} - 1)\left(1 - \frac{N_t}{K}\right) - N_t c_t \quad (1)$$

The proportion of dolphins caught was a function of area-standardised fishing effort:

$$c_t = M\frac{E_t}{A},$$

where M is the entanglement rate; proportion of dolphins caught per metre of setnet, per km^2. Note that M is similar to the catchability coefficient of Davies et al. (2008) (q), although the latter applies to vulnerable dolphins rather than the entire dolphin population. Davies et al. (2008) also measured area in terms of nmi^2 while Slooten and Dawson (2010) used km^2. Therefore the two quantities are not directly comparable.

While Slooten and Dawson (2010) provided a general description of their approach for determining abundance in 1970, there are a number of critical aspects they neglect to detail (or provide through supplemental material) that would enable an independent assessment or review of their work. Middleton et al. (2007) noted the same issue with the earlier impact assessment of Slooten (2007). In particular, Slooten and Dawson (2010) do not supply the value for M that they used in their modelling. The do cite a "catch rate" of 0.037 estimated by (Baird & Bradford, 2000) from observed setnet fishing effort in the 1997/98 fishing season, however this catch rate is not equal to M, and has units of dolphins caught per gillnet set. Conversion of the catch rate to an entanglement rate requires an estimate of abundance for the area, the size of the area, and average length of setnet per set. None of these details are provided by Slooten and Dawson (2010), and they do not clarify that the catch rate cited and the entanglement rate used are two related, but different, quantities.

Pre-1983, setnet fishing effort was not recorded by fishers and hence it had to be approximate by both Davies et al. (2008) and Slooten and Dawson (2010). Monofilament setnets were gradually adopted by fishers in New Zealand waters during the 1970's, hence Davies et al. (2008) assumed that setnet effort gradually increased during the 1970's within the level of effort in 1970 approximated based on the level of take reported by fishers. For the WCNI (i.e., Maui's dolphin) this meant effort in 1970 was set at 15% of the 1983-1985 average, then linearly increased. Furthermore, Davies et al. (2008) only used effort for the 'other' target species (primarily sharks; excludes estuarine and deepwater target species), whose methods were considered to most likely pose a threat to Hector's and Maui's dolphin. In contrast, from the description of their methods, Slooten and Dawson (2010) assumed that mean effort during the 1970's was at the same level as the 1983-1985 average (i.e., did not gradually increase), and used the recorded effort for all target species in WCNI. This leads to a greater level of assumed fishing effort.

All fishing effort data was sourced from Davies et al. (2008), where the first half of the 2006/7 fishing year is the final entry. In order to project through to a 2009 (as per Slooten and Dawson, 2010), the recorded effort of 2006/7 was doubled, and the setnet fishing effort in 2007/8 was set equal to the previous year. Setnet fishing effort for the 1988/89 fishing year was not recorded in Davies et al. (2008), hence an intermediate value was used based on the preceding and subsequent values in the time series. This differs from the assumption made by Davies et al. (2008) who set the value equal to the 1989/90 fishing effort.

To reassess the historical impact of setnet fishing on Maui's dolphin given the more recent Hector's dolphin abundance estimates, it was necessary to approximate the exact methods and input values used by Slooten and Dawson (2010) given the lack of detail provided in the paper. Some simplifications were applied that are unlikely to impact upon the relative effect of the updated abundance estimate on the historical impact. In particular, no movement between areas was assumed, and no annual variation in pre-1983 fishing effort.

The surplus production model (Eqn 1) was applied to each of the four Fisheries Statistical Areas that encompass the known Maui's dolphin distribution, excluding the Manukau and Kaipara Harbours (040, 041, 042 and 045). It is unclear what Slooten and Dawson (2010) assumed about what proportion of dolphins and fishing effort was within 0-4 and 4-15 nmi, so here the two offshore areas have been combined into a single area. It is noted that Davies et al. (2008) assumed the proportion of effort within 4 nmi was very low for areas 041, 042 and 045 (based on log-book returns; Table 4). The abundance assumed in each Statistical Area is given in Table 4, which is the 111 estimated by Slooten et al. (2006), plus 5 animals in Statistical Area 040 to allow for a potentially small number of animals in this region. Slooten and Dawson (2010) do not document exactly what numbers they used, or the year in which the estimated abundance was applied. The abundance estimates were applied to 2004 as that was the year of surveying.

Table 4: Area within 0-15 nmi of the coast for each Fisheries Statistical Area, and the proportion of setnet fishing effort within 0-4nmi assumed by Davies et al. (2008). The 2004 Maui dolphin abundance values assumed for this approximation is also given.

Statistical Area	Area (km^2)	Prop. Effort in 0-4nmi	2004 Abundance
040	5,519.326	0.57	5
041	6,502.061	0.06	18
042	4,525.513	0.00	74
045	4,248.377	0.00	19

To reassess potential historical impacts on Maui's dolphin based on the methods of Slooten and Dawson (2010), a calibration study was first conducted to identify what level of entanglement would be required to produce the substantial decline they postulated. From Figure 2 of Slooten and Dawson (2010), their median value for the population size of Maui's dolphin across the 4 statistical areas appears to be about 2200 individuals, with no information provided on the back-calculated number of individuals in each of the 4 areas. Therefore, an optimization algorithm was used to find the entanglement rate and proportion of the Maui's population in each statistical area in 1970 that would result in the 2004 abundance levels (Table 4), based on the above assumptions about fishing effort. Namely, the values of interest where iteratively changed until the surplus production model would predict 2004 population sizes that were 'close' to the assumed values, starting from a combined 1970 population size of 2200. 'Close' was determined by minimising the likelihood of normally-distributed deviates between the predicted and assumed 2004 abundance values. As a numerical optimization procedure was used, 20 random sets of starting values for the parameters of interest to check for convergence. The median λ_{max} value considered by Slooten and Dawson (2010) was used in the calibration study (i.e., 1.033).

Once the potential entanglement rate was determined, a simulation study was conducted to verify that the results of Slooten and Dawson (2010) could be reproduced (approximately). For each simulated set of data, a random value for the 2004 population size was drawn from a log-normal distribution with mean = 116 and CV = 0.44. The number of dolphins in each Statistical Area was then assigned in proportion to the assumed abundance values (Table 4). The 1970 population sizes were then determined by numerical optimization using the surplus production model and assumed fishing effort over time. The optimization was similar to the calibration study, except in the simulations the entanglement rate is known and we are solving for the 1970 population size. The 1970 population size was determined for each statistical area independently, and then summed. 5000 simulated sets of data with the population trajectories over time, and number of setnet captures, recorded. This scenario is named *M_SD*.

Simulation scenarios were also conducted where the entanglement rate was rescaled to be 0.35, 0.30, 0.25, 0.20 or 0.15 of the value used in the verification simulation to reassess the potential historical impact of the higher abundance estimates for ECSI. These scalars were selected based on the results of rerunning the Davies et al. (2008) analysis, and also by recalculation of the entanglement rates from the 1998, 2000 and 2001 observed setnet fishing effort. These scenarios are named *M_SD_35*, *M_SD_30*, *M_SD_25*, *M_SD_20* and *M_SD_15*, respectively.

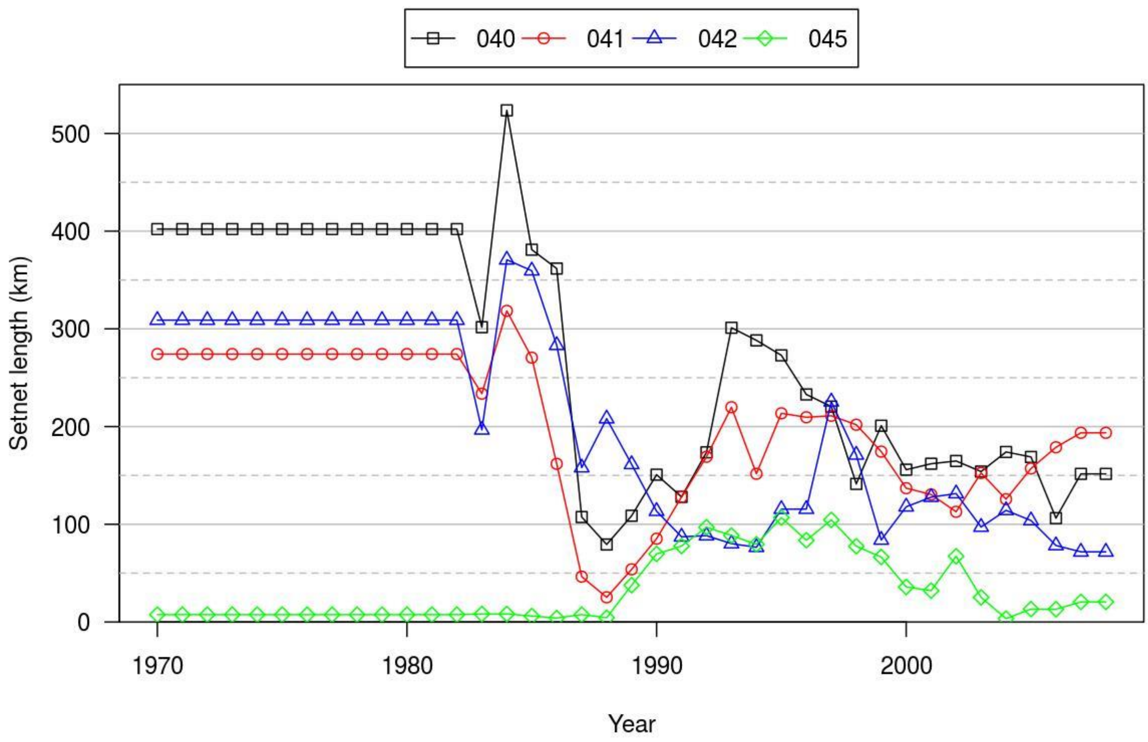

Figure 1: Total setnet fishing effort in each statistical area used to approximate results of Slooten and Dawson (2010). Pre-1983 effort was set at the mean of the 1983-1985 period. 1989 effort was set at an intermediate value between 1988 and 1990 effort.

Two final simulation scenarios were also considered. In both cases fishing effort was assumed to gradually increase during the 1970's and early 1980's (Figure 2), and the entanglement rate set at 0.000078 (per metre of setnet, per km^2). In the first case, λ_{max} was assumed to be a random value from a uniform distribution between 1.018 and 1.049 (as above, and Slooten and Dawson 2010), and in the second case a uniform distribution with limits of 1.025 and 1.069 was used. These latter values are derived from the 2.5th and 97.5th percentiles of the r_{max} values used by Roberts et al. (2019) for Hector's and Maui's dolphin, obtained from allometric modelling of r_{max} across vertebrate species (see Appendix 2 of Roberts et al. (2019) for details). These scenarios are named *INCR_78* and *INCR_78_R*.

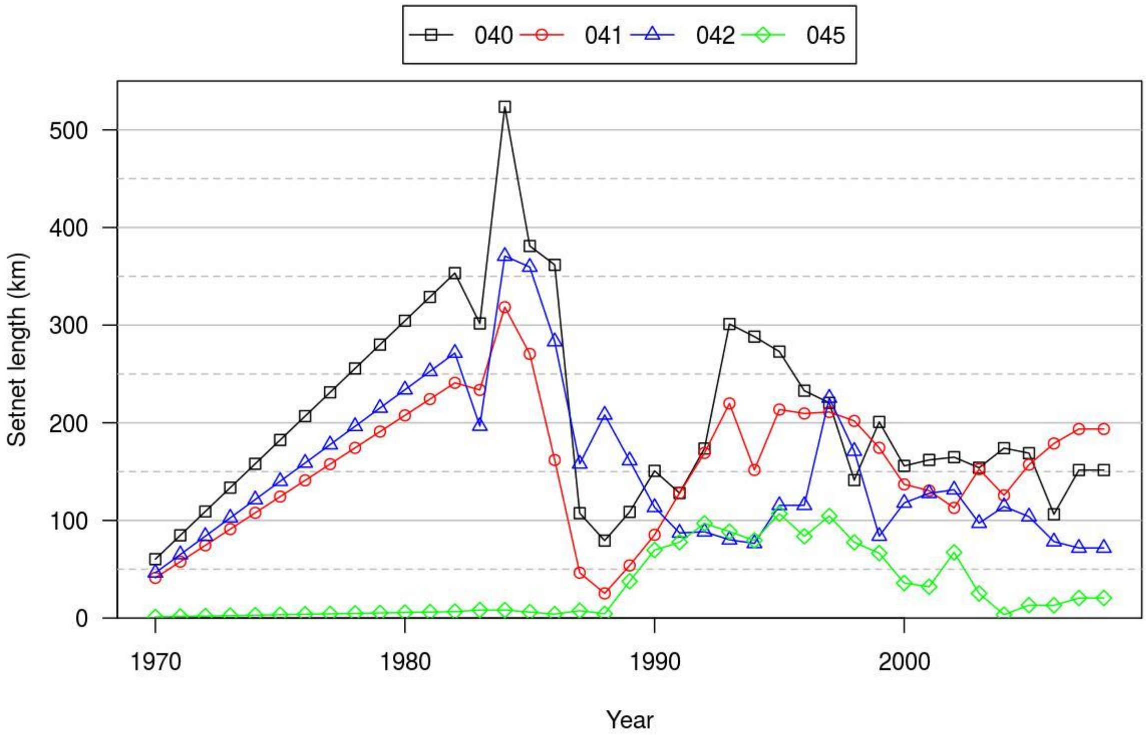

Figure 2: Total setnet fishing effort in each statistical area assuming effort gradually increased during the 1970s. 1989 effort was set at an intermediate value between 1988 and 1990 effort.

All R code and input values used in this assessment are included in the Appendix. Files are available upon request.

3. RESULTS

3.1 Entanglement rate calculation from observed catch

When maintaining the 0-4 nmi and 4-15 nmi offshore zones as separate strata (in addition to separate along-shore strata), the values presented in Table 2 result in a calculated entanglement rate of 0.000238 (with units proportion of dolphin population captured per m of setnet, per km^2) using the abundance estimates of Davies et al. (2008). Incorporation of the updated abundance estimates from MacKenzie and Clement (2016) produces an estimated entanglement rate of 0.000078 when only the estimates in the 4-12 nmi strata are assigned to the 4-15 strata, and 0.000072 when the estimates from the 4-12 and 12-20 nmi strata are assigned.

Combining the offshore zones into a single strata to assume that animals in each strata are also at risk to setnet fishing effort in the other zone results in an entanglement rate estimate of 0.000214, 0.000070 and 0.000066 when using abundance estimates of Davies et al. (2008) or MacKenzie and Clement (2016).

That is, the updated abundance estimates produce an entanglement rate that is approximately one-third of the rate calculated using older abundance estimates (with either combination of zones), and combining the offshore zones produces an estimated entanglement rate that is about 10% lower than maintaining separate offshore zones.

3.2 Reanalysis of Davies et al. (2008)

Using the updated abundance estimates from MacKenzie and Clement (2016) in the Davies et al. (2008) analysis of the Banks Peninsula population model (scenario KRG8_1.5%) reduces the estimate of q from 0.000150 to 0.000048 when using the 4-12 strata of MacKenzie and Clement (2016) for the 4-15 strata of Davies et al. (2008), and 0.000044 if combining the 4-12 and 12-20 strata (units of q are proportion of dolphins, per m of setnet, per nmi^2). That is, the catchability coefficient is approximately a third of its previous value when using the updated abundance estimates for ECSI Hector's dolphins. The Theta and K parameters (Table 5) would also be expected to change given the updated abundance estimate, while all other values are very similar as they are primarily informed by other data sources in the model.

Applying these results and the deterministic population projection model to the WCNI Maui's population, carrying capacity is estimated to be 201 when q = 0.000048 or 199 if q = 0.000044. This is slightly less than Davies et al. (2008) estimate of 227 dolphins. Therefore, using the previous ECSI abundance estimates Davies et al. (2008) results suggest the 2004 Maui's dolphin population was at 59% of carry capacity (using deterministic model KRG8_1.5%), while the updated ECSI abundance estimates suggest the population was at 67% of carrying capacity in 2004.

Table 5: Estimates for MPD run of Banks Peninsula population model (KRG8_1.5%), with abundance values from Davies et al. (2008), and MacKenzie and Clement (2016; MC_a = 4-12nmi attributed to 4-15 nmi; MC_b 4-20 attributed to 4-15 nmi).

	Abundance source		
	Davies	MC_a	MC_b
q	0.000150	0.000048	0.000044
Theta_020_o	0.12	0.12	0.14
Theta_020_s	0.06	0.29	0.33
Theta_022_s	0.43	0.35	0.32
Theta_022_o	0.39	0.24	0.22
K	2118	5480	6142
R0	0.25	0.25	0.25
Sig1	1.87	1.91	1.91
Sig2	4.94	4.82	4.82
PSI	0.08	0.08	0.08
S_L	2.78	2.86	2.85
S_R	1.5	1.5	1.5
A1	1.27	1.27	1.27
A2	17.57	17.63	17.64
Amax	0.95	0.95	0.95

A_50	7.16	7.13	7.13
Ato95	2.73	2.72	2.72

Addendum on Davies et al. (2008)

An inspection of the model code used by Davies et al. (2008) revealed a possible inconsistency in how *K* is determined from the projection model and assumed abundance of Maui dolphin in 2004. *K* is defined as the population size in 1970, and an iterative procedure is used to determine the value of *K* such that the projected population size in 2004 (N^*_{2004}) matches the assumed value that was derived from published abundance estimates (N_{2004}). Davies et al. (2008) used $N_{2004} = 134$, which was the total population size for the Maui dolphin (i.e., west coast North Island) across the 4 statistical areas and two distance offshore strata (0-4 nmi and 4-15 nmi). It is not explicitly stated, but it is assumed that this also includes any calves (age class 0) being a total population size.

However, in the model code only the projected population sizes in the 0-4 nmi strata are used to calculate N^*_{2004}, and furthermore N^*_{2004} excludes the 0 age class animals. The relevant lines of code are 519-526 in file `WCNIprog_strat.for` and 1128-1131 in file `functions.for`. The inconsistency is demonstrated in Figure 1 where the trajectory of different sub-groups of the projected population are presented, with the assumed value of $N_{2004} = 134$ indicated. Given that N_{2004} includes animals in the 4-15 nmi strata, the calibration appears to be incorrect, with the consequence being that the inferred value for *K* is too high. Modifying the code such that the calculation of N^*_{2004} includes both offshore distance strata, results in the population trajectories given in Figure 4 and Figure 5, depending on whether N_{2004} is presumed to include 0 age class animals or not.

Assuming that N_{2004} does not include calves, using the same catchability coefficient as Davies et al. (2008) yields a value for *K* of 188, and 167 using the updated estimates for *q*. Interestingly, setting *q* = 0 gives *K* = 158, and the population is projected to decline even in the absence of set net fisheries mortality (Table 6, Figure 6 and Figure 7), which may imply the assumed age-structure population structure is not at equilibrium and the decline is the consequence of the population heading to the equilibrium state. Therefore, the decline in the projected population size with set net fisheries mortality should not be presumed to only being due to fishing. Figure 8 presents the expected catch of Maui dolphins under the three scenarios for *q*, noting the calculated bycatch is always low even using the original value for *q*.

Table 6: Inferred value for carrying capacity *K* for three different catchability coefficients, using population projection model assuming abundance estimates do not include calves of the year (0 age class animals). The value for *K* (which is also population size in 1970) and status of the population in 2004 is given. Total abundance (including calves) in 2004 was estimated to be 147 for all scenarios.

q	*K*	Status 2004
Original	188	0.81
Updated	167	0.88
Zero	158	0.94

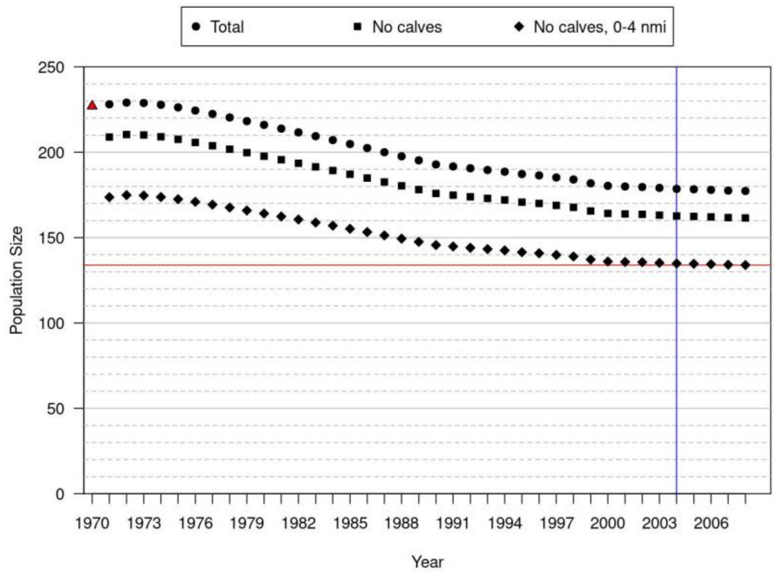

Figure 3: Projected trajectories for sub-groups of the population using the original model code of Davies et al. (2008). The population size for the total Maui dolphin population is given (i.e., both offshore strata and calves), as is the size of the population excluding calves, and excluding calves and only within the 0-4 nmi offshore strata. The 2004 abundance estimate of 134 is indicated.

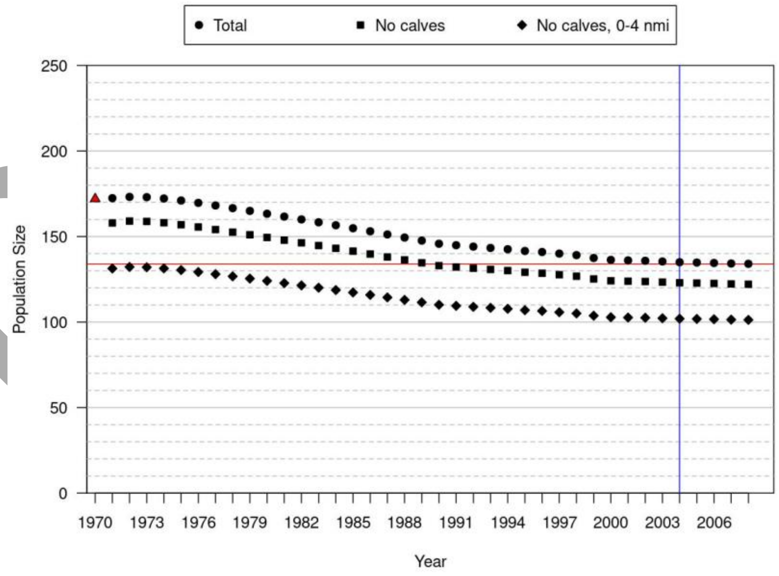

Figure 4: Projected trajectories for sub-groups of the population using modified model code where N^{*}_{2004} was defined to include calves and both offshore strata. The population size for the total Maui dolphin population is given (i.e., both offshore strata and calves), as is the size of the population excluding calves, and excluding calves and only within the 0-4 nmi offshore strata. The 2004 abundance estimate of 134 is indicated.

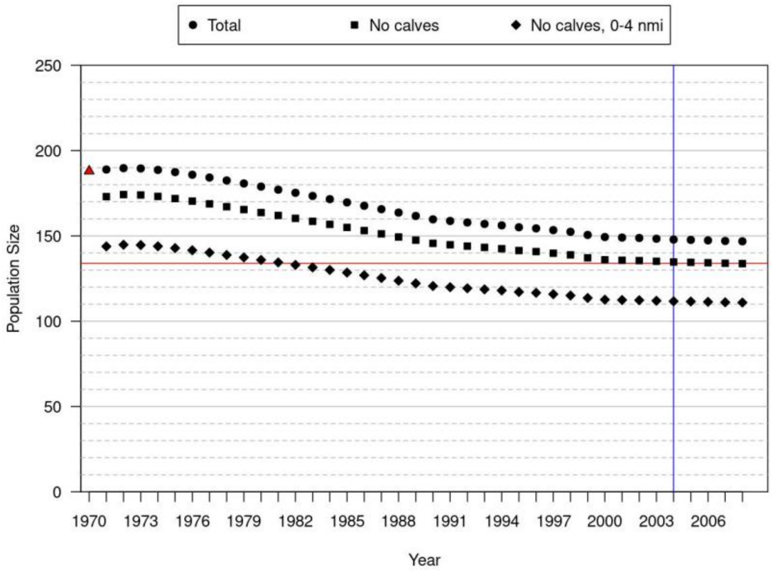

Figure 5: Projected trajectories for sub-groups of the population using modified model code where N^*_{2004} was defined to exclude calves, but include both offshore strata. The population size for the total Maui dolphin population is given (i.e., both offshore strata and calves), as is the size of the population excluding calves, and excluding calves and only within the 0-4 nmi offshore strata. The 2004 abundance estimate of 134 is indicated.

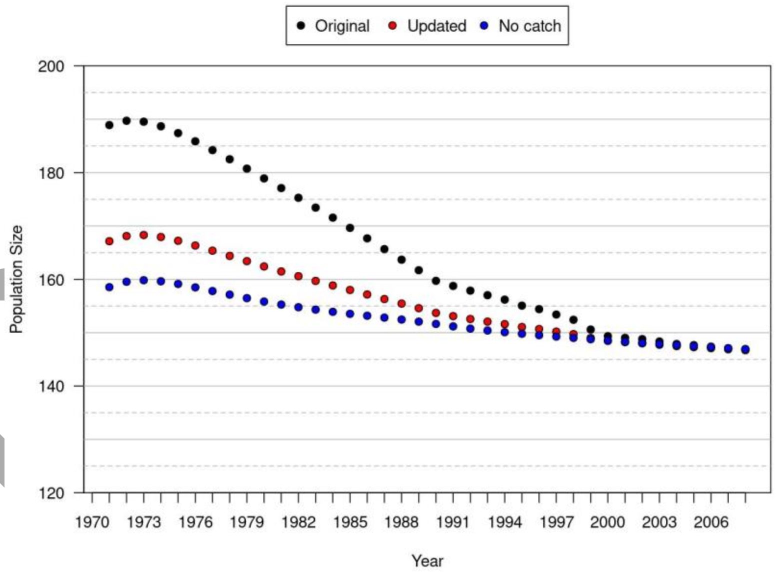

Figure 6: Projected total population size under three scenarios for the catchability coefficient, where N^*_{2004} was defined to include calves and both offshore strata.

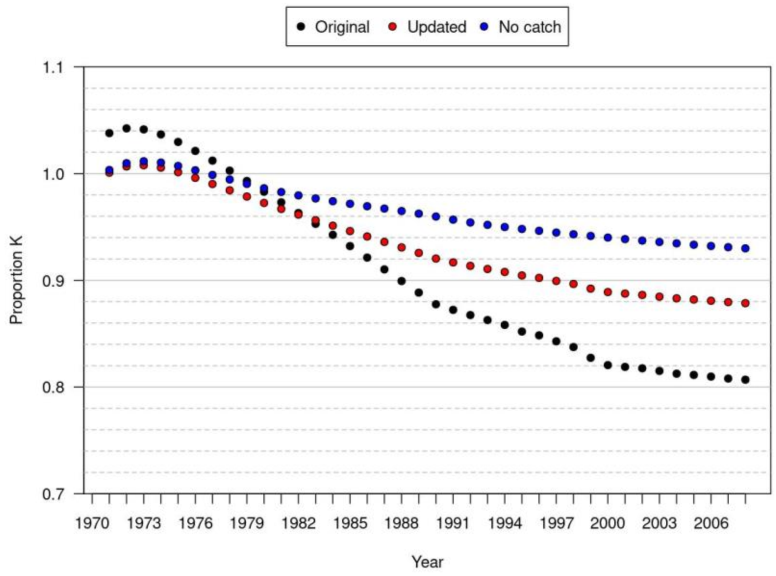

Figure 7: Projected total population size expressed as proportion of K under three scenarios for the catchability coefficient, where N^*_{2004} was defined to include calves and both offshore strata.

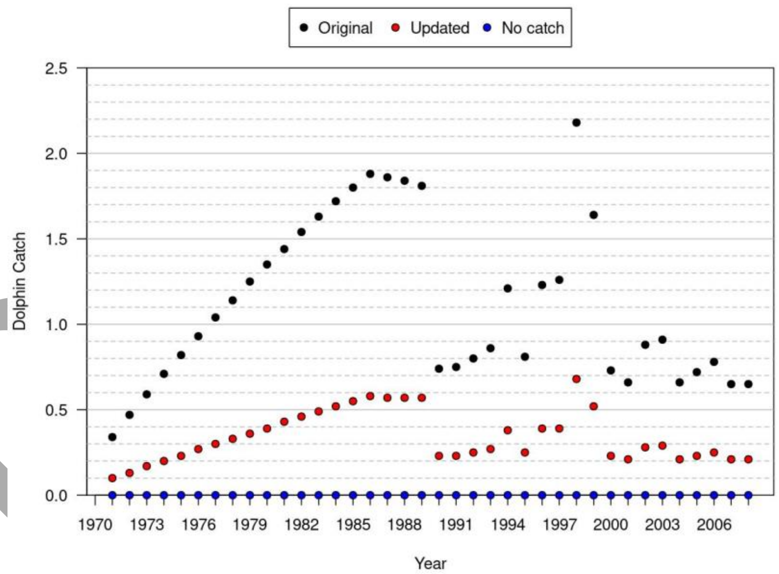

Figure 8: Estimated annual catch of Maui dolphin in set net fisheries under three scenarios for the catchability coefficient, where N^*_{2004} was defined to include calves and both offshore strata.

3.3 Approximation of Slooten and Dawson (2010)

The calibration study suggests that an entanglement rate of M_{SD}= 0.000500 (proportion of dolphins, per m of setnet, per km^2) is required to produce a similar decline as that reported by Slooten and Dawson (2010), assuming λ_{max} = 1.033 and fishing effort as per Figure 1. The calibrated proportion of the 1970 population in Statistical Areas 040, 041, 042 and 045 was 0.36, 0.10, 0.52 and 0.01, respectively (although simulation results suggest proportion of dolphins that were in 040 and 041 was more similar).

Table 7 presents the median, mean and CV of the 5000 simulated population sizes for Maui's dolphin in 1970, where the entanglement rate (ER) scalar is the multiplier for M_{SD}. Using the full value of M_{SD} produces results that are similar to those presented by Slooten and Dawson (2010), although reducing the level of entanglement has a marked effect on the back-calculated population size, reducing it by an order of magnitude to approximately 200 individuals, or fewer. Histograms of the simulated 1970 population sizes are given in Figure 9, note the order of magnitude difference between the upper left and other plots.

Table 7: Median, Mean and CV of the back-calculated 1970 population sizes for Maui's dolphin from the simulation study. M is the entanglement rate and ER Scalar is the associated multiplier to M_{SD}.

Scenario	M	ER Scalar	Median	Mean	CV
M_SD	0.000500	1.00	2001	2250	0.51
M_SD_35	0.000175	0.35	226	250	0.46
M_SD_30	0.000150	0.30	199	220	0.45
M_SD_25	0.000125	0.25	177	195	0.45
M_SD_20	0.000100	0.20	157	174	0.45
M_SD_15	0.000075	0.15	141	156	0.45

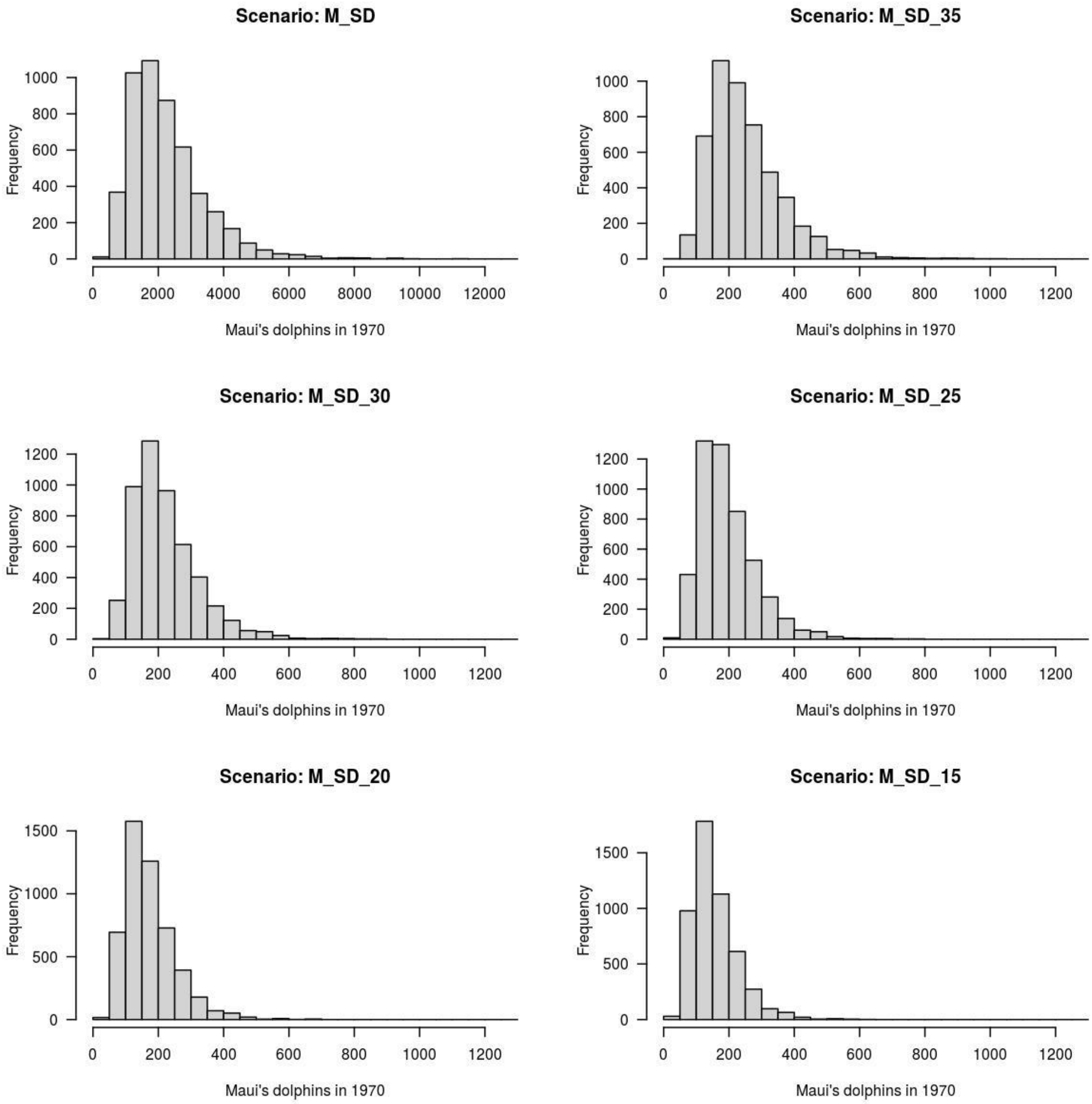

Figure 9: Histograms of the back-calculated 1970 Maui's dolphin population size for the 5000 simulated data sets, using different entanglement rates. Note the order of magnitude difference between the top left plot and other plots.

Figure 10 and Figure 11 present a summary of the population size trajectories for Maui's dolphin given the different entanglement rates. Figure 10 presents the full time period while Figure 11 is for the period from 1987 to 2009. The red and blue lines indicate the median and mean (respectively) population size in each year, and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey). Intuitively, the lower entanglement rates suggest a much less rapid decline compared to the value that gave agreement with the results of Slooten and Dawson (2010). The corresponding number of captures in each year are given in Figure 12 and Figure 13. To produce a decline similar to that reported by Slooten and Dawson (2010), there must have been 100's of Maui's dolphins captured (and killed) each year during the 1970's, while the simulations with the lower entanglement rates would suggest the number of captures was in the 10's.

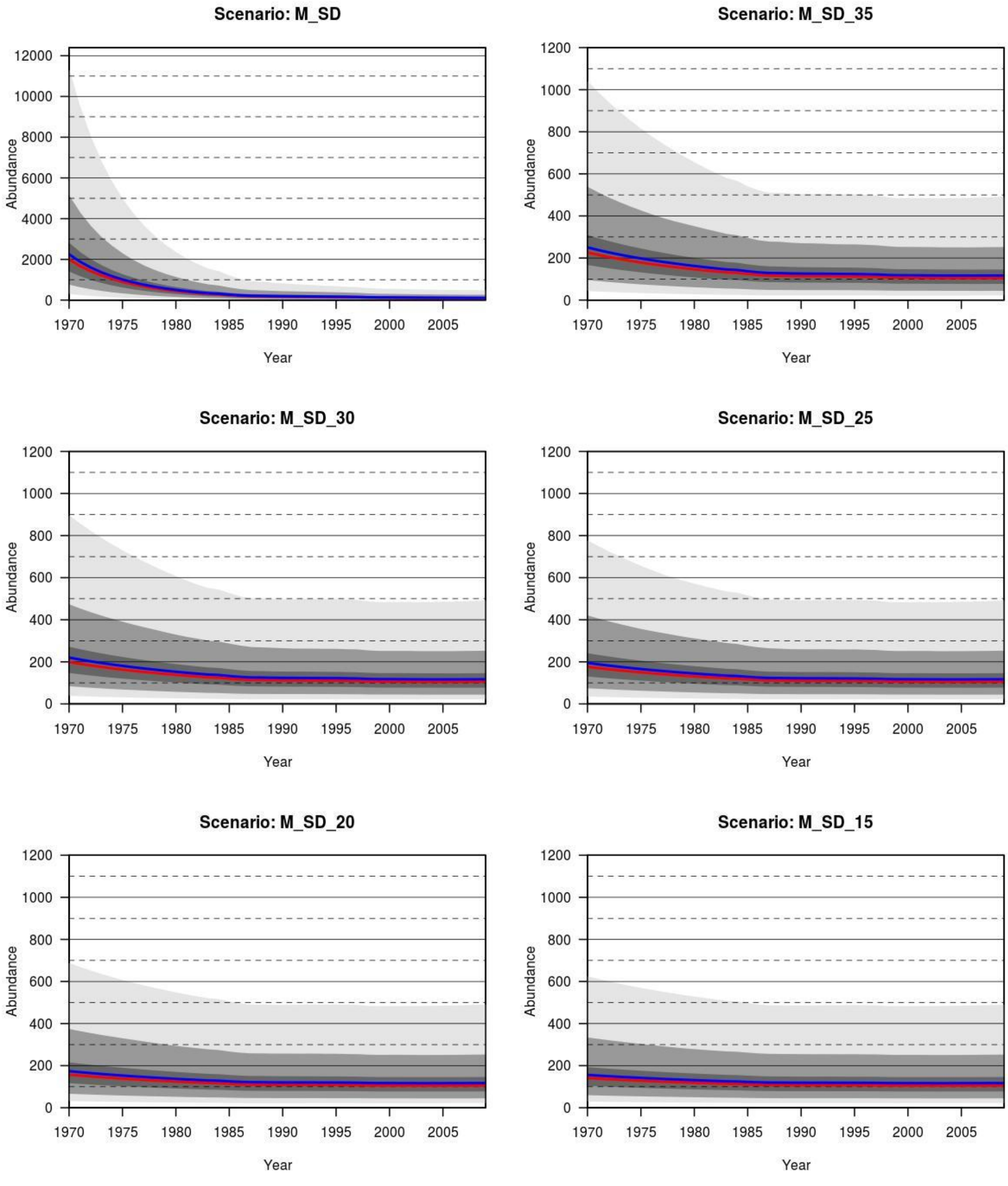

Figure 10: Simulated population trajectories between 1970 and 2009 assuming different entanglement rates. The red and blue lines indicate the median and mean (respectively), and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey).

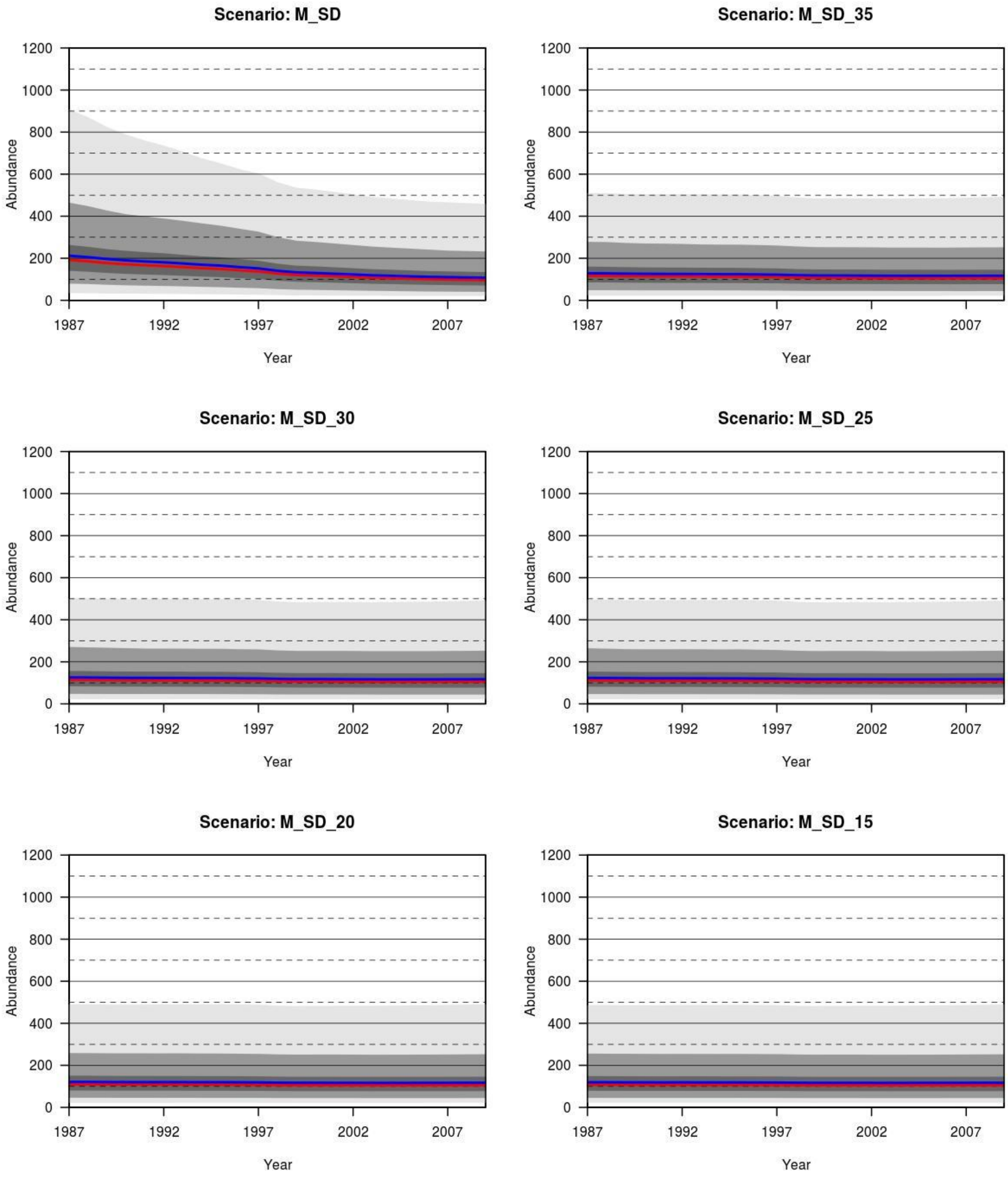

Figure 11: Simulated population trajectories between 1987 and 2009 assuming different entanglement rates. The red and blue lines indicate the median and mean (respectively), and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey).

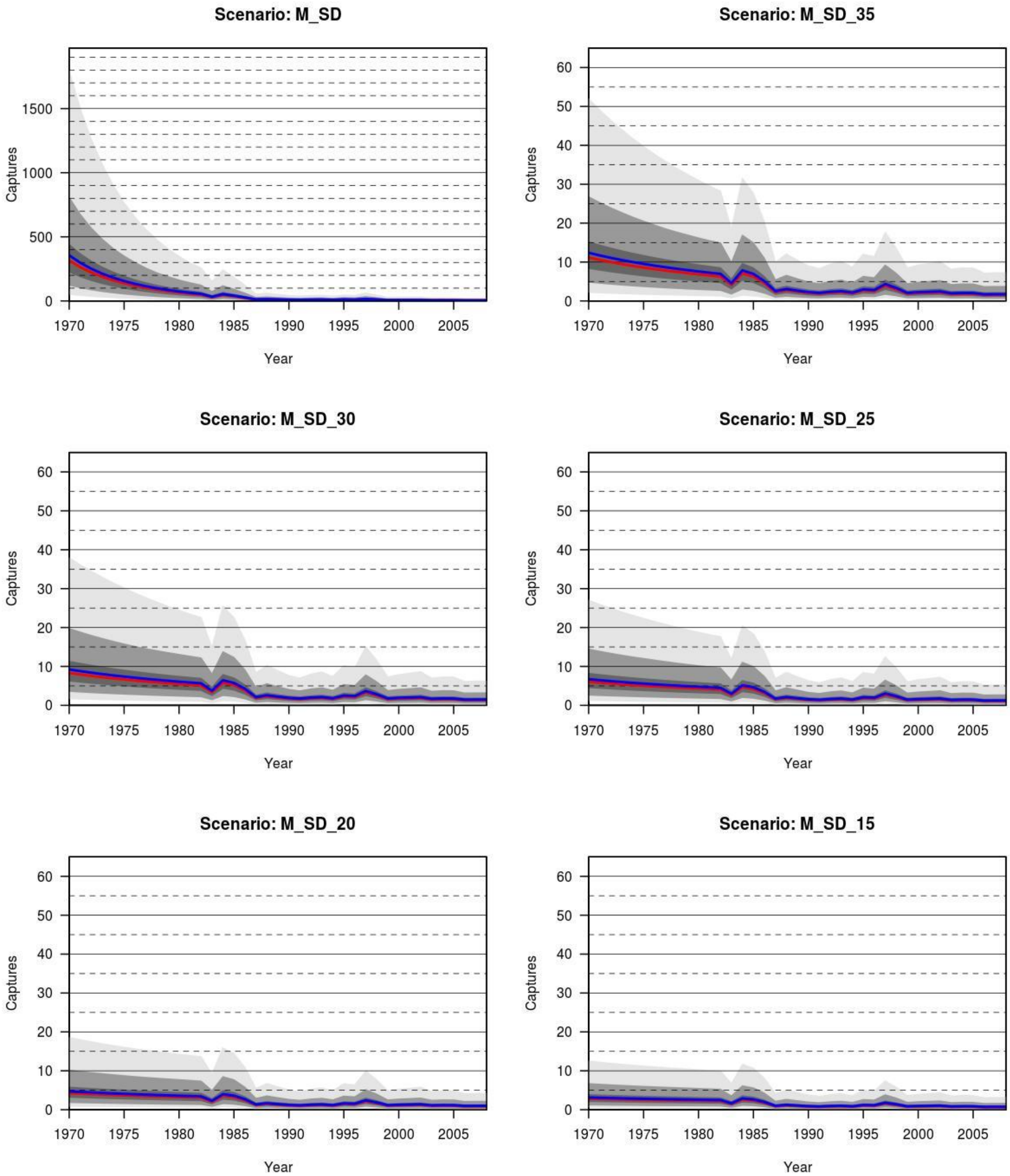

Figure 12: Simulated number of captures each year 1970 and 2008 assuming different entanglement rates. The red and blue lines indicate the median and mean (respectively), and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey).

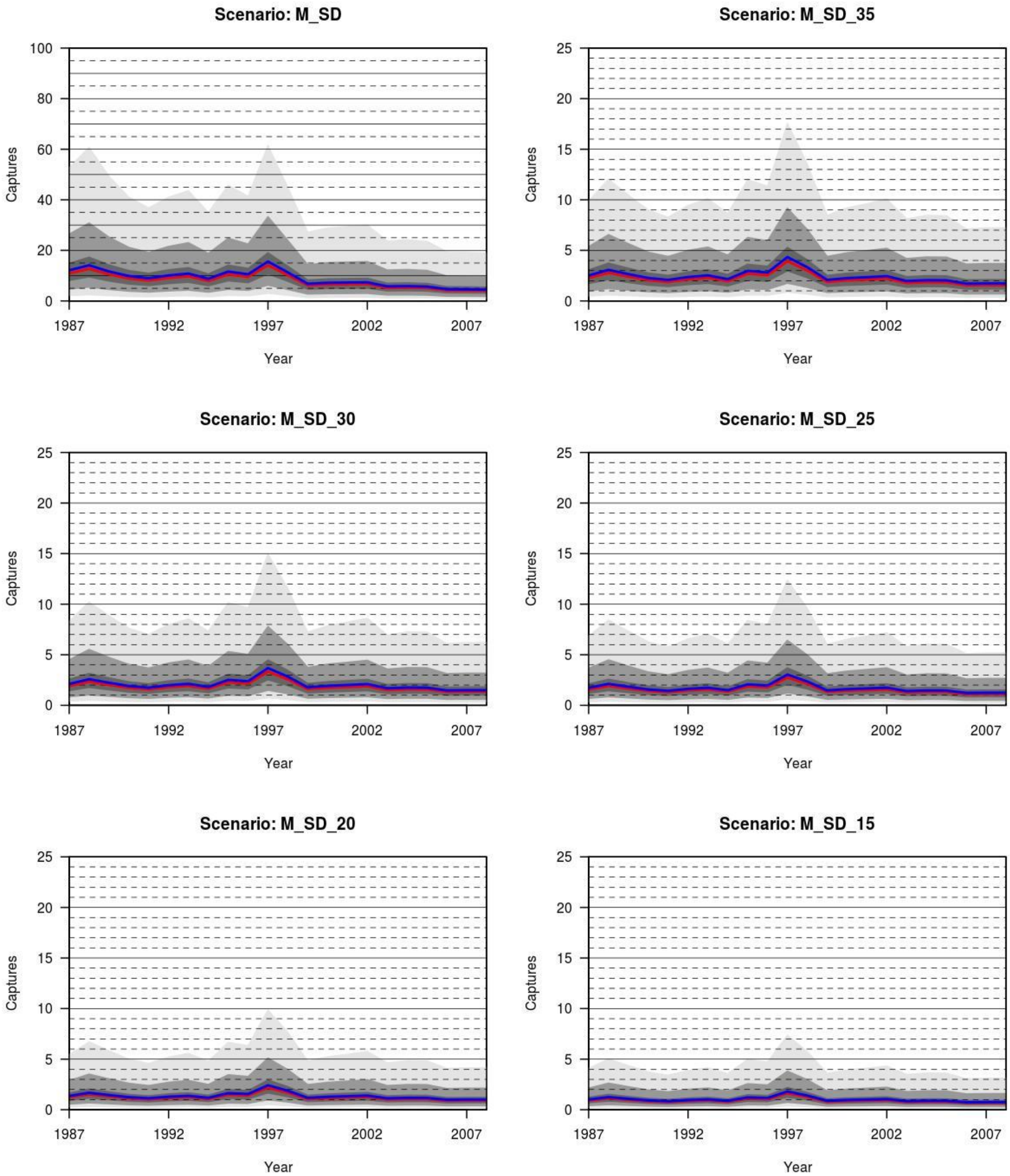

Figure 13: Simulated number of captures each year 1987 and 2008 assuming different entanglement rates. The red and blue lines indicate the median and mean (respectively), and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey).

The population trajectories can also be expressed in relative terms, as the proportion of the 1970 population size for each simulated trajectory (so the first value is always 1.0; Figure 14 and Figure 15). Clearly the implied impact upon the Maui dolphin population reduces as a lower entanglement rate is assumed. An entanglement rate of 0.000500 would suggest the 2009 population was as less than 10% of it's 1970 level, while an entanglement rate of 0.000075 suggests the population was between 70-80% of it's 1970 level in 2007 (Table 8).

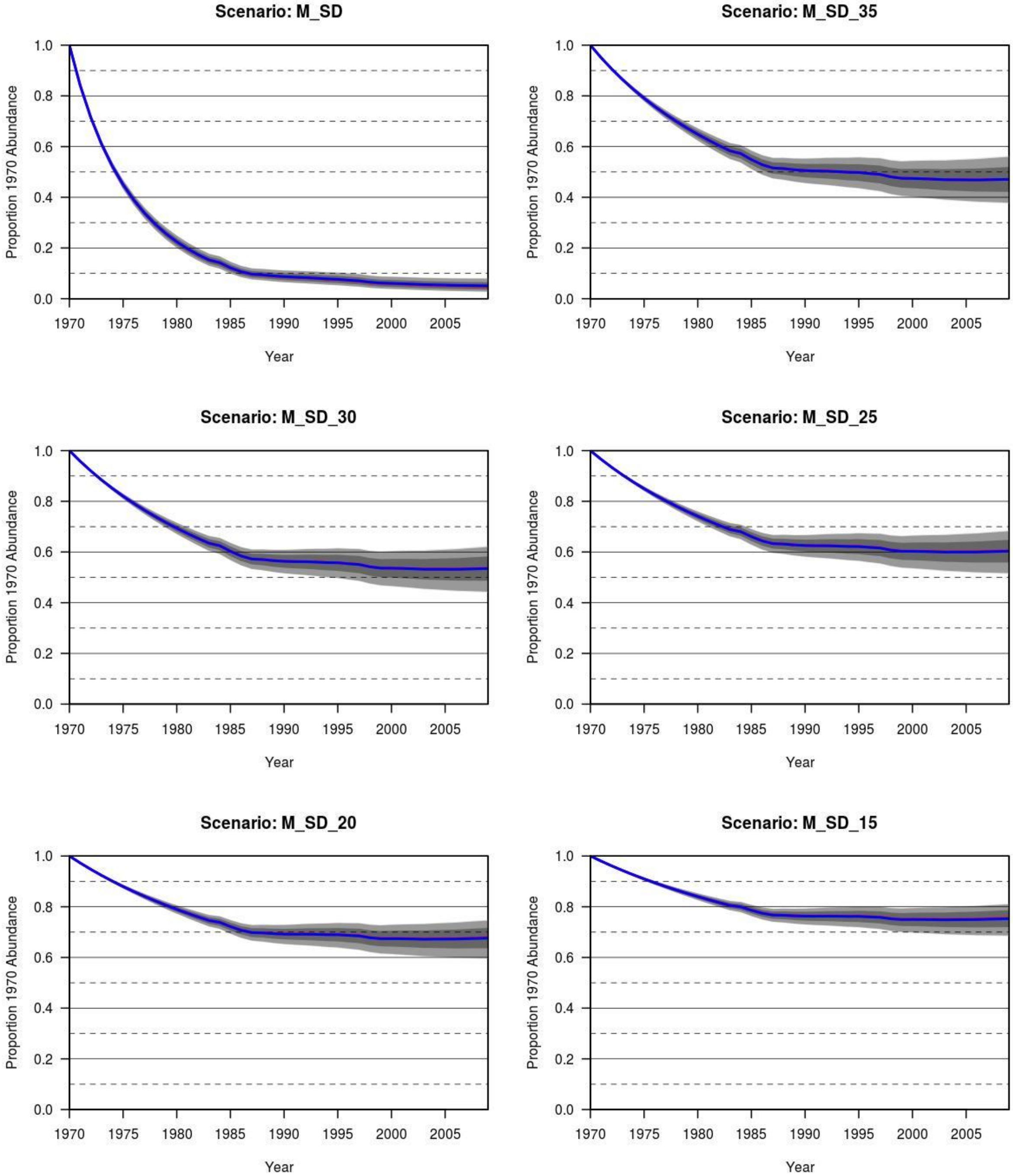

Figure 14: Simulated population trajectory expressed as proportion of 1970 population size from 1970 to 2009, assuming different entanglement rates. The red and blue lines indicate the median and mean (respectively), and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey).

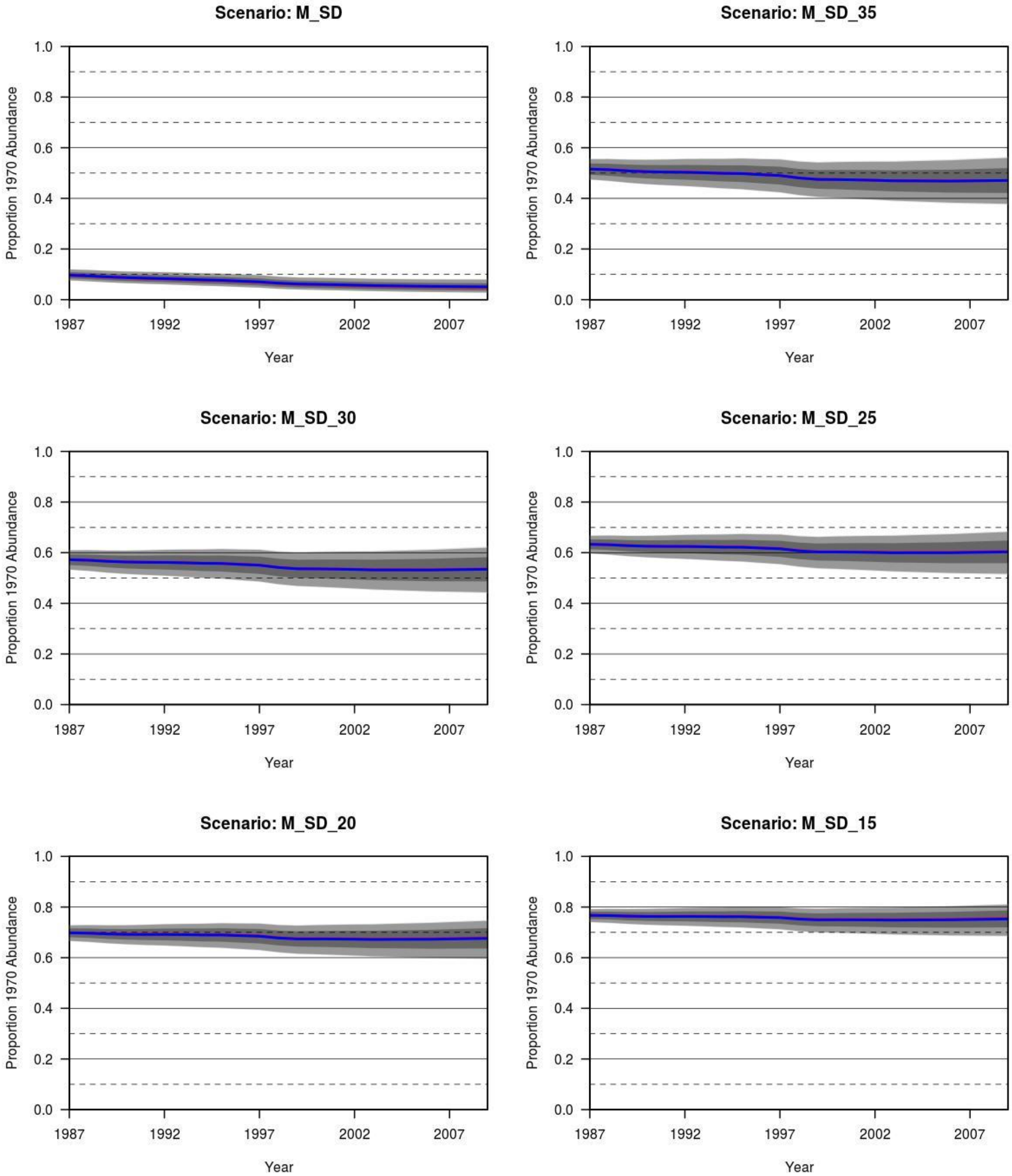

Figure 15: Simulated population trajectory expressed as proportion of 1970 population size from 1987 to 2009, assuming different entanglement rates. The red and blue lines indicate the median and mean (respectively), and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey).

Table 8: Projected proportion of 1970 population size in 2009 under alternative entanglement rate scenarios, from approximation of Slooten and Dawson (2010) model. The 2.5th, 50.0th and 97.5th percentiles of the simulated population trajectories are given. M is the assumed entanglement rate with the scenario M_SD approximating the decline obtained by Slooten and Dawson (2010).

			Proportion 1970 Population Size		
Scenario	M	**ER Scalar**	**2.5th**	**50.0th**	**97.5th**
M_SD	0.000500	1.00	0.03	0.05	0.08
M_SD_35	0.000175	0.35	0.38	0.47	0.56
M_SD_30	0.000150	0.30	0.44	0.54	0.62
M_SD_25	0.000125	0.25	0.52	0.60	0.68
M_SD_20	0.000100	0.20	0.60	0.68	0.74
M_SD_15	0.000075	0.15	0.69	0.75	0.81

Figure 16 presents the results of the final simulations with increasing fishing effort through the 1970's and an entanglement rate of 0.000078, and using either a uniform (1.018, 1.049) or (1.025, 1.069) distribution (scenarios *INCR_78* and *INCR_78_R*, respectively). Assuming increasing setnet effort decreases the number of captures and rate of decline in the 1970's and early 1980's (compared to assuming constant effort), and also the back-calculated 1970 population size. Therefore, the 2009 population size is projected to be at a higher proportion of the 1970 population size (Table 9). Assuming a lower range of values for λ_{max} suggests the 2009 population is at a lower fraction of the 'unimpacted' population size.

Table 9: Projected proportion of 1970 population size in 2009 assuming increasing setnet fishing effort from 1970, for two different assumed uniform distributions for λ_{max}. The 2.5th, 50.0th and 97.5th percentiles of the simulated population trajectories are given. M is the assumed entanglement.

			Proportion 1970 Population Size		
Scenario	M	λ_{max}	**2.5th**	**50.0th**	**97.5th**
INCR_78	0.000078	(1.018, 1.049)	0.74	0.79	0.83
INCR_78_R	0.000078	(1.025, 1.069)	0.77	0.82	0.87

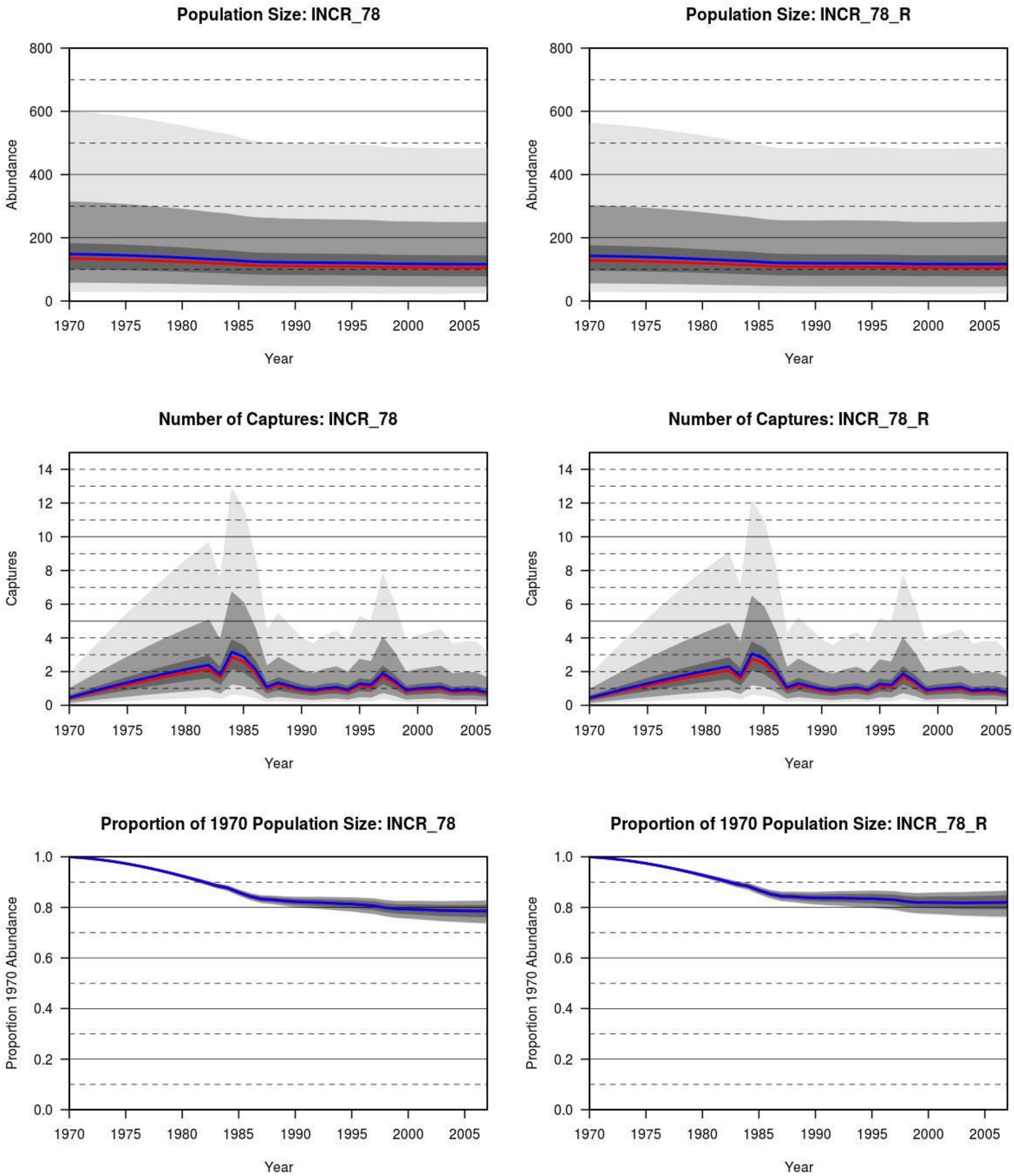

Figure 16: Simulated population size, number of captures and proportion of 1970 population size from 1970 to 2009, for scenarios where λ_{max} was random between 1.018 and 1.049 (SC1) or between 1.025 and 1.069 (SC2), with increasing setnet effort in 1970s and entanglement rate of 0.000078. The red and blue lines indicate the median and mean (respectively), and the grey-shaded regions indicate different percentiles of the simulated values (central 50%, 95% and full range of values for dark, mid and light grey).

4. DISCUSSION

The estimated entanglement rate based on the observed setnet fishing effort reported in Davies et al. (2008) is much lower when the updated ECSI abundance values are used from MacKenzie and Clement (2016). While this will lead to a reduction in the estimated number of dolphins caught in some areas and years (e.g., WCNI, WCSI and SCSI), the number of captures along ECSI may not reduce by the same degree because of the greater number of dolphins estimated to be at risk of capture in some strata. It is possible the estimated number of captures may even increase in some strata. However, the lower entanglement rate does suggest that the population-level historical impact of setnet fishing on Hector's and Maui's dolphins is likely to be less than previous publications have suggested.

Using the updated ECSI Hector's dolphin abundance estimates results in a catchability coefficient that is approximately two-thirds smaller than the value using the older abundance estimates. This has little impact on the back-calculated carrying capacity for Maui's dolphin using Davies et al. (2008) modelling approach as they assumed very little historical setnet fishing effort within 4 nmi of the coast in Statistical Areas 040, 041, 042 and 045, which is where the majority of the dolphin population was assumed to be by Davies et al. (2008). Therefore, in their analyses there is little historical overlap between fishing effort and Maui's dolphins, hence little opportunity for setnet captures. From the deterministic projection model scenario notated as KRG8_1.5% by Davies et al. (2008), carrying capacity changed from 227 using the older abundance estimates to approximately 200 with the newer estimates. While this is a notable difference, the carrying capacity is associated with a relatively high degree of uncertainty (Figure 39, Davies et al. 2008) and a value of 200 is well within the range of likely values as indicated by the posterior distribution. Conducting a stochastic version of the projection model using the updated abundance estimate will likely lower the posterior distribution of Maui's dolphin by 20-30 individuals as well. Based on the point estimates, Davies et al. (2008) KRG8_1.5% model suggests Maui's dolphin was at 59% of carrying capacity in 2004 (with their assumed 134 2004 population size), while the new results suggest the population was at 67% carrying capacity.

Subsequent additional work has identified a possible error in the code used by Davies et al. (2008) that if confirmed would lead to a further reduction in the estimated carry capacity to 167, and a 2004 status of 88%. Furthermore, it has been found that even if the catchability coefficient is set to 0 the population is projected to decline from 1970 to 2004, possibly due to the assumed age distribution not being at the equilibrium level implied by the population structure. Hence the apparent level of depletion is due to other sources besides set net fishery catch.

There is insufficient detail given in Slooten and Dawson (2010) to enable their method to be exactly replicated. Based on their description it appears the 0-4 nmi and 4-15nmi strata have been combined into a single area so that setnet fishing effort and Maui dolphins occur in the same areas, hence there is a greater level of overlap leading to a greater number of captures. Slooten and Dawson (2010) also assumed a constant mean setnet fishing effort in 1970's at the same level as the 1983-1985 average, rather than a gradual increase in effort through the 1970's like Davies et al. (2008). Had Slooten and Davies (2008) allowed effort to gradually increase that would have the effect of shifting captures from the 1970's to the 1980's.

The 1970 abundance estimates for Maui dolphin given by Slooten (2007), and Slooten and Dawson (2010), are much higher than the values given by other authors (e.g., Martien et al. 1999, Burkhart and Slooten 2003, Davies et al. 2008). Detailed information on the exact methods and input values used, which would allow independent verification of their results was not included in either publication.

The entanglement rate of 0.000500 that was obtained by calibration in this implementation of Slooten and Dawson's model should not, necessarily, be viewed as the value they used. It was the value obtained that produced a level of decline in the Maui's dolphin population that was similar to the one they reported. The approximation of their approach implemented here is slightly different, and some assumptions were made about certain aspects of what they actually did. If there is a consequential departure in our implementation from what Slooten and Dawson (2010) used, there could be a substantial difference between the calibrated entanglement rate and what they used. If the departures from their modelling are only minor, then the calibrated entanglement rate is expected to be similar to what they must have used. Accordingly, an entanglement rate of 0.000500 (and constant fishing effort in the 1970s and early 1980s) suggests the Maui's dolphin population size in 2009 was at less than 10% of the back-calculated 1970 level. However, assuming an entanglement rate that is similar to the entanglement rate calculated using the updated ECSI Hector's dolphin abundance (i.e., 0.000075 vs 0.000072 or 0.000078), suggest the 2009 population size was between 69%-81% of the 1970 level.

The scenario of setnet fishing effort increasing through the 1970s as the methods were more widely adopted (as used by Davies et al. 2008) is arguably more reasonable than assuming constant (average) effort from 1970 (Slooten and Dawson 2010). In combination with an estimated entanglement rate of 0.000078, which is the largest of the new values that have been estimated in this report, the 2009 population size was simulated to be between 74%-83% of the 1970 level using the same λ_{max} distribution as Slooten and Dawson (2010), or 77%-87% using a distribution based on the results of Roberts et al. (2019). These results clearly suggest that the historical impact of set fishing effort on Maui's dolphin is much smaller than that found by Slooten and Dawson (2010).

An important assumption of the modelling conducted here, and elsewhere (e.g., Martien et al. 1999, Burkhart and Slooten 2003, Slooten 2007, Davies et al. 2008, Slooten and Dawson 2010), is that the entanglement rate calculated from observed setnet fishing effort in Statistical Areas 020 and 022 around the turn of the century, is accurate for other areas and times. When this assumption is unreasonable, then the results of any modelling may be inaccurate, particularly when there is assumed to be a greater degree of overlap between setnet fishing effort and dolphin distribution (e.g., Slooten and Dawson 2010). It should also be noted that the modelling based on setnet fishing effort does not account for cryptic mortality (e.g., dolphins that were captured during observed effort, but were not recorded due to escape or carcasses that were not recovered) or other sources of anthropogenic mortality, including other fishing-related sources of mortality (Roberts et al. 2019).

5. MANAGEMENT IMPLICATIONS

How the incorporation of updated Hector's dolphin abundance estimates of MacKenzie and Clement (2016) affects our understanding of the potential historical impacts of setnet fishing effort on Maui's dolphin population depends on the level of assumed overlap in fishing effort and dolphin distribution. When little overlap is assumed (i.e., Davies et al. 2008), the estimated carrying capacity reduces by 12%, but when a greater level of overlap is assumed (i.e., Slooten and Dawson 2010) the reduction is by an order of magnitude. The lack of transparency associated with Slooten and Dawson (2010) makes it impossible to meaningfully compare the reasonableness of the assumptions made in each piece of research.

If the implementation used here closely approximates the work of Slooten and Dawson (2010), the updated abundance estimates would suggest an entanglement rate that is much lower than what would have been used previously, and the back-calculated 1970 population sizes for Maui's dolphin are comparable with those obtained from the Davies et al. (2008). Indeed, based on the calculated entanglement rates of 0.000078 or 0.000072, the back-calculated population size may have been even lower (i.e., simulated mean < 200). Expressed as a proportion of the back-calculated 1970 population size, the 2009 population size was likely at greater than 50% of the earlier level based on the updated entanglement rates.

The lower entanglement rates that result from incorporation of the updated abundance estimates also suggest the population-level impact of setnet fishing on Hector's dolphin populations will be less than previously thought. Therefore, the current population sizes are likely to be at a higher proportion of carrying capacity than previous research has indicated. This should be assessed further for Hector's dolphin populations.

6. ACKNOWLEDGMENTS

Thanks to Jim Roberts for useful discussions on historical setnet fishing effort. Fisheries New Zealand provided funding for this work under Project CON2020-15.

7. REFERENCES

Baird, S. J. & Bradford, E. (2000). *Estimation of Hector's dolphin bycatch from inshore fisheries, 1997/98 fishing year*. s.l.:Department of Conservation Wellington.

Burkhart, S. M. & Slooten, E. (2003). Population viability analysis for Hector's dolphin (*Cephalorhynchus hectori*): a stochastic population model for local populations. *New Zealand Journal of Marine and Freshwater Research 37*: 553–566.

Davies, N. M. et al. (2008). Risk analysis of Hector's dolphin and Maui's dolphin sub-populations to commercial set net fishing using a temporal-spatial age-structured model. *Report prepared for National Institute of Water and Atmospheric Research (NIWA).*

Dawson, S. et al. (2004). Small-boat surveys for coastal dolphins: line-transect surveys of Hector’s dolphins (Cephalorhynchus hectori). *Fishery Bulletin 102*: 441–451.

MacKenzie, D. I. & Clement, D. M. (2016). *Abundance and distribution of WCSI Hector's dophin.*, Wellington: Ministry for Primary Industries, Manatū Ahu Matua.

Martien, K. K., Taylor, B. L., Slooten, E. & Dawson, S. (1999). A sensitivity analysis to guide research and management for Hector's dolphin. *Biological Conservation 90*: 183–191.

Middleton, D. A. J., Starr, P. J. & Gilbert, D. J. (2007). Modelling the impact of fisheries bycatch on Hector’s dolphin: comment on Slooten (2007). *Endangered Species Research 3*: 331–334.

Roberts, J. O. et al. (2019). *Spatial risk assessment of threats to Hector's/Maui dolphins (Cepthalorhynchus hectori),* Wellington: Fisheries New Zealand.

Slooten, E. (2007). Conservation management in the face of uncertainty: effectiveness of four options for managing Hector’s dolphin bycatch. *Endangered Species Research 3*: 169–179.

Slooten, E. & Dawson, S. M. (2010). Assessing the effectiveness of conservation management decisions: likely effects of new protection measures for Hector's dolphin (*Cephalorhynchus hectori*). *Aquatic Conservation: Marine and Freshwater Ecosystems 20*: 334–347.

Slooten, E., Dawson, S. M. & Rayment, W. J., 2004. Aerial surveys for coastal dolphins: abundance of Hector's dolphins off the South Island west coast, New Zealand. *Marine Mammal Science 20*: 477–490.

Slooten, E., Dawson, S., Rayment, W. & Childerhouse, S., 2006. A new abundance estimate for Maui’s dolphin: what does it mean for managing this critically endangered species?. *Biological Conservation 128*: 576–581.

APPENDIX 1: R CODE AND INPUT VALUES TO APPROXIMATE SLOOTEN AND DAWSON (2010) MODEL

Mauis trajectories SPM.R

```
setwd("/home/darryl/Documents/MPI/Maui's modelling")
source("functions.R")

## set up effort
source("effort_prep.R")

## SD_eff = data frame with Slooten and Dawson (2010) effort (constant effort in 1970s),
## although no random variation in this implementation
## incr_eff = data frame with effort increasing in 1970s (eg Davies et al. 2008)
## con_eff = data frame with effort = 1, so entanglement rate M = proportional
##      impact on population

#######################################################################
## Calibration study to determine level of entanglement to approximate Slooten and Dawson.

## assumed abundance in each area. Order = 040, 041, 042, 045
abun<-c(5,18,74,19)
a_prop<-abun/116

## WCNI abundance measured in 2004
targ_yr<-2004-1970+1

## estimate entanglement rate and K in each area, using 20 sets of random start values
## assuming expected total K=2200 and lambda max=1.033
res<-lapply(1:20,function(ii){
  init<-c(runif(1,-8,-6),log(c(runif(1,0.5,1),runif(1,1,3),runif(1,0.05,0.05))))
  res<-optim(par=init,findM3,K=2200,lambda_max=1.033,target=abun,target_yr=targ_yr,
       effort=SD_eff,statareas=c(40,41,42,45),control=list(maxit=10000),method = "BFGS")
  return(res)
})

## identify set of estimates that minimise likelihood
idx<-which.min(unlist(lapply(res,function(rr) rr$value)))
res1<-res[[idx]]

exp(res1$par[1]) # M
round(exp(c(1,res1$par[-1]))/sum(exp(c(1,res1$par[-1]))),2) # proportion in each strata

M<-exp(res1$par[1])
M

## quick check that K values seem reasonable
temp<-sapply(1:4, function(ii){
  sel<-SD_eff$StatArea==c(40,41,42,45)[ii]
  return(exp(optimize(findK,interval=c(1,log(1000000)),lambda_max=1.033,M=M,target=abun[ii],
                      target_yr=targ_yr,effort=SD_eff[sel,])$minimum))
})
temp # 1970 N in each strata
sum(temp) ## 1970 total N


############################################################################33
############################################################################33

## run simulations with random total abundance and lambda max
nsims<-5000
# M<-0.000500
M<-M

# mean total abundance and CV
mean<-116
cv<-0.44

## mean and variance for lognormal distribution
var<-log(cv^2+1)
mu<-log(mean)-var/2
```

```
## proportion to allocate random N to each strata in 2007 for back calculation
abun<-c(5,18,74,19)
a_prop<-abun/116

set.seed(99) ## for repeatability
N<-rlnorm(nsims,mu,sqrt(var)) # random N
ll<-runif(nsims,1.018,1.049) # random lambda_max
ER_scalars<-c(1,0.35,0.3,0.25,0.2,0.15) # entanglement rate scalars for alternative scenarios

## run simulations with calibrated entanglement rate, range of scalars and assumed effort =
SD_eff
K_sims<-run_scenarios(M,ER_scalars,N,ll,abund,a_prop,SD_eff,nsims,targ_yr)

## used in plot output
ER<-round(M*ER_scalars,6)
titles<-paste0("Scenario: M_SD",c("",paste0("_",seq(35,15,-5))))

###########################################
## numerical summary of N 1970
summ<-t(sapply(K_sims,function(sims){
  temp<-colSums(sims)
  c(summary(temp),cv=sd(temp)/mean(temp))
}))
summ


###########################################
## run trajectories from 1970 to 2009

sim_traj<-lapply(1:length(K_sims),function(ii){
  return(traj_summ(K_sims[[ii]],M*ER_scalars[ii],nsims,ll,SD_eff))
})
names(sim_traj)<-paste0("ER_S_",ER_scalars)

## create jpegs of plots
source("plots.R")

## numerical summary of %K in 2009
sapply(sim_traj,function(traj) traj$K[[5]][40,])

################################
## run simulation INCR_78 with increasing effort, and M=0.000078

K1_sim<-run_scenarios(M=0.000078,ER_scale = 1,N,ll,abund,a_prop,incr_eff,nsims,targ_yr)
## numerical summary
c(summary(colSums(K1_sim[[1]])),cv=sd(colSums(K1_sim[[1]]))/mean(colSums(K1_sim[[1]])))

## run trajectory
one_traj<-lapply(1:length(K1_sim),function(ii){
  return(traj_summ(K1_sim[[ii]],0.000078,nsims,ll,incr_eff))
})

## histogram of 1970 N
jpeg("Increasing_effort_1970_N.jpg",width = 600,height=1400/3,res=144)
hist(colSums(K1_sim[[1]]),breaks=seq(0,1300,50),main="Entanglement Rate = 0.000078",  las=1,
    xlab="Maui's dolphins in 1970")
dev.off()

################################
## run simulation INCR_78+Rwith increasing effort, and M=0.000078, and Roberts et al lambda max

ll2<-runif(nsims,exp(0.025),exp(0.067))
K2_sim<-run_scenarios(M=0.000078,ER_scale = 1,N,ll2,abund,a_prop,incr_eff,nsims,targ_yr)
## summary
c(summary(colSums(K2_sim[[1]])),cv=sd(colSums(K2_sim[[1]]))/mean(colSums(K2_sim[[1]])))

## do trajectory
one_traj2<-lapply(1:length(K2_sim),function(ii){
  return(traj_summ(K2_sim[[ii]],0.000078,nsims,ll2,incr_eff))
})

## histogram of 1970 N
jpeg("Increasing_effort_1970_N2.jpg",width = 600,height=1400/3,res=144)
hist(colSums(K2_sim[[1]]),breaks = seq(0,1300,50),main="Entanglement Rate = 0.000078",las=1,
    xlab="Maui's dolphins in 1970")
dev.off()
```

```
## create plot of side-by-side comparison of these last 2 scenarios.
jpeg("Increasing_effort_trajectories3.jpg",width = 1200,height=1400,res=144)
par(mfrow=c(3,2))
plot_traj(one_traj[[1]]$N[[5]],start=1,end=38,lines=seq(100,700,100),ylab="Abundance",
    ylim=c(0,800),main="Population Size: INCR_78")
plot_traj(one_traj2[[1]]$N[[5]],start=1,end=38,lines=seq(100,700,100),ylab="Abundance",
    ylim=c(0,800),main="Population Size: INCR_78_R")
plot_traj(one_traj[[1]]$D[[5]],start=1,end=37,lines=1:14,lines_lty = c(rep(2,4),1),
    ylim = c(0,15),ylab="Captures",main="Number of Captures: INCR_78")
plot_traj(one_traj2[[1]]$D[[5]],start=1,end=37,lines=1:14,lines_lty = c(rep(2,4),1),
    ylim = c(0,15),ylab="Captures",main="Number of Captures: INCR_78_R")
plot_traj(one_traj[[1]]$K[[5]],start=1,end=38,lines=seq(0.1,0.9,0.1),
    ylab="Proportion 1970 Abundance",ylim=c(0,1),
    main="Proportion of 1970 Population Size: INCR_78")
plot_traj(one_traj2[[1]]$K[[5]],start=1,end=38,lines=seq(0.1,0.9,0.1),
    ylab="Proportion 1970 Abundance",ylim=c(0,1),
    main="Proportion of 1970 Population Size: INCR_78_R")
dev.off()

## numerical summary of %K in 2009
sapply(one_traj,function(traj) traj$K[[5]][40,])
sapply(one_traj2,function(traj) traj$K[[5]][40,])

save.image(file="MD trajectories.RData")
```

functions.R

```
## calculate Nt+1, assuming no movement
Nt1<-function(N,lambda_max,K,M,E){return(N*(1+(lambda_max-1)*(1-N/K)-M*E))}

## find value for K assuming fixed M
findK<-function(pars,lambda_max,M,target,target_yr,effort){
  K<-exp(pars)
  t<-nrow(effort)
  t1<-t+1
  N<-rep(NA,t1)
  D<-rep(NA,t1)
  N[1]<-K
  for(ii in 2:t1){
    N[ii]<-Nt1(N[ii-1],lambda_max,K,M,effort$Effort[ii-1])
    D[ii]<-N[ii-1]*M*effort$Effort[ii-1]
  }
  # print(cbind(N,D))
  ret<- -sum(dnorm(N[target_yr],target,0.01,log = TRUE))
  return(ret)

  # return(abs(target-N[target_yr]))
}


## find entanglement rate and K for multiple areas
findM3<-function(par,K,lambda_max,target,target_yr,effort,statareas){
  M<-exp(par[1])
  Kprop<-c(1,exp(par[-1]))/sum(c(1,exp(par[-1])))
  A<-length(statareas)
  t<-nrow(effort)/A
  t1<-t+1
  N<-array(NA,dim=c(A,t1))
  D<-array(NA,dim=c(A,t1))
  areaK<-K*Kprop
  N[,1]<-areaK
  for(jj in 1:A){
    sel<-effort$StatArea==statareas[jj]
    for(ii in 2:t1){
      N[jj,ii]<-Nt1(N[jj,ii-1],lambda_max,areaK[jj],M,effort$Effort[sel][ii-1])
      D[jj,ii]<-N[jj,ii-1]*M*effort$Effort[sel][ii-1]
    }
  }
  ret<- -sum(dnorm(N[,target_yr],target,0.01,log = TRUE))
  return(ret)
}

## calculate trajectory and number of deaths
traj<-function(K,lambda_max,M,effort){
  t<-nrow(effort)
  t1<-t+1
  N<-rep(NA,t1)
  D<-rep(NA,t1)
  N[1]<-K
  for(ii in 2:t1){
    N[ii]<-Nt1(N[ii-1],lambda_max,K,M,effort$Effort[ii-1])
    D[ii]<-N[ii-1]*M*effort$Effort[ii-1]
  }
  return(data.frame(N,D))
}

## function for plotting trajectories
plot_traj<-function(traj,start,end,lines=NULL,lines_lty=2:1,ylab="",ylim=NULL,main=""){
  traj2<-traj[start:end,]
  if(is.null(ylim)) ylim<-c(0,1.1*max(traj2$'100%'))
  plot(traj2$'100%',type="n",yaxs="i",xaxs="i",xaxt="n",las=1,
       ylim=ylim,ylab=ylab,xlab="Year",main=main)
  axis(1,at=seq(1,(end-start)+1,5),labels=seq(start,end,5)+1969)
  polygon(c(start:end,end:start)-start+1,c(traj2$'0%',rev(traj2$'100%')),
      border = "gray90",col="gray90")
  polygon(c(start:end,end:start)-start+1,c(traj2$'2.5%',rev(traj2$'97.5%')),
      border = "gray60",col="gray60")
  polygon(c(start:end,end:start)-start+1,c(traj2$'25%',rev(traj2$'75%')),
      border = "gray40",col="gray40")
```

```
  if(is.null(lines)){
    lines<-pretty(traj2$'100%')
    incr<-abs(lines[1]-lines[2])/2
    lines<-seq(incr,max(lines),incr)
  }

  abline(h=lines,col="black",lty=lines_lty,lwd=0.5)
  points(traj2$'50%',type="l",lwd=2,col="red")
  points(traj2$mean,type="l",lwd=2,col="blue")

  box()
}


##########################################
## compute N and D trajectories with full entanglement rate from simulated values
traj_summ<-function(KK,M,nsims,ll,effort){
  print(paste0("Starting trajectory for ER = ",M))
  traj_est<-lapply(1:nsims,function(ii){
    K<-KK[,ii]
    temp<-lapply(1:4, function(jj){
      sel<-effort$StatArea==c(40,41,42,45)[jj]
      return(traj(K=K[jj],lambda_max=ll[ii],M=M,effort=effort[sel,]))
    })
    temp<-do.call("cbind",temp)
    return(temp)
  })
  print(paste0("Finished trajectory for ER = ",M,". Calculating summaries"))

  ## collate values for N
  ## for each area
  traj_N<-lapply(1:4,function(ii){
    sapply(traj_est, function(sim){
      sim[,2*ii-1]
    })
  })
  ## in total
  traj_N[[5]]<-sapply(traj_est, function(sim){rowSums(sim[,c(1,3,5,7)])})

  summ_traj_N<-lapply(traj_N,function(traj){
    as.data.frame(t(apply(traj,1,function(xx){
      c(mean=mean(xx),quantile(xx,c(0,0.025,0.05,0.25,0.5,0.75,0.95,0.975,1)))
    })))
  })

  ## collate values for D
  ## for each area
  traj_D<-lapply(1:4,function(ii){
    sapply(traj_est, function(sim){
      sim[-1,2*ii]
    })
  })
  ## in total
  traj_D[[5]]<-sapply(traj_est, function(sim){rowSums(sim[-1,c(2,4,6,8)])})

  summ_traj_D<-lapply(traj_D,function(traj){
    as.data.frame(t(apply(traj,1,function(xx){
       c(mean=mean(xx),quantile(xx,c(0,0.025,0.05,0.25,0.5,0.75,0.95,0.975,1)))
    })))
  })

  ## express N trajectory as fraction of N 1970
  ## for each area
  traj_K<-lapply(traj_N, function(traj){
    return(apply(traj,2,function(xx) xx/xx[1]))
  })

  summ_traj_K<-lapply(traj_K,function(traj){
    as.data.frame(t(apply(traj,1,function(xx){
      c(mean=mean(xx),quantile(xx,c(0,0.025,0.05,0.25,0.5,0.75,0.95,0.975,1)))
    })))
  })

  return(list(N=summ_traj_N,D=summ_traj_D,K=summ_traj_K))
}
```

```
###################
run_scenarios<-function(M,ER_scale=1,N,ll,abund,a_prop,effort,nsims,target_yr){
  temp<-lapply(ER_scale,function(er_s){
    print(paste0("Starting ER_scale = ",er_s))
    test<-sapply(1:nsims,function(ii){
      abund<-N[ii]*a_prop
      K<-rep(NA,4)
      for (jj in 1:4){
        sel<-effort$StatArea==c(40,41,42,45)[jj]
        K[jj]<-exp(optimize(findK,interval=c(1,log(1000000)),lambda_max=ll[ii],M=M*er_s,
                            target=abund[jj],target_yr=target_yr,effort=effort[sel,])$minimum)
      }
      return(K)
    })
    print(paste0("Finished ER_scale = ",er_s))
    return(test)
  })

  names(temp)<-paste0("ER_S_",ER_scale)

  return(temp)

}
```

effort_prep.R

```
## set working directory prior to running this file
## must be same location as effort csv file

effort<-read.csv("mauis effort.csv")
## effort measured in km
## S&D2010 used m/square km of Stat Area
## note Davies et al. (2008) measured area in square nmi

# From Davies et al (2008)
area<-read.csv("mauis areas.csv")
area2<-aggregate(area$Area_nm,list(area$StatArea,area$Depth),sum)
names(area2)<-c("StatArea","Depth","Area_nm2")
area2$Area_km2<-area2$Area_nm2*3.4299 ## convert nm2 to km2

#inshore_eff<-data.frame(StatArea=c(40,41,42,45),prop=c(0.57,0.06,0,0))

## summarise effort
summ_effort<-aggregate(effort$Effort,list(effort$Year,effort$StatArea),sum)
names(summ_effort)<-c("Year","StatArea","Effort")

## double 2007 effort as only part year
sel<-summ_effort$Year==2007
summ_effort$Effort[sel]<-2*summ_effort$Effort[sel]

## set 2008 effort same as 2007
summ_effort<-rbind(summ_effort,data.frame(Year=2008,StatArea=summ_effort$StatArea[sel],
                                          Effort=summ_effort$Effort[sel]))

## find mean and sd of 1983:1985 effort
sel<-summ_effort$Year %in% 1983:1985
summ_effort[sel,]
m<-aggregate(summ_effort$Effort[sel],list(summ_effort$StatArea[sel]),mean)
names(m)<-c("StatArea","Effort")
s<-aggregate(summ_effort$Effort[sel],list(summ_effort$StatArea[sel]),sd)
names(m)<-c("StatArea","Effort")


yr<-1970:1982

## assume constant effort using mean for 1983-1985.
## could have random effort instead. Would have to be redrawn for each simulation
eff<-data.frame(Year=yr,StatArea=m$StatArea[rep(1:4,each=length(yr))],
                Effort=m$Effort[rep(1:4,each=length(yr))])

SD_eff<-rbind(eff,summ_effort)

## no values for 1989, use numbers that are intermediate between 1988 and 1990
SD_eff<-rbind(SD_eff,data.frame(Year=1989,StatArea=c(40,41,42,45),Effort=c(600,350,730,160)))
SD_eff<-SD_eff[order(SD_eff$StatArea,SD_eff$Year),]

# SD_eff

## convert effort to m/km2 (using total area)
idx<-match(SD_eff$StatArea,area2$StatArea)
SD_eff$TotalArea_km2 <- area2$Area_km2[area2$Depth=="Total"][idx]
SD_eff$Area100_km2 <- area2$Area_km2[area2$Depth=="<100"][idx]
SD_eff$Effort_km<-SD_eff$Effort
SD_eff$Effort<-1000*SD_eff$Effort_km/SD_eff$TotalArea_km2

## constant effort data frame. M becomes strictly proportional impact, not effort related
cons_eff<-SD_eff
cons_eff$Effort<-1

## increasing effort
## Davies et al. assume 15% in 1970 of mean 1983-85
incr_eff<-SD_eff

prop_trend<-0.15 + 0.85/14*(yr-1970)

sel<-incr_eff$Year%in%yr
incr_eff$Effort_km[sel]<-incr_eff$Effort_km[sel]*prop_trend
incr_eff$Effort<-1000*incr_eff$Effort_km/incr_eff$TotalArea_km2
```

```
###########################################################################33
###########################################################################33
## plot fishing effort

jpeg("SD Fishing effort.jpg",width=1200,height=800,res=144)
plot(SD_eff$Year,SD_eff$Effort,type="n",las=1,xlab="Year",ylab="Setnet length (km)",
   yaxs="i",ylim=c(0,550))
abline(h=seq(50,500,50),lty=2:1,col="grey")
sel<-SD_eff$StatArea=="40"
points(SD_eff$Year[sel],SD_eff$Effort[sel],type="o",pch=0,col="black")
sel<-SD_eff$StatArea=="41"
points(SD_eff$Year[sel],SD_eff$Effort[sel],type="o",pch=1,col="red")
sel<-SD_eff$StatArea=="42"
points(SD_eff$Year[sel],SD_eff$Effort[sel],type="o",pch=2,col="blue")
sel<-SD_eff$StatArea=="45"
points(SD_eff$Year[sel],SD_eff$Effort[sel],type="o",pch=5,col="green")
legend("top",legend=c("040","041","042","045"),col=c("black","red","blue","green"),
       inset = -0.14,horiz = TRUE,xpd=TRUE, pch=c(0:2,5),lwd=1)
dev.off()

###########################################################################33
###########################################################################33
## plot fishing effort

jpeg("Incr Fishing effort.jpg",width=1200,height=800,res=144)
plot(incr_eff$Year,incr_eff$Effort,type="n",las=1,xlab="Year",ylab="Setnet length (km)",
    yaxs="i",ylim=c(0,550))
abline(h=seq(50,500,50),lty=2:1,col="grey")
sel<-incr_eff$StatArea=="40"
points(incr_eff$Year[sel],incr_eff$Effort[sel],type="o",pch=0,col="black")
sel<-incr_eff$StatArea=="41"
points(incr_eff$Year[sel],incr_eff$Effort[sel],type="o",pch=1,col="red")
sel<-incr_eff$StatArea=="42"
points(incr_eff$Year[sel],incr_eff$Effort[sel],type="o",pch=2,col="blue")
sel<-incr_eff$StatArea=="45"
points(incr_eff$Year[sel],incr_eff$Effort[sel],type="o",pch=5,col="green")
legend("top",legend=c("040","041","042","045"),col=c("black","red","blue","green"),
       inset = -0.14,horiz = TRUE,xpd=TRUE, pch=c(0:2,5),lwd=1)
dev.off()
```

plots.R

```
jpeg("pop_sizes.jpg",width=1200,height=1200,res=144)
par(mfrow=c(3,2))
hist(colSums(K_sims[[1]]),breaks = seq(0,13000,500),main=titles[1],las=1,
   xlab="Maui's dolphins in 1970")
hist(colSums(K_sims[[2]]),breaks = seq(0,1300,50),main=titles[2],las=1,
   xlab="Maui's dolphins in 1970")
hist(colSums(K_sims[[3]]),breaks = seq(0,1300,50),main=titles[3],las=1,
   xlab="Maui's dolphins in 1970")
hist(colSums(K_sims[[4]]),breaks = seq(0,1300,50),main=titles[4],las=1,
   xlab="Maui's dolphins in 1970")
hist(colSums(K_sims[[5]]),breaks = seq(0,1300,50),main=titles[5],las=1,
   xlab="Maui's dolphins in 1970")
hist(colSums(K_sims[[6]]),breaks = seq(0,1300,50),main=titles[6],las=1,
   xlab="Maui's dolphins in 1970")
dev.off()


jpeg("full_N_traj.jpg",width=1200,height=1400,res=144)
par(mfrow=c(3,2))
## create some plots of the trajectories, for each area and overall
plot_traj(sim_traj[[1]]$N[[5]],start=1,end=40,lines=seq(1000,13000,1000),ylab="Abundance",
          main=titles[1])
plot_traj(sim_traj[[2]]$N[[5]],start=1,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[2])
plot_traj(sim_traj[[3]]$N[[5]],start=1,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[3])
plot_traj(sim_traj[[4]]$N[[5]],start=1,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[4])
plot_traj(sim_traj[[5]]$N[[5]],start=1,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[5])
plot_traj(sim_traj[[6]]$N[[5]],start=1,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[6])
dev.off()

jpeg("short_N_traj.jpg",width=1200,height=1400,res=144)
par(mfrow=c(3,2))
plot_traj(sim_traj[[1]]$N[[5]],start=18,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[1])
plot_traj(sim_traj[[2]]$N[[5]],start=18,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[2])
plot_traj(sim_traj[[3]]$N[[5]],start=18,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[3])
plot_traj(sim_traj[[4]]$N[[5]],start=18,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[4])
plot_traj(sim_traj[[5]]$N[[5]],start=18,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[5])
plot_traj(sim_traj[[6]]$N[[5]],start=18,end=40,lines=seq(100,1100,100),ylab="Abundance",
          ylim=c(0,1200),main=titles[6])
dev.off()

jpeg("full_Cap_traj.jpg",width=1200,height=1400,res=144)
par(mfrow=c(3,2))
plot_traj(sim_traj[[1]]$D[[5]],start=1,end=39,lines=seq(100,2500,100),
          lines_lty = c(rep(2,4),1),
          ylab="Captures",main=titles[1])
plot_traj(sim_traj[[2]]$D[[5]],start=1,end=39,lines=seq(5,60,5),ylim = c(0,65),
          ylab="Captures",main=titles[2])
plot_traj(sim_traj[[3]]$D[[5]],start=1,end=39,lines=seq(5,60,5),ylim = c(0,65),
          ylab="Captures",main=titles[3])
plot_traj(sim_traj[[4]]$D[[5]],start=1,end=39,lines=seq(5,60,5),ylim = c(0,65),
          ylab="Captures",main=titles[4])
plot_traj(sim_traj[[5]]$D[[5]],start=1,end=39,lines=seq(5,60,5),ylim = c(0,65),
          ylab="Captures",main=titles[5])
plot_traj(sim_traj[[6]]$D[[5]],start=1,end=39,lines=seq(5,60,5),ylim = c(0,65),
          ylab="Captures",main=titles[6])
dev.off()

jpeg("short_Cap_traj.jpg",width=1200,height=1400,res=144)
par(mfrow=c(3,2))
plot_traj(sim_traj[[1]]$D[[5]],start=18,end=39,lines=seq(5,95,5),ylim = c(0,100),
          ylab="Captures",main=titles[1])
plot_traj(sim_traj[[2]]$D[[5]],start=18,end=39,lines=1:24,lines_lty = c(rep(2,4),1),
          ylim = c(0,25),
          ylab="Captures",main=titles[2])
```

```
plot_traj(sim_traj[[3]]$D[[5]],start=18,end=39,lines=1:24,lines_lty = c(rep(2,4),1),
          ylim = c(0,25),
          ylab="Captures",main=titles[3])
plot_traj(sim_traj[[4]]$D[[5]],start=18,end=39,lines=1:24,lines_lty = c(rep(2,4),1),
          ylim = c(0,25),
          ylab="Captures",main=titles[4])
plot_traj(sim_traj[[5]]$D[[5]],start=18,end=39,lines=1:24,lines_lty = c(rep(2,4),1),
          ylim = c(0,25),
          ylab="Captures",main=titles[5])
plot_traj(sim_traj[[6]]$D[[5]],start=18,end=39,lines=1:24,lines_lty = c(rep(2,4),1),
          ylim = c(0,25),
          ylab="Captures",main=titles[6])
dev.off()


jpeg("full_K_traj.jpg",width=1200,height=1400,res=144)
par(mfrow=c(3,2))
## create some plots of the trajectories, for each area and overall
plot_traj(sim_traj[[1]]$K[[5]],start=1,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[1])
plot_traj(sim_traj[[2]]$K[[5]],start=1,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[2])
plot_traj(sim_traj[[3]]$K[[5]],start=1,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[3])
plot_traj(sim_traj[[4]]$K[[5]],start=1,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[4])
plot_traj(sim_traj[[5]]$K[[5]],start=1,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[5])
plot_traj(sim_traj[[6]]$K[[5]],start=1,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[6])
dev.off()

jpeg("short_K_traj.jpg",width=1200,height=1400,res=144)
par(mfrow=c(3,2))
## create some plots of the trajectories, for each area and overall
plot_traj(sim_traj[[1]]$K[[5]],start=18,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[1])
plot_traj(sim_traj[[2]]$K[[5]],start=18,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[2])
plot_traj(sim_traj[[3]]$K[[5]],start=18,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[3])
plot_traj(sim_traj[[4]]$K[[5]],start=18,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[4])
plot_traj(sim_traj[[5]]$K[[5]],start=18,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[5])
plot_traj(sim_traj[[6]]$K[[5]],start=18,end=40,lines=seq(0.1,0.9,0.1),
          ylab="Proportion 1970 Abundance",ylim=c(0,1),
          main=titles[6])
dev.off()
```

mauis effort.csv

```
Target,yr,Year,StatArea,Season,Effort
Other,82/83 ,1983,40,S,637.7
Other,83/84 ,1984,40,S,1461.3
Other,84/85 ,1985,40,S,1168.9
Other,85/86 ,1986,40,S,1224.3
Other,86/87 ,1987,40,S,248.5
Other,87/88 ,1988,40,S,284.3
Other,89/90 ,1990,40,S,380.9
Other,90/91 ,1991,40,S,294.6
Other,91/92 ,1992,40,S,348.6
Other,92/93 ,1993,40,S,800.6
Other,93/94 ,1994,40,S,681.5
Other,94/95 ,1995,40,S,632.8
Other,95/96 ,1996,40,S,489.4
Other,96/97 ,1997,40,S,391.9
Other,97/98 ,1998,40,S,231.6
Other,98/99 ,1999,40,S,622.3
Other,99/00 ,2000,40,S,499.6
Other,00/01 ,2001,40,S,371.8
Other,01/02 ,2002,40,S,270.7
Other,02/03 ,2003,40,S,350.6
Other,03/04 ,2004,40,S,321.2
Other,04/05 ,2005,40,S,266.6
Other,05/06 ,2006,40,S,219.6
Other,06/07 ,2007,40,S,408.3
YEM,82/83 ,1983,40,S,13.7
YEM,83/84 ,1984,40,S,3.9
YEM,84/85 ,1985,40,S,2
YEM,85/86 ,1986,40,S,15.1
YEM,86/87 ,1987,40,S,0
YEM,87/88 ,1988,40,S,0
YEM,89/90 ,1990,40,S,0
YEM,90/91 ,1991,40,S,0
YEM,91/92 ,1992,40,S,0.3
YEM,92/93 ,1993,40,S,1.6
YEM,93/94 ,1994,40,S,0
YEM,94/95 ,1995,40,S,0.9
YEM,95/96 ,1996,40,S,2
YEM,96/97 ,1997,40,S,6.2
YEM,97/98 ,1998,40,S,1.3
YEM,98/99 ,1999,40,S,1.8
YEM,99/00 ,2000,40,S,1.5
YEM,00/01 ,2001,40,S,1.9
YEM,01/02 ,2002,40,S,0
YEM,02/03 ,2003,40,S,0
YEM,03/04 ,2004,40,S,2
YEM,04/05 ,2005,40,S,0
YEM,05/06 ,2006,40,S,0.5
YEM,06/07 ,2007,40,S,0
TAR,82/83 ,1983,40,S,3
TAR,83/84 ,1984,40,S,37.5
TAR,84/85 ,1985,40,S,11.5
TAR,85/86 ,1986,40,S,6.8
TAR,86/87 ,1987,40,S,9.9
TAR,87/88 ,1988,40,S,0
TAR,89/90 ,1990,40,S,45.6
TAR,90/91 ,1991,40,S,35.9
TAR,91/92 ,1992,40,S,82.6
TAR,92/93 ,1993,40,S,168.7
TAR,93/94 ,1994,40,S,216.9
TAR,94/95 ,1995,40,S,143.7
TAR,95/96 ,1996,40,S,125.7
TAR,96/97 ,1997,40,S,99.8
TAR,97/98 ,1998,40,S,95.3
TAR,98/99 ,1999,40,S,44.3
TAR,99/00 ,2000,40,S,60
TAR,00/01 ,2001,40,S,113.8
TAR,01/02 ,2002,40,S,143
TAR,02/03 ,2003,40,S,79.5
TAR,03/04 ,2004,40,S,122.6
TAR,04/05 ,2005,40,S,123.5
TAR,05/06 ,2006,40,S,60.3
TAR,06/07 ,2007,40,S,10
```

```
Other,82/83 ,1983,40,W,670.7
Other,83/84 ,1984,40,W,1054.4
Other,84/85 ,1985,40,W,713.4
Other,85/86 ,1986,40,W,539.1
Other,86/87 ,1987,40,W,221.6
Other,87/88 ,1988,40,W,94.8
Other,89/90 ,1990,40,W,188.2
Other,90/91 ,1991,40,W,153.7
Other,91/92 ,1992,40,W,266.3
Other,92/93 ,1993,40,W,289.1
Other,93/94 ,1994,40,W,290.3
Other,94/95 ,1995,40,W,263.9
Other,95/96 ,1996,40,W,254.1
Other,96/97 ,1997,40,W,269.6
Other,97/98 ,1998,40,W,262.6
Other,98/99 ,1999,40,W,293.5
Other,99/00 ,2000,40,W,107.8
Other,00/01 ,2001,40,W,95
Other,01/02 ,2002,40,W,157.8
Other,02/03 ,2003,40,W,100
Other,03/04 ,2004,40,W,242.7
Other,04/05 ,2005,40,W,255.3
Other,05/06 ,2006,40,W,96.3
Other,06/07 ,2007,40,W,0
YEM,82/83 ,1983,40,W,26.9
YEM,83/84 ,1984,40,W,3
YEM,84/85 ,1985,40,W,46.3
YEM,85/86 ,1986,40,W,15.8
YEM,86/87 ,1987,40,W,0
YEM,87/88 ,1988,40,W,0
YEM,89/90 ,1990,40,W,0.8
YEM,90/91 ,1991,40,W,0
YEM,91/92 ,1992,40,W,0
YEM,92/93 ,1993,40,W,0.8
YEM,93/94 ,1994,40,W,0
YEM,94/95 ,1995,40,W,0
YEM,95/96 ,1996,40,W,1
YEM,96/97 ,1997,40,W,3
YEM,97/98 ,1998,40,W,2.1
YEM,98/99 ,1999,40,W,0.4
YEM,99/00 ,2000,40,W,0
YEM,00/01 ,2001,40,W,0.7
YEM,01/02 ,2002,40,W,1.3
YEM,02/03 ,2003,40,W,0
YEM,03/04 ,2004,40,W,0
YEM,04/05 ,2005,40,W,0.6
YEM,05/06 ,2006,40,W,1.4
YEM,06/07 ,2007,40,W,0
TAR,82/83 ,1983,40,W,313.1
TAR,83/84 ,1984,40,W,330
TAR,84/85 ,1985,40,W,160.9
TAR,85/86 ,1986,40,W,195.3
TAR,86/87 ,1987,40,W,112.9
TAR,87/88 ,1988,40,W,58.6
TAR,89/90 ,1990,40,W,216.5
TAR,90/91 ,1991,40,W,222.4
TAR,91/92 ,1992,40,W,260.6
TAR,92/93 ,1993,40,W,401.1
TAR,93/94 ,1994,40,W,402
TAR,94/95 ,1995,40,W,464.8
TAR,95/96 ,1996,40,W,412.9
TAR,96/97 ,1997,40,W,446
TAR,97/98 ,1998,40,W,187
TAR,98/99 ,1999,40,W,146.2
TAR,99/00 ,2000,40,W,191.3
TAR,00/01 ,2001,40,W,310.7
TAR,01/02 ,2002,40,W,336.6
TAR,02/03 ,2003,40,W,319.5
TAR,03/04 ,2004,40,W,271.8
TAR,04/05 ,2005,40,W,286.1
TAR,05/06 ,2006,40,W,208.5
TAR,06/07 ,2007,40,W,0
Other,82/83 ,1983,41,S,506.3
Other,83/84 ,1984,41,S,1057
Other,84/85 ,1985,41,S,857.2
Other,85/86 ,1986,41,S,597.9
Other,86/87 ,1987,41,S,154.2
```

```
Other,87/88 ,1988,41,S,100.1
Other,89/90 ,1990,41,S,249.8
Other,90/91 ,1991,41,S,345
Other,91/92 ,1992,41,S,422.4
Other,92/93 ,1993,41,S,665.1
Other,93/94 ,1994,41,S,540.6
Other,94/95 ,1995,41,S,697.6
Other,95/96 ,1996,41,S,668.1
Other,96/97 ,1997,41,S,538.6
Other,97/98 ,1998,41,S,668.7
Other,98/99 ,1999,41,S,638.3
Other,99/00 ,2000,41,S,520.1
Other,00/01 ,2001,41,S,408.7
Other,01/02 ,2002,41,S,359.1
Other,02/03 ,2003,41,S,393.2
Other,03/04 ,2004,41,S,379.3
Other,04/05 ,2005,41,S,320
Other,05/06 ,2006,41,S,338
Other,06/07 ,2007,41,S,357
YEM,82/83 ,1983,41,S,66.9
YEM,83/84 ,1984,41,S,126.6
YEM,84/85 ,1985,41,S,117.1
YEM,85/86 ,1986,41,S,89.4
YEM,86/87 ,1987,41,S,46.8
YEM,87/88 ,1988,41,S,12.5
YEM,89/90 ,1990,41,S,10.9
YEM,90/91 ,1991,41,S,40.5
YEM,91/92 ,1992,41,S,47.8
YEM,92/93 ,1993,41,S,60.8
YEM,93/94 ,1994,41,S,27.2
YEM,94/95 ,1995,41,S,31
YEM,95/96 ,1996,41,S,26.8
YEM,96/97 ,1997,41,S,47
YEM,97/98 ,1998,41,S,78.4
YEM,98/99 ,1999,41,S,59
YEM,99/00 ,2000,41,S,72.1
YEM,00/01 ,2001,41,S,63.9
YEM,01/02 ,2002,41,S,78.4
YEM,02/03 ,2003,41,S,76.5
YEM,03/04 ,2004,41,S,102.4
YEM,04/05 ,2005,41,S,77.6
YEM,05/06 ,2006,41,S,133.5
YEM,06/07 ,2007,41,S,237.4
TAR,82/83 ,1983,41,S,23.3
TAR,83/84 ,1984,41,S,69.5
TAR,84/85 ,1985,41,S,61.4
TAR,85/86 ,1986,41,S,18.5
TAR,86/87 ,1987,41,S,9.6
TAR,87/88 ,1988,41,S,0
TAR,89/90 ,1990,41,S,10.4
TAR,90/91 ,1991,41,S,41.3
TAR,91/92 ,1992,41,S,114.7
TAR,92/93 ,1993,41,S,59
TAR,93/94 ,1994,41,S,34.4
TAR,94/95 ,1995,41,S,65.8
TAR,95/96 ,1996,41,S,90.6
TAR,96/97 ,1997,41,S,127.7
TAR,97/98 ,1998,41,S,61.3
TAR,98/99 ,1999,41,S,3.4
TAR,99/00 ,2000,41,S,16.6
TAR,00/01 ,2001,41,S,29.3
TAR,01/02 ,2002,41,S,0
TAR,02/03 ,2003,41,S,95
TAR,03/04 ,2004,41,S,0
TAR,04/05 ,2005,41,S,117
TAR,05/06 ,2006,41,S,45
TAR,06/07 ,2007,41,S,35
Other,82/83 ,1983,41,W,497.1
Other,83/84 ,1984,41,W,475.6
Other,84/85 ,1985,41,W,407.7
Other,85/86 ,1986,41,W,213.8
Other,86/87 ,1987,41,W,39.7
Other,87/88 ,1988,41,W,29.9
Other,89/90 ,1990,41,W,215.2
Other,90/91 ,1991,41,W,201.2
Other,91/92 ,1992,41,W,388.1
Other,92/93 ,1993,41,W,461.6
```

```
Other,93/94 ,1994,41,W,222.2
Other,94/95 ,1995,41,W,360
Other,95/96 ,1996,41,W,295.1
Other,96/97 ,1997,41,W,375.1
Other,97/98 ,1998,41,W,390.2
Other,98/99 ,1999,41,W,251.6
Other,99/00 ,2000,41,W,175
Other,00/01 ,2001,41,W,244.9
Other,01/02 ,2002,41,W,224.1
Other,02/03 ,2003,41,W,300.5
Other,03/04 ,2004,41,W,227.2
Other,04/05 ,2005,41,W,310.3
Other,05/06 ,2006,41,W,376
Other,06/07 ,2007,41,W,0
YEM,82/83 ,1983,41,W,161.4
YEM,83/84 ,1984,41,W,153.2
YEM,84/85 ,1985,41,W,150.2
YEM,85/86 ,1986,41,W,87.4
YEM,86/87 ,1987,41,W,43
YEM,87/88 ,1988,41,W,17.5
YEM,89/90 ,1990,41,W,45.1
YEM,90/91 ,1991,41,W,51.4
YEM,91/92 ,1992,41,W,81.2
YEM,92/93 ,1993,41,W,59.2
YEM,93/94 ,1994,41,W,46.8
YEM,94/95 ,1995,41,W,63.6
YEM,95/96 ,1996,41,W,77.2
YEM,96/97 ,1997,41,W,99.9
YEM,97/98 ,1998,41,W,87.3
YEM,98/99 ,1999,41,W,142.5
YEM,99/00 ,2000,41,W,72.4
YEM,00/01 ,2001,41,W,96.3
YEM,01/02 ,2002,41,W,54.4
YEM,02/03 ,2003,41,W,98.8
YEM,03/04 ,2004,41,W,90.5
YEM,04/05 ,2005,41,W,83
YEM,05/06 ,2006,41,W,229.5
YEM,06/07 ,2007,41,W,0
TAR,82/83 ,1983,41,W,264.2
TAR,83/84 ,1984,41,W,188.3
TAR,84/85 ,1985,41,W,165.3
TAR,85/86 ,1986,41,W,45.5
TAR,86/87 ,1987,41,W,8.4
TAR,87/88 ,1988,41,W,4
TAR,89/90 ,1990,41,W,22.7
TAR,90/91 ,1991,41,W,152.4
TAR,91/92 ,1992,41,W,45.1
TAR,92/93 ,1993,41,W,123.4
TAR,93/94 ,1994,41,W,115.2
TAR,94/95 ,1995,41,W,170.5
TAR,95/96 ,1996,41,W,204.4
TAR,96/97 ,1997,41,W,183.9
TAR,97/98 ,1998,41,W,26.6
TAR,98/99 ,1999,41,W,39
TAR,99/00 ,2000,41,W,34
TAR,00/01 ,2001,41,W,5.3
TAR,01/02 ,2002,41,W,17.5
TAR,02/03 ,2003,41,W,27.5
TAR,03/04 ,2004,41,W,17.5
TAR,04/05 ,2005,41,W,113.3
TAR,05/06 ,2006,41,W,40.5
TAR,06/07 ,2007,41,W,0
Other,82/83 ,1983,42,S,89.4
Other,83/84 ,1984,42,S,189.5
Other,84/85 ,1985,42,S,389.1
Other,85/86 ,1986,42,S,272.8
Other,86/87 ,1987,42,S,170.5
Other,87/88 ,1988,42,S,258.5
Other,89/90 ,1990,42,S,163.7
Other,90/91 ,1991,42,S,101.8
Other,91/92 ,1992,42,S,134.1
Other,92/93 ,1993,42,S,115.6
Other,93/94 ,1994,42,S,121.3
Other,94/95 ,1995,42,S,203.6
Other,95/96 ,1996,42,S,183.1
Other,96/97 ,1997,42,S,417.9
Other,97/98 ,1998,42,S,288.4
```

```
Other,98/99 ,1999,42,S,101.9
Other,99/00 ,2000,42,S,100.3
Other,00/01 ,2001,42,S,70.5
Other,01/02 ,2002,42,S,92
Other,02/03 ,2003,42,S,64.4
Other,03/04 ,2004,42,S,111
Other,04/05 ,2005,42,S,121.8
Other,05/06 ,2006,42,S,81.6
Other,06/07 ,2007,42,S,69.4
YEM,82/83 ,1983,42,S,348.4
YEM,83/84 ,1984,42,S,904.1
YEM,84/85 ,1985,42,S,709
YEM,85/86 ,1986,42,S,535.2
YEM,86/87 ,1987,42,S,246.9
YEM,87/88 ,1988,42,S,367.9
YEM,89/90 ,1990,42,S,171.8
YEM,90/91 ,1991,42,S,101.7
YEM,91/92 ,1992,42,S,109.2
YEM,92/93 ,1993,42,S,45
YEM,93/94 ,1994,42,S,68.9
YEM,94/95 ,1995,42,S,93.4
YEM,95/96 ,1996,42,S,103.8
YEM,96/97 ,1997,42,S,169.7
YEM,97/98 ,1998,42,S,155.3
YEM,98/99 ,1999,42,S,92.3
YEM,99/00 ,2000,42,S,221.6
YEM,00/01 ,2001,42,S,214.2
YEM,01/02 ,2002,42,S,233.8
YEM,02/03 ,2003,42,S,166.2
YEM,03/04 ,2004,42,S,165.8
YEM,04/05 ,2005,42,S,139.1
YEM,05/06 ,2006,42,S,102.5
YEM,06/07 ,2007,42,S,93
TAR,82/83 ,1983,42,S,0
TAR,83/84 ,1984,42,S,5.4
TAR,84/85 ,1985,42,S,4.8
TAR,85/86 ,1986,42,S,6
TAR,86/87 ,1987,42,S,0
TAR,87/88 ,1988,42,S,0
TAR,89/90 ,1990,42,S,0
TAR,90/91 ,1991,42,S,0
TAR,91/92 ,1992,42,S,1.2
TAR,92/93 ,1993,42,S,0
TAR,93/94 ,1994,42,S,0
TAR,94/95 ,1995,42,S,0
TAR,95/96 ,1996,42,S,0
TAR,96/97 ,1997,42,S,0
TAR,97/98 ,1998,42,S,0
TAR,98/99 ,1999,42,S,0
TAR,99/00 ,2000,42,S,0
TAR,00/01 ,2001,42,S,0
TAR,01/02 ,2002,42,S,0
TAR,02/03 ,2003,42,S,0
TAR,03/04 ,2004,42,S,0
TAR,04/05 ,2005,42,S,0
TAR,05/06 ,2006,42,S,0
TAR,06/07 ,2007,42,S,0
Other,82/83 ,1983,42,W,198.9
Other,83/84 ,1984,42,W,284.9
Other,84/85 ,1985,42,W,291.2
Other,85/86 ,1986,42,W,175.1
Other,86/87 ,1987,42,W,108.1
Other,87/88 ,1988,42,W,147
Other,89/90 ,1990,42,W,84.3
Other,90/91 ,1991,42,W,110.6
Other,91/92 ,1992,42,W,76.3
Other,92/93 ,1993,42,W,136.1
Other,93/94 ,1994,42,W,82.4
Other,94/95 ,1995,42,W,138.6
Other,95/96 ,1996,42,W,168
Other,96/97 ,1997,42,W,323.7
Other,97/98 ,1998,42,W,231.9
Other,98/99 ,1999,42,W,61.5
Other,99/00 ,2000,42,W,49.5
Other,00/01 ,2001,42,W,128.7
Other,01/02 ,2002,42,W,108
Other,02/03 ,2003,42,W,56.9
```

```
Other,03/04 ,2004,42,W,93.9
Other,04/05 ,2005,42,W,92.8
Other,05/06 ,2006,42,W,53.5
Other,06/07 ,2007,42,W,0
YEM,82/83 ,1983,42,W,253.1
YEM,83/84 ,1984,42,W,293.7
YEM,84/85 ,1985,42,W,232.8
YEM,85/86 ,1986,42,W,292.5
YEM,86/87 ,1987,42,W,189.3
YEM,87/88 ,1988,42,W,168.3
YEM,89/90 ,1990,42,W,93.4
YEM,90/91 ,1991,42,W,78.4
YEM,91/92 ,1992,42,W,79.1
YEM,92/93 ,1993,42,W,66.1
YEM,93/94 ,1994,42,W,66.4
YEM,94/95 ,1995,42,W,86.8
YEM,95/96 ,1996,42,W,67.9
YEM,96/97 ,1997,42,W,108.9
YEM,97/98 ,1998,42,W,98.2
YEM,98/99 ,1999,42,W,124.1
YEM,99/00 ,2000,42,W,162.3
YEM,00/01 ,2001,42,W,164.8
YEM,01/02 ,2002,42,W,161
YEM,02/03 ,2003,42,W,149.2
YEM,03/04 ,2004,42,W,142.8
YEM,04/05 ,2005,42,W,116.1
YEM,05/06 ,2006,42,W,116.7
YEM,06/07 ,2007,42,W,0
TAR,82/83 ,1983,42,W,0
TAR,83/84 ,1984,42,W,0
TAR,84/85 ,1985,42,W,0
TAR,85/86 ,1986,42,W,0
TAR,86/87 ,1987,42,W,0
TAR,87/88 ,1988,42,W,0
TAR,89/90 ,1990,42,W,0
TAR,90/91 ,1991,42,W,2
TAR,91/92 ,1992,42,W,0
TAR,92/93 ,1993,42,W,0
TAR,93/94 ,1994,42,W,7
TAR,94/95 ,1995,42,W,0
TAR,95/96 ,1996,42,W,0
TAR,96/97 ,1997,42,W,0
TAR,97/98 ,1998,42,W,0
TAR,98/99 ,1999,42,W,0
TAR,99/00 ,2000,42,W,0
TAR,00/01 ,2001,42,W,0
TAR,01/02 ,2002,42,W,0
TAR,02/03 ,2003,42,W,3
TAR,03/04 ,2004,42,W,3.6
TAR,04/05 ,2005,42,W,0
TAR,05/06 ,2006,42,W,0
TAR,06/07 ,2007,42,W,0
Other,82/83 ,1983,45,S,0
Other,83/84 ,1984,45,S,6.1
Other,84/85 ,1985,45,S,5.6
Other,85/86 ,1986,45,S,4.4
Other,86/87 ,1987,45,S,0
Other,87/88 ,1988,45,S,14
Other,89/90 ,1990,45,S,9
Other,90/91 ,1991,45,S,11.4
Other,91/92 ,1992,45,S,7.5
Other,92/93 ,1993,45,S,21.2
Other,93/94 ,1994,45,S,18.8
Other,94/95 ,1995,45,S,13.2
Other,95/96 ,1996,45,S,31.6
Other,96/97 ,1997,45,S,157.1
Other,97/98 ,1998,45,S,54
Other,98/99 ,1999,45,S,13.4
Other,99/00 ,2000,45,S,36.9
Other,00/01 ,2001,45,S,32.1
Other,01/02 ,2002,45,S,170.9
Other,02/03 ,2003,45,S,77.7
Other,03/04 ,2004,45,S,1.9
Other,04/05 ,2005,45,S,12.2
Other,05/06 ,2006,45,S,32.5
Other,06/07 ,2007,45,S,42.1
YEM,82/83 ,1983,45,S,3.2
```

```
YEM,83/84 ,1984,45,S,5.6
YEM,84/85 ,1985,45,S,1
YEM,85/86 ,1986,45,S,0
YEM,86/87 ,1987,45,S,0
YEM,87/88 ,1988,45,S,0.5
YEM,89/90 ,1990,45,S,116
YEM,90/91 ,1991,45,S,133.1
YEM,91/92 ,1992,45,S,174.6
YEM,92/93 ,1993,45,S,197.6
YEM,93/94 ,1994,45,S,139
YEM,94/95 ,1995,45,S,196.6
YEM,95/96 ,1996,45,S,144.9
YEM,96/97 ,1997,45,S,94.5
YEM,97/98 ,1998,45,S,117.8
YEM,98/99 ,1999,45,S,102.5
YEM,99/00 ,2000,45,S,23.8
YEM,00/01 ,2001,45,S,20.9
YEM,01/02 ,2002,45,S,32.1
YEM,02/03 ,2003,45,S,4.3
YEM,03/04 ,2004,45,S,4
YEM,04/05 ,2005,45,S,11.6
YEM,05/06 ,2006,45,S,4.7
YEM,06/07 ,2007,45,S,1.5
TAR,82/83 ,1983,45,S,0
TAR,83/84 ,1984,45,S,0
TAR,84/85 ,1985,45,S,0
TAR,85/86 ,1986,45,S,0
TAR,86/87 ,1987,45,S,0
TAR,87/88 ,1988,45,S,0
TAR,89/90 ,1990,45,S,0
TAR,90/91 ,1991,45,S,0
TAR,91/92 ,1992,45,S,0
TAR,92/93 ,1993,45,S,0
TAR,93/94 ,1994,45,S,0
TAR,94/95 ,1995,45,S,0
TAR,95/96 ,1996,45,S,0
TAR,96/97 ,1997,45,S,0
TAR,97/98 ,1998,45,S,0
TAR,98/99 ,1999,45,S,0
TAR,99/00 ,2000,45,S,0
TAR,00/01 ,2001,45,S,0
TAR,01/02 ,2002,45,S,0
TAR,02/03 ,2003,45,S,0
TAR,03/04 ,2004,45,S,0
TAR,04/05 ,2005,45,S,0
TAR,05/06 ,2006,45,S,0
TAR,06/07 ,2007,45,S,0
Other,82/83 ,1983,45,W,23.7
Other,83/84 ,1984,45,W,5.1
Other,84/85 ,1985,45,W,8
Other,85/86 ,1986,45,W,8.8
Other,86/87 ,1987,45,W,20
Other,87/88 ,1988,45,W,1.6
Other,89/90 ,1990,45,W,5.7
Other,90/91 ,1991,45,W,22.5
Other,91/92 ,1992,45,W,9.6
Other,92/93 ,1993,45,W,27.9
Other,93/94 ,1994,45,W,15.9
Other,94/95 ,1995,45,W,15.6
Other,95/96 ,1996,45,W,19.7
Other,96/97 ,1997,45,W,43.7
Other,97/98 ,1998,45,W,25
Other,98/99 ,1999,45,W,11
Other,99/00 ,2000,45,W,69
Other,00/01 ,2001,45,W,49.5
Other,01/02 ,2002,45,W,57.3
Other,02/03 ,2003,45,W,9.3
Other,03/04 ,2004,45,W,0
Other,04/05 ,2005,45,W,13.7
Other,05/06 ,2006,45,W,7.5
Other,06/07 ,2007,45,W,0
YEM,82/83 ,1983,45,W,7.7
YEM,83/84 ,1984,45,W,17.9
YEM,84/85 ,1985,45,W,11.2
YEM,85/86 ,1986,45,W,3.9
YEM,86/87 ,1987,45,W,11.9
YEM,87/88 ,1988,45,W,2.4
```

```
YEM,89/90 ,1990,45,W,165.1
YEM,90/91 ,1991,45,W,163
YEM,91/92 ,1992,45,W,220.1
YEM,92/93 ,1993,45,W,129.3
YEM,93/94 ,1994,45,W,164
YEM,94/95 ,1995,45,W,173.6
YEM,95/96 ,1996,45,W,159.1
YEM,96/97 ,1997,45,W,148.5
YEM,97/98 ,1998,45,W,132.4
YEM,98/99 ,1999,45,W,155.4
YEM,99/00 ,2000,45,W,22.5
YEM,00/01 ,2001,45,W,33.8
YEM,01/02 ,2002,45,W,25.3
YEM,02/03 ,2003,45,W,15.6
YEM,03/04 ,2004,45,W,8.6
YEM,04/05 ,2005,45,W,18.5
YEM,05/06 ,2006,45,W,10.6
YEM,06/07 ,2007,45,W,0
TAR,82/83 ,1983,45,W,0
TAR,83/84 ,1984,45,W,0
TAR,84/85 ,1985,45,W,0
TAR,85/86 ,1986,45,W,0
TAR,86/87 ,1987,45,W,0
TAR,87/88 ,1988,45,W,0
TAR,89/90 ,1990,45,W,0
TAR,90/91 ,1991,45,W,0
TAR,91/92 ,1992,45,W,0
TAR,92/93 ,1993,45,W,0
TAR,93/94 ,1994,45,W,0
TAR,94/95 ,1995,45,W,55.1
TAR,95/96 ,1996,45,W,0
TAR,96/97 ,1997,45,W,0
TAR,97/98 ,1998,45,W,0
TAR,98/99 ,1999,45,W,0
TAR,99/00 ,2000,45,W,0
TAR,00/01 ,2001,45,W,0
TAR,01/02 ,2002,45,W,0
TAR,02/03 ,2003,45,W,0
TAR,03/04 ,2004,45,W,0
TAR,04/05 ,2005,45,W,0
TAR,05/06 ,2006,45,W,0
TAR,06/07 ,2007,45,W,0
```

mauis areas.csv

```
StatArea,Dist,Depth,Area_nm
45,0-4,Total,322.01
45,4-15,Total,916.62
42,0-4,Total,366.04
42,4-15,Total,953.39
41,0-4,Total,559.39
41,4-15,Total,1336.31
40,0-4,Total,487.55
40,4-15,Total,1121.63
45,0-4,<100,320.52
45,4-15,<100,711.29
42,0-4,<100,350.36
42,4-15,<100,784.51
41,0-4,<100,556.63
41,4-15,<100,1153.04
40,0-4,<100,487.55
40,4-15,<100,818.82
```