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AGREEMENT ON THE CONSERVATION OF SMALL CETACEANS OF THE BALTIC, NORTH EAST ATLANTIC, IRISH AND NORTH SEAS

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Agenda Item 3.1

SIMULATION STUDY ON REMOVAL RATES CONSISTENT WITH THE ASCOBANS CONSERVATION OBJECTIVE

(Prepared by Peter Evans and Justin Cooke)

1. In 2023, the Joint Bycatch Working Group of ACCOBAMS and ASCOBANS was tasked with reviewing the appropriateness of the conservation objectives that ASCOBANS had been applying for many years since Resolution 8.5. Those objectives had defined “unacceptable interactions” as being a total anthropogenic removal above 1.7% of the best available estimate of abundance, with the precautionary objective to reduce anthropogenic removals to less than 1% of the best available abundance estimate.

2. Two workshops were held in April and May of 2023. One of the main conclusions from the workshops was that those thresholds were too high and needed revising downwards. The workshops also considered whether the ASCOBANS conservation objective should continue to be to “restore or maintain populations at ≥80% of carrying capacity with a 95% probability over an unspecified more or less infinite time period”, or if these parameters also needed modifying.

3. Proposals under discussion at the two workshops were to consider whether setting the probability at 95% was feasible or needed reducing to 80%, and whether one could set a specific time window such as 100 years, as used within the US Marine Mammal Protection Act, or work towards a lower one such as 20 years. These aspects were not fully resolved, and it was concluded that simulation studies were needed to determine the levels of removals (notably bycatch) that would be consistent with the ASCOBANS conservation objective, and that those should cover a wide range of alternative scenarios. Justin Cooke was contracted to perform these further investigations and then report back – see Annex 1. This annex forms that report which Parties and Range States are invited to review and provide feedback. The report will in due course also be peer reviewed.

Action requested:

4. The Advisory Committee is requested to review the report in Annex 1 and provide feedback.

Annex 1

SIMULATION STUDY ON REMOVAL RATES CONSISTENT WITH THE ASCOBANS CONSERVATION OBJECTIVE

Version 31.07.2026

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SUMMARY

Simulation studies were conducted to determine the rate of removals (e.g. bycatch) consistent with achieving the ASCOBANS conservation objective of ensuring that affected marine mammal populations are maintained at or above 80% of their carrying capacity (0.8*K*) with the proposed 80-95% probability level over the proposed time horizon of 20-100 years. The removal rates tested included the 1.0% and 1.7% previously recommended as thresholds by ASCOBANS, and the rates of 0.7% and 0.2% that arise from applying the PBR rule with Recovery Factors of 0.35 and 0.1 respectively, using the default value of R_{max} (0.04), as recommended by an OSPAR Working Group.

Because carrying capacity is difficult to determine in the face of environmental variability and incomplete historical records, carrying capacity is defined dynamically for any scenario as the population level in the equivalent scenario without removals. Different scenarios were tested in which the population, in the absence of removals, was stable, increasing (recovering), decreasing, or fluctuating, and with low (0.02), medium (0.04) or high (0.08) values of R_{max}.

The results show little difference between whether the removal rate refers to an assumed known population size, or to one estimated from surveys using the N_{min} rule (lower 20%-ile of the distribution of the estimate). In the latter case, alternative assumptions about population monitoring (surveys every 6 or 12 years; CVs ranging from 0.15 to 0.35; using only the latest estimate or the average of the last three) also have little effect on whether a nominal removal rate is compatible with the conservation objective. This indicates that the N_{min} rule adequately accounts for uncertainty in population size.

The true value of R_{max} in the simulated population is found to be the most influential factor: removal rates of 1% and 1.7% of population size are compatible with the 0.8*K* objective only if R_{max} is high. A removal rate of 0.7% is largely compatible with the conservation objective if R_{max} is medium or high, but not for low R_{max} with a time horizon beyond 20 years. A removal rate of 0.2% is compatible with the objective in all scenarios including those with low R_{max}.

The results show that for any given value of R_{max}, the choice of probability (50%, 80% or 95%) with which the objective is to be satisfied is relatively unimportant. Two alternative definitions of the probability level (as a percentile of ratios or a ratio of percentiles) also yield virtually identical results.

A review of approaches to estimate R_{max} for small cetaceans shows that none of the methods used to date yield reliable values for R_{max}, but that R_{max} is likely to be lower on average for small cetaceans than for baleen whales, in contrast to the predictions of some inter-specific allometric models. The default R_{max} value of 0.04 used for implementation of the PBR rule may not be sufficiently conservative for all small cetacean populations. It is recommended that the previously adopted removal thresholds of 1% and 1.7% be reduced to 0.7%, but that lower thresholds be considered on a case-by-case basis for populations of high conservation interest that are suspected to have below average resilience.

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1 INTRODUCTION

This document was produced pursuant to the ASCOBANS Workshops to Recommend Small Cetacean Conservation Objectives in Relation to Anthropogenic Removals (ASCOBANS, 2023).

Removal thresholds have been considered by ASCOBANS and other bodies for the achievement of the ASCOBANS conservation objective of restoring or maintaining biological management units at 80% percent or more of their carrying capacity, as reiterated in Resolution 8.5 (Rev MOP9) (www.ascobans.org/en/documents/mop-resolutions). These include both fixed percentages of population size, and various implementations of the Potential Biological Removal (PBR) formula.

The two central population parameters in this context are the carrying capacity, K, of a cetacean population and its intrinsic rate of increase, conventionally denoted R_{max}. The concept of carrying capacity was originally developed with deterministic models in mind, and we discuss how it can be interpreted in the face of the levels of variability that occur in marine ecosystems, in relation to the ASCOBANS conservation objective.

R_{max} determines the level of removals that a population can withstand, and the rate at which it can recover from past overexploitation when the removals are reduced or eliminated. The concept of R_{max} was also originally developed with deterministic models in mind, where the rate of natural increase (the actual rate of increase, positive or negative, plus the removal rate) of a population depends only on the population density. Under this assumption, the natural rate of increase is a maximum at low population sizes, hence the term R_{max}. In a variable environment, the rate of increase depends on variable factors other than population size, such that R_{max} is not actually the maximum possible rate of increase, but rather the average rate of increase at low population sizes, which is a potential source of confusion.

As discussed below, R_{max} is difficult to estimate for populations of small cetaceans, hence almost all applications of the PBR (Potential Biological Removal) formula to small cetaceans have used the default value of R_{max} = 0.04 for cetaceans. Thus, the PBR approaches reduce in practice to a fixed percentage of population size. The experience of the IWC Scientific Committee is that the default value is probably sufficiently conservative for most baleen whale populations, excepting those that are substantially impacted by sublethal factors in addition to direct removals. However, comparison of life histories of baleen whales with small cetaceans suggests that R_{max} is likely to be lower for the latter, contrary to the predictions of some allometric models.

It is therefore necessary to allow for the possibility of R_{max} being below the default value of 0.04 for small cetaceans in the ASCOBANS area. This paper presents results of simulation studies conducted to determine the levels of removals (e.g. bycatch) that would be consistent with the ASCOBANS conservation objective. These cover a wide range of alternative scenarios, including those with assumed R_{max} values of 0.02 and 0.08 in addition to the conventional default value of 0.04.

The bycatch levels considered in the simulation studies are the two percentage thresholds (1% and 1.7%) specified in Resolution 8.5 and alternative thresholds of 0.2% and 0.7%, which correspond to use of the PBR formula with Recovery Factors 0.1 or 0.35, as recommended by OSPAR (2023) for meeting the ASCOBANS conservation objective.

2 KEY ISSUES

2.1 Removal thresholds

2.1.1 The PBR formula

The PBR formula provides a recommended maximum level of direct removal from a marine mammal population. It was developed by Wade (1998) for use in the implementation of certain provisions of the US Marine Mammal Protection Act. The formula is:

$$PBR = ½ F_R \times R_{max} \times N_{min}$$

where R_{max} is the maximum intrinsic growth rate of the population, F_R is the Recovery Factor, and N_{min} is the lower 20%-ile of the distribution of the best recent estimate of population size. The term N_{min} is potentially confusing because it is not a minimum population size, but merely a moderately conservative estimate of population size, as discussed below.

R_{max} is the intrinsic growth rate of the population. If a specific estimate of R_{max} is not available for the population in question, the default value of R_{max} = 0.04 can be used for cetaceans.

The Recovery Factor, F_R, originally referred to the proportion of the natural increase that is allocated to bycatch, the rest being available to allow recovery of the population. In practice, F_R is now used as a tuneable parameter to achieve conservation targets and does not necessarily retain its original meaning.

The factor ½ is derived from the original objective that a population should approach a level not less than 0.5*K* (where *K* denotes carrying capacity) coupled with the assumption that the population level of maximum net annual increment is also 0.5*K*. To adapt the PBR to the ASCOBANS objective of maintaining a population at or above 0.8*K*, the factor of ½ should in principle be changed to ⅕, but the practice has been to retain the ½ factor and to make the adjustment by tuning the value of F_R.

The OSPAR (2023) working group recommended, based on simulation results for a specific set of scenarios that they tested, F_R values ranging from 0.1 in data-poor scenarios to 0.35 in data-rich scenarios to achieve the ASCOBANS 0.8*K* conservation objective with 80% probability after 100 years. Given that the default value R_{max} = 0.04 was used, these F_R values correspond to bycatch thresholds of 0.2% and 0.7% of population size (as estimated by N_{min})

2.1.2 Percentage thresholds

ASCOBANS Resolution 3.3 (updated in Resolution 8.5 rev COP9) specifies bycatch thresholds of 1% (as a precautionary aim for all species) and 1.7% (as a maximum acceptable level for harbour porpoise) of the "best available" estimate of population size or abundance. The origin of the 1.7% threshold was a deterministic calculation of the removal rate that would stabilize a population with R_{max} = 0.04 at the level of 0.8*K*, if it is assumed that the population level for the maximum net annual increment is 0.6*K*.

The Resolution does not define what constitutes a "best" estimate, but in practice the percentage has been applied to published estimates which are usually maximum-likelihood estimates. The distribution of abundance estimates is usually assumed to be approximated by a log-normal distribution, except for estimates based on very sparse data. For abundance estimates with typical levels of precision (CV in the range 0.15 – 0.35), the mode of the log-normal distribution (the maximum likelihood estimate) lies between the 36th and 44th percentile of the distribution. The PBR formula uses the 20th percentile for the abundance estimate (N_{min}). For the above range of CVs, N_{min} is 10-15% lower than the mode. Given the performance advantages in using the 20th percentile compared to higher percentiles (Wade 1998), and the modest size of the difference between N_{min} and the modal estimate, it seems appropriate to standardize

on N_{min} as the "best" estimator for a cetacean population. This allows PBR-derived removal rates that use the default value of R_{max} to be expressed as simple percentages of the population estimate.

2.2 Definition of carrying capacity (*K*)

Carrying capacity (*K*) is challenging to define and to estimate, not least because environmental and ecological variation can cause substantial population fluctuations even in the absence of direct removals. Reference to historical population levels is problematic because of the fragmentary nature of much of the historical information, and because natural and manmade environmental changes in the meantime reduce their applicability to today's situation.

The classical (static) model of carrying capacity (*K*) is a constant level at which an ecological population will stabilise in the absence of anthropogenic removals. When all other factors remain constant, the population is predicted in the absence of removals to tend towards the carrying capacity: a population below *K* will recover towards *K*, while a population already at *K* will remain constant (Fig. 1a). A population above *K* will decline towards *K*, although this case begs the question as to how the population exceeded *K* in the first place. In the presence of a limited degree of fluctuation about a constant average (Fig 1b), it may still be possible to identify a single population level that corresponds to an "average" *K*, but in the face of substantial fluctuations caused by external ecological factors (Fig. 1c), it is harder to identify a fixed level that corresponds to *K*.

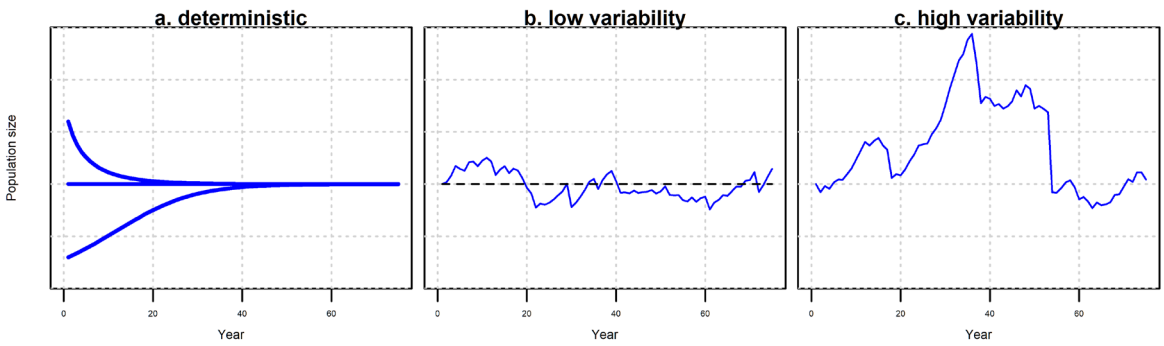

Fig. 1. Schematic illustration of definition of K in deterministic cases (a) and in the presence of low (b) or high (c) variability.

In the context of managing anthropogenic removals, such as bycatch, carrying capacity can be defined dynamically as the population level that would pertain in the absence of direct removals. The ASCOBANS conservation objective then amounts to ensuring that bycatch and other removals do not reduce a population by more than 20% below the level it would have in the absence of bycatch and other direct removals.

The ASCOBANS 0.8*K* conservation objective is understood here to apply specifically to the context of managing removals. Satisfaction of the ASCOBANS conservation objective does not necessarily imply that population status would be favourable relative to other criteria, such as the "favourable conservation status" criterion of the Habitats Directive, or to the "good environmental status" criteria of the Marine Strategy Framework Directive.

The question of how to choose or estimate the probability with which the ASCOBANS objective is achieved involves some technical issues which are discussed below.

2.3 Definition and estimation of R_{max}

2.3.1 Introduction

The intrinsic growth rate, *r*, of a population denotes the rate of increase that would pertain under current circumstances in the absence of offtake. The quantity R_{max} as used in the PBR and related management approaches is based on the assumption of a deterministic population dynamics model in which the only variable affecting the growth rate, *r*, is population density. In such models, the maximum growth rate is achieved at low population sizes, where "low" means low enough for reproduction and survival rates not to be affected by density-dependent factors, but not so low that random events in the lives of individuals, and other small-population risks such as inbreeding, dominate the dynamics of the population.

In the face of environmental variability, the relevant quantity is not the maximum possible rate of increase but the average rate of increase (in the absence of offtake) at low population size. Because it is not a maximum, the notation R_0 would have been preferable, but we retain the notation R_{max} for consistency with the recent literature. R_{max} is the average realised rate of increase at low population size, under average environmental conditions, while we use R_{opt} to refer to the maximum rate of increase that the population can achieve in optimal conditions. R_{opt} is a characteristic of a species and depends on factors such as minimum calving interval, age at first reproduction and maximum longevity. R_{max} depends on these factors too, but also on the environmental conditions that can vary over time and between different populations of the same species. The ratio R_{max}/R_{opt} is always less than 1.0 and tends to be lower in a more variable environment. For example, a population may spend most of the time increasing exponentially at a rate close to R_{opt}, but be subject to irregular population crashes that reduce the average R_{max}. If the population is only observed during a period without such crashes, the R_{max} estimated from this period alone will be an overestimate of the long-term average R_{max}.

Only populations with $R_{max} > 0$ can persist in the longer term. The average expected persistence time (in the absence of offtake) of a population with $R_{max} > 0$ depends mainly on: (i) the value of R_{max}, (ii) the variability in *r*; and (iii) the absolute size of the population. Generally, larger populations (high *K*) in favourable ($R_{max} >> 0$) and stable (low variability in *r*) habitats will persist the longest. In rough terms, the natural range of occurrence of a species is enclosed by the contour $R_{max} = 0$, but temporary populations may become established outside this range from time to time. Populations in marginal habitat within but near the periphery of the range will tend to have lower values of R_{max} than those in favourable habitat in the core part of the range (Wilberg *et al*. 2024).

In the case of highly mobile species that are less prone to population differentiation, the effects of environmental variation may be more reflected in the distribution of the population, such that the species occurs continuously in core areas, while marginal areas are occupied more sporadically.

Wade (1998) recommended using $R_{max} = 0.04$ as a default value for cetaceans for the purpose of calculating the PBR. Given the lack of empirical estimates of R_{max} for most cetacean populations subject to bycatch, the default value of 0.04 has been used in almost all applications of the PBR to cetaceans since then.

The IWC Scientific Committee reviewed the question of R_{max} for baleen whales in a series of workshops (IWC 2009, 2010, 2011, 2014) devoted to the topic. Available empirical estimates of R_{max} for cetaceans are nearly all for populations of baleen whales that have been recovering from low levels, such as humpback and right whales, where the observed rates of increase have often been quite high (0.04 - 0.10; IWC 2009). That Committee uses the terminology *MSYR* for the sustainable rate of offtake at the level of maximum sustainable yield (MSYL). Under the assumption that MSYL = 0.6*K*, traditionally used by that Committee, MSYR corresponds to approximately 0.7 R_{max} in non-age-structured models. However, they used two alternative versions of MSYR; $MSYR_{mat}$ which applies to the mature population only, and $MSYR_{1+}$

which applies to the population aged 1 and above (i.e. all animals except calves of the year). The ratio $MSYR_{mat}/MSYR_{1+}$ is not simply the proportion of mature animals in the non-calf population, because $MSYR_{mat}$ is defined for the case where only mature animals are removed. The conclusion of the review was that $MSYR_{mat}$ = 0.04 had high plausibility, and could be assumed to ensure satisfactory conservation performance in typical cases, while a lower value, $MSYR_{1+}$ = 0.01 had medium plausibility and its use should ensure at least marginally acceptable conservation performance (IWC 2014b). These two values correspond to R_{max} values of 0.038 and 0.014 under the assumption MSYL = 0.6*K*. the corresponding R_{max} values under the assumption MSYL = 0.5*K*, which is implicit in the PBR formula, are 0.053 and 0.02.

Thus, for baleen whales, it appears that R_{max} = 0.04 is sufficiently conservative for general use, but sensitivity of conservation performance to R_{max} = 0.02 should routinely be evaluated. However, the question of whether R_{max} = 0.04 is a sufficiently conservative assumption for the smaller odontocetes has not yet been fully answered. A recent general review of the estimation of R_{max} for small cetaceans conducted for the IWC Scientific Committee (Wilberg et al. 2024) was inconclusive; the strengths and weaknesses of different approaches were noted, but no general recommendations were made for the value or values to be used for management purposes.

Approaches to the estimation of R_{max} to date have been based on the following types of data:

(i) direct observations of population trend
(ii) estimates of age and life history parameters from samples of stranded animals
(iii) longitudinal studies of individually recognisable living animals
(iv) inter-specific allometric relationships.

2.3.2 Direct estimates of population trend

An example of a direct trend estimate for a small cetacean in the wider ASCOBANS area is an increase rate of 9.6% (2.5% - 14.6%) per year for common dolphins in northwest Spanish waters over the period 2007-16 (Saavedra et al. 2018). It is tempting to use such trends as estimates or at least indicators of R_{max}. However, in the face of a scatter of increasing or decreasing trends in the abundance of different species in different areas, it would be misleading to treat the positive trends as indicators of R_{max} while zero or negative trends are interpreted as a population being near K, or stable or declining under the current rate of offtake, or subject to other negative influences. At best, an observed positive trend could be an indicator of R_{opt}, but only if it refers to a discrete population rather than merely part of the range of a larger population that is subject to shifts in distribution.

Trend information from wide-scale populations tends to be equivocal with respect to R_{max}. For example, the trend in abundance estimates for harbour porpoises in the North Sea estimated from the four SCANS surveys conducted over the period 1994-2022 was +0.5% (-1.1% to +2.2%) per year (Gilles et al. 2023). Given the estimated bycatch rate of 1.08-2.42% (Evans and Cordes 2023), the observed trend is consistent with R_{max} values ranging from near zero to arbitrarily high values.

To provide an indicator of R_{max}, a trend would need to be observed in a situation where an observed increase could plausibly represent a density-dependent recovery from a past reduction, as in the case of the recovering baleen whale populations noted above, or where the estimated offtake is high compared to the precision of the trend estimate.

2.3.3 Age distribution and other biological parameters from recovered carcasses

The age distribution of recovered carcasses, as determined by tooth analysis, provides some information on lifespan and other biological parameters, such as the age at first calving and the pregnancy rate (Learmonth et al. 2014; Kesselring et al. 2017).

On the assumption that carcasses of all ages are equally likely to be recovered, such data provide a profile of the distribution of ages at death. The samples are likely be subject to some biases. For example, smaller carcasses may be more likely to be consumed by scavengers before they are recovered. Carcasses recovered near fishing areas may be biassed towards bycaught animals, which may themselves be unrepresentative of the age distribution, for example if younger animals are more likely to become ensnared in nets (Mannocci et al. 2012).

Disregarding the possible biases, the expected age distribution of carcasses represents a mortality-weighted survival curve, adjusted for population trend. Assuming ages estimated to the nearest year, and a constant reproductive rate, the expected relative number of individuals aged *a* in the sample is proportional to:

$$(S_a - S_{a+1})\exp(-ar) \quad (1)$$

where S_a is the survival rate from birth to age *a* and *r* is the instantaneous population growth rate (adapted from Mannocci *et al.,* 2012).

In samples of carcasses of harbour porpoise from the North and Baltic Seas, Kesselring et al (2017) obtained mean ages at death of 5.70 (± 0.27) years for 311 animals from the North Sea and 3.67 (± 0.30) years for 215 animals from the Baltic Sea. They found a mean age at first appearance of a *corpus luteum* or a *corpus albicans* in ovaries of females of 4.95 ($\pm$0.60) years with no significant difference between the two areas. Murphy et al. (2015) found a mean age at death of 3.9 yr from 250 female harbour porpoise carcasses stranded on UK coasts and a mean age at of first corpus of 4.73 ($\pm$0.03) yr. The pregnancy rate among mature females was 0.29 (37/127), revised to 0.47 (48/102) by Murphy et al (2020). Learmonth et al. (2014) obtained similar results to Murphy et al (2015) for the porpoises collected on Scottish coasts.

Given a gestation time of 10-11 months (Learmonth et al. 2014), the above results imply a mean age at first calving of 5-6 years. Disregarding other biases, pregnancy rate is a positively biased proxy for the live birth rate if there are some miscarriages or stillbirths.

Table 1 shows the annual birth rate per mature female needed to match different observed mean ages at death using formula (1), assuming an age at first calving of five years, for a range of assumed values for the annual population trend, allowing for the mortality rate to differ between mature and immature animals. These results show that observed mean ages of death below 4 years are impossible (birth rate >100%) in an unbiased sample, and observed mean ages below 5 years are unlikely, given the above information on pregnancy rates.

The conclusion is that the samples with a low average age at death are biased towards young animals. This example illustrates a difficulty in inferring survival rates from ages at death. A high mortality rate alone cannot explain a low mean age at death if it is not balanced by a high birth rate, because a population decline tends to increase the average age. Because the relationship between mean age at death and birth rate is fairly insensitive to the population trend, these results imply that such data are rather uninformative about population trend and hence R_{max}.

Table 1. Annual birth rates per mature female needed to match different observed mean ages at death, for a range of assumed values for the population trend

Mean age at death	Population trend (r) -0.05	-0.025	0	0.025	0.05
3.5	1.39	1.35	1.29	1.22	1.12
4	1.11	1.07	1.02	0.96	0.88
4.5	0.92	0.88	0.84	0.79	0.72
5	0.78	0.75	0.71	0.67	0.6
5.5	0.67	0.65	0.62	0.58	0.57
6	0.59	0.57	0.54	0.51	0.51

2.3.4 Longitudinal studies of known, live individuals

Studies that involve following identified individuals over a long period have several advantages over studies based on carcasses. Account can be taken of the various forms of heterogeneity, such as different probabilities of capture by age and reproductive class, thereby enabling unbiased estimation of parameters such as survival and reproductive rates from biased samples. For these advantages to be realised, population size should not be too large relative to the amount of sampling, such that there is a good chance of capturing individuals three or more times. If the time series is long enough, temporal variation in the parameters can be estimated, thereby helping to elucidate the relationship between R_{max} and R_{opt}. An example in the ASCOBANS region is for bottlenose dolphins in east Scottish waters (Arso Civil *et al*. 2019). To date, reliable estimates of R_{max} have only been obtained from populations recovering from past exploitation (e.g. Cooke et al. 2001), but studies of other populations could provide information on equation (2) R_{max}, if the population density varies across a sufficient range over the duration of the study to enable detection of a density-dependent component in the observed variations in life history parameters.

2.3.5 Inferring R_{max} from inter-specific allometric relationships

Dillingham et al. (2016) proposed an approach to estimation of R_{max} based on inter-specific allometric relationships, building on an approach by Niel and Lebreton (2005) developed for birds. Under this approach, R_{max} for a species is predicted to be inversely proportional to the generation time:

$$R_{\max} = \alpha / T \quad (2)$$

where the constant of proportionality, α, was estimated to be 1.17 (± 0.09) for mammals, and *T*, the generation time, is the average age of parents when r = R_{max}. To fit this relationship, Dillingham et al. (2016) used "empirical" estimates of R_{max} for mammal species from Duncan et al. (2007). However, following the reference trail back reveals that the only empirical estimates for cetaceans were those from recovering baleen whales provided by Best (1993). The values for odontocetes were derived from a (different) allometric relationship assumed by Cole (1954). Hence the relationship in equation (2) does have empirical backing for odontocetes.

Duncan et al. (2007) found some support for the alternative allometric relationship:

$$R_{\max} \propto M^{-0.25} \quad (3)$$

where M is adult body mass. However, this finding is similarly compromised by the use of R_{max} values derived from a different allometric relationship rather than from empirical observations. Because baleen whales have a much larger body mass than the smaller odontocetes, the validity of the relationship in equation (3) for cetaceans can be tested by comparing these two groups of species.

Taylor et al. (2007) compiled demographic parameters for cetacean species. Table 2 summarises these for (a) baleen whales and (b) small cetaceans (i.e. odontocetes excluding sperm, killer and Baird's beaked whales). Taylor et al. (2007) derived values for the longevity of reproductive females; we have subtracted the age at first reproduction to give a female reproductive lifespan.

Table 2. Comparison of demographic parameters between baleen whales and small odontocetes

Species group	Age at 1st calving (yr)	Mean calving interval (yr)	Female reproductive lifespan (yr)	Body mass (kg) (geometric mean)
Baleen whales (n = 12)	9.8 (sd 3.4)	2.4 (sd 0.8)	46.2 (sd 4.3)	32 366 (CV 0.32)
Small cetaceans (n = 42)	8.7 (sd 2.5)	2.5 (sd1.1)	24.3 (sd 5.6)	168 (CV 0.60)

Source data: Taylor *et al*. 2007

We see that age at first calving and mean calving intervals are similar for the two groups, but that the mean female reproductive lifespan for small cetaceans is only about half that for baleen whales. The shorter reproductive lifespan of small cetaceans relative to baleen whales is not counterbalanced by a higher calving rate or lower age at first reproduction. Therefore, R_{max} is likely to be lower for small cetaceans than for baleen whales.

By contrast, the allometric relationship, equation (3), predicts that small cetaceans would have higher R_{max} values than baleen whales, by a factor of 2.7 times (the ratio of mean body weights taken to the -0.25 power). This is clearly impossible and raises serious doubts about such allometric inferences.

2.3.6 Conclusions on R_{max}

The above brief review suggests that none of the approaches to estimating R_{max} for small cetaceans can be considered reliable without further development, but that R_{max} is likely lower on average for small cetaceans than for baleen whales. The default value of R_{max}= 0.04, which is judged to be reasonably conservative for baleen whales, may not be sufficiently conservative for small cetaceans. The simulations reported below assume a range of 0.02 to 0.08 for the true value of R_{max}.

3 SIMULATION STUDIES ON REMOVAL RATES

3.1 Management strategy evaluation: the simulation approach

Simulation studies are an established approach in management strategy evaluation (MSE) and provide various benefits, as explained by Cooke (1999) and others. Through simulations we can investigate the likely effect of different bycatch levels in a broad range of scenarios despite the difficulty of determining which of the scenarios is most likely to come to pass.

The following components feature in the simulation framework:

(i) The dynamics of the simulated cetacean population
(ii) The generation of abundance estimates from surveys of the cetacean population

(iii) The application of the chosen removal rate to these abundance estimates to determine a quantity of removals that is deducted from the simulated population.

For comparison, runs were also conducted of a simplified system in which the cetacean population is assumed known, such that component (ii) can be omitted.

Components (i) and (ii) are both subject to stochasticity. To account for this, 1,000 replicates of each scenario were simulated.

The simulated population is subject to both short-term (annual) and medium-term (half-life 5-10 yr) environmental variability. The population is assumed to be large enough that demographic stochasticity from individual effects is negligible in the face of environmental variability.

The abundance estimates are assumed to be derived from surveys conducted every 6 or 12 years, and to be subject to sampling error with CVs ranging from 0.15 to 0.35. The removal limit is based either on the latest abundance estimate only, or on the average of the last three. It is assumed that removals up to the limit are taken from the population.

3.2 Operating Model

The model used to represent the simulated population is the age-aggregated stochastic modified logistic model that was used by IWC (2009) for examining baleen whale sustainable yield rates. The formula for the population growth at time *t* is:

$$r(x,t) = R_{\text{opt}}\left(1 - a\left(1+bx\right)^{z}\varepsilon_t\right)$$

where *x* is population size and *a* and *b* are constants relating to the size and suitability of the habitat. The deviants ε_t are non-negative (possibly correlated) random variables with mean 1.0 that reflect environmental variability. R_{opt} refers to the maximum possible growth rate of the population under good conditions. It is greater than R_{max} as defined in this document, which is the average intrinsic growth rate at low population sizes. R_{opt} is determined by physiological constraints, whereas R_{max} depends also on environmental factors. The two are related by:

$$R_{\text{max}} = R_{\text{opt}}(1 - a)$$

The population level at which the mean growth rate is zero, which represents one possible definition of carrying capacity, is given by:

$$\tilde{K} = b^{-1}(a^{-1/z} - 1)$$

The exponent *z* is conventionally taken to be 2.39 which corresponds to an MNPL of 0.6*K* in the deterministic case. For any given *z*, the presence of environmental variability tends to push the realised MNPL towards 0.5*K*, even for high values of *z*.

The population dynamics in the presence of removals is given by:

$$x_{t+1} = x_t \exp\left(r(x_t,t) - c_t/x_t\right)$$

where c_t the removal (e.g. bycatch) in year *t*. This formulation slightly discounts the nominal removals but has the advantage that the population size always remains positive.

To allow for the possibility of some inter-annual correlation in the environmental factors (i.e. environmental variation over a time scale of more than one year), the stochastic component is modelled as the sum of an uncorrelated annual component and a correlated component:

$$\varepsilon_t = \exp(\sigma \nu_t + \tau \eta_t) \quad \nu_t \text{ i.i.d. } N(0,1)$$
$$\eta_t = \rho \eta_t + \sqrt{1-\rho^2}\,\xi_t \quad \xi_t \text{ i.i.d. } N(0,1)$$

Where σ and τ are the standard deviations of the annual and longer-term components of the variation and ρ is the correlation coefficient that determines the persistence of longer-term deviations.

3.3 Population scenarios

Table 3 lists the parameters of the population scenarios tested. These have been chosen to cover a range of different ways the population without removals could behave, in particular whether the population, in the absence of removals, would be stable, increasing, decreasing, or fluctuating. Two alternative scenarios of a decreasing population are considered, namely a population occupying either (i) a shrinking habitat (parameter *b* increases, R_{max} remains constant); or (ii) a decaying habitat (parameter *a* increases, R_{max} declines). The conservation concern in the cases of decreasing population is that the removals should not accelerate the decline to an extent that would materially reduce the time available to address the primary factors behind the decline. Each of the five scenarios listed in Table 3 are replicated for each of the three values of R_{max} (Table 4), making 15 cases.

Table 3. Parameters of the population scenarios

σ_1	σ_2	ρ	*a* trend	*b* trend	*Caption text*
0.3					Stable population
0.3					Recovering population
0.3				+2% p.a.	Shrinking habitat
0.3			+2% p.a.		Decaying habitat
0.35	0.25	0.85			Fluctuating population

Table 4. Values of R_{max} and related parameters

R_{opt}	A	R_{max}
0.1	0.6	0.04
0.1	0.8	0.02
0.1	0.2	0.08

Fig. 2 shows samples of population trajectories with and without removals (at the rate of 0.7%) for each of these 15 cases.

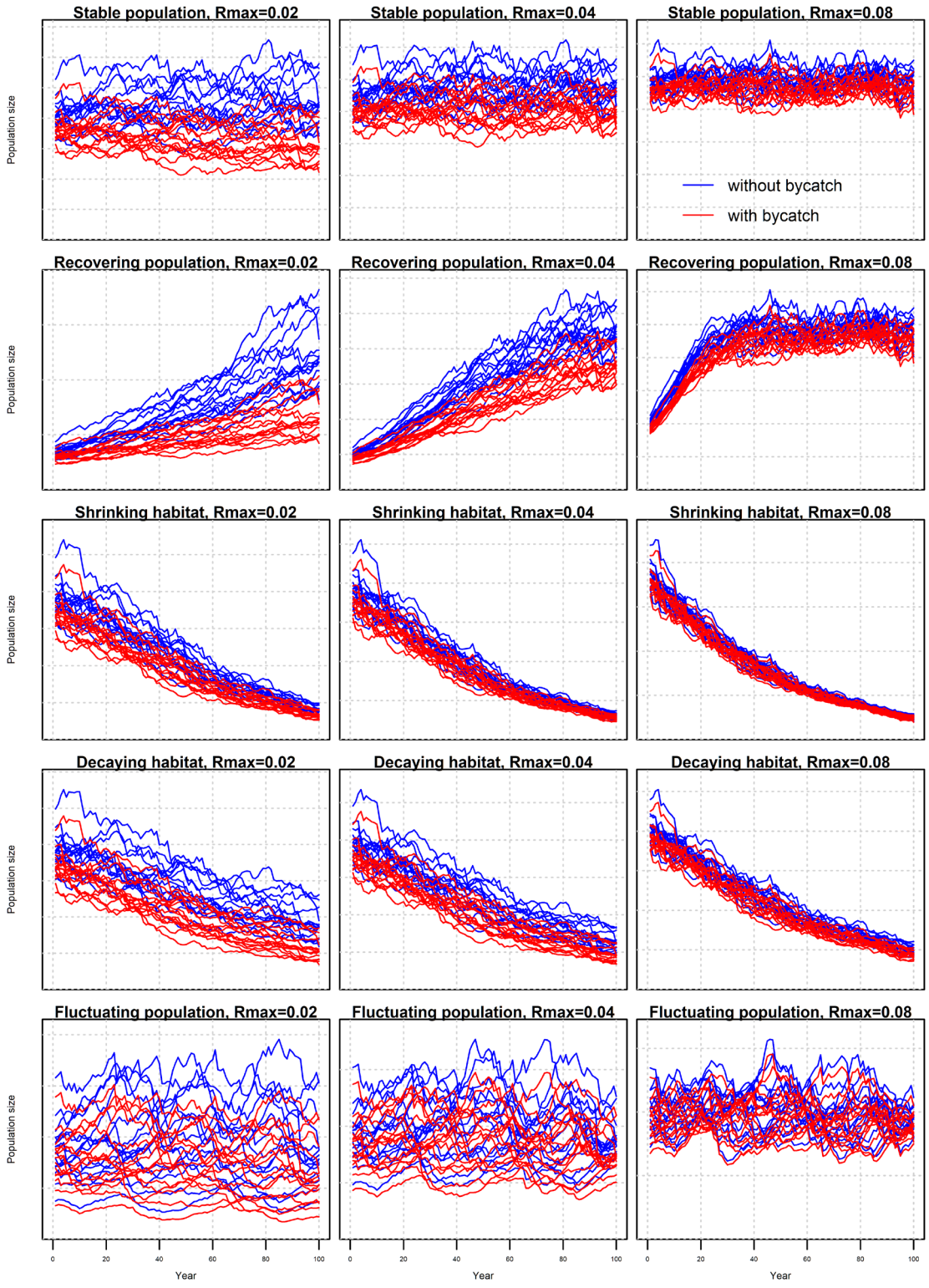

Fig. 2. Samples of population trajectories with and without removals (at 0.7%) for different population scenarios and R_{max} values.

3.4 Removal rate and monitoring options

Table 5 lists the rates of removal (bycatch) that were considered. The default value R_{max} = 0.04 was used to determine bycatch limits from the PBR formula except in the final case where the true R_{max} value was used.

Table 5. Removal rates tested in the simulations

Rate	Comment
0.0%	No-removal scenario
0.2%	OSPAR lower recommendation for PBR, F_R = 0.1
0.7%	OSPAR higher recommendation for PBR, F_R = 0.35
1.0%	ASCOBANS Res 8.5 generic precautionary aim
1.7%	ASCOBANS Res 8.5 maximum acceptable for harbour porpoise)
0.35%-1.4%	OSPAR higher recommendation for PBR using true R_{max}

Table 6 lists the alternative monitoring options. The first option refers to the theoretical case where the population is assumed known, and the removal percentage is applied directly to the known population. The remaining options assume that the removal limit is set to a percentage of an abundance estimate derived from surveys, which occur with the given CVs and frequencies. The abundance estimate was based on either (i) the most recent survey; or (ii) the average of last three surveys. In each of these cases, the lower 20%-ile of the distribution of the abundance estimate (known as N_{min} in the PBR terminology) is the point value used. This is assumed as considered to represent the "best available estimate" referred to in Resolution 8.5 (Rev MOP9).

A delay of five years is assumed between the conduct of a survey and the implementation of a removal limit based on the survey result. Possible failure to implement the limit is not considered in this study, although it would likely be an important factor in practice.

Table 6. Monitoring regimes tested in the simulations

	Survey interval	Survey CV	Estimates used	Caption text
a	(abundance treated as known)			fixed removal %
b	6	0.25	1	6-yearly surveys
c	6	0.15	1	low survey CV
d	6	0.35	1	high survey CV
e	12	0.25	1	12-yearly surveys
f	6	0.25	3	last 3 estimates

3.5 Performance measures

3.5.1 Probability of achieving the 0.8K objective

The population in a pessimistic scenario will typically drop more than 20% below the population level of an optimistic scenario, with or without bycatch. We cannot expect the population in a pessimistic scenario, even with zero bycatch, to exceed 80% of the population level in an optimistic scenario. Therefore, in determining whether a population in a bycatch scenario exceeds 80% of the no-bycatch scenario in any given year, we compare only equivalent scenarios. In the case of stochastic scenarios, we

compare any given percentile of the population distribution with bycatch with the same percentile of the no-bycatch scenario.

Two approaches to calculating the "probability" of satisfying the objective suggest themselves, of which only the first is a probability in the strict sense:

(i) *Percentiles of ratios*

The probability of satisfying the 0.8 *K* conservation objective in a given year is estimated as the proportion of replicates (out of 1,000) in which the population size in the scenario with removals exceeds 80% of the same percentile of the population size in the scenario without removals.

For each scenario, let $P(j,t)$ be the population size in year t in replicate j, and $P_0(j,t)$ be the population size in year t replicate j of the no-removals scenario. For each year t, the vectors $P(j,t)$ (j = 1, … 1000) and $P_0(j,t)$ (j = 1, …, 1000) are separately sorted in ascending order of population size. The ratios of interest are $P^*(j,t)/P_0^*(j,t)$ where P^* and P_0^* refer to the sorted arrays. The probability of satisfying the objective is the proportion of replicates in which this ratio exceeds 0.8. In this document we plot specific percentiles of the ratio, such as the lower 5th, 20th and 50th percentiles. For example, when the 5th percentile exceeds 0.8, the probability of satisfying the objective exceeds 95%.

(ii) *Ratios of percentiles*

A potential drawback to the above method of calculating the probability of satisfying the objective is that, in theory at least, the cases where the objective is not satisfied may occur among the more optimistic replicates. From a conservation point of view, we would be more concerned about failure to satisfy the objective when the population is low than when it is high. To address this reservation, the following option was also considered.

Selected percentiles (e.g. 5th, 20th and 50th) of the distributions of P and P_0 are extracted separately and the ratios taken. For example, if the ratio of the lower 5%-iles of the P and P_0 distributions exceed 0.8, then the conservation objective is deemed to be satisfied "with 95% probability". Unlike the preceding approach, this is not strictly a probability.

3.5.2 Time horizon for satisfying the 0.8K conservation objective

The comparison of the simulations with and without removals is made separately for each year in the simulation. The two alternative performance measures (percentiles of ratios and ratios of percentiles) were plotted over a 100-year period. The ASCOBANS workshops had not reached agreement on a single time horizon for satisfying the 0.8*K* objective but a range of 20-100 years into the future was discussed.

The simulations with and without removals were started 20 years before the start of the 100-year period. Historical removals prior to 20 years before the start of the simulation are, therefore, not taken explicitly into account. However, the likelihood of past, higher, removals is implicit in those scenarios where the population without removals is recovering.

4 RESULTS AND DISCUSSION

Figs 3a-f show the 5th, 20th and 50th percentiles of the ratios of population size by year between the removal and no-removal scenarios, for the removal rates listed in Table 5, for each of the monitoring options listed in Table 6. Figs 4a-f show the corresponding results for the ratios of percentiles.

The results show that there is very little difference between the percentiles of ratios (Figs 3a-f) and the ratios of percentiles (Figs 4a-f) under any combination of the other factors, apart from a slightly greater year-to-year variability in the ratios of percentiles.

In each scenario, the spread between the different percentiles (5%, 20% and 50%) is rather small, except in cases where the population is anyway depleted to well below the 0.8*K* target. Therefore, for a given scenario, it makes little difference whether the chosen criterion is to satisfy the 0.8*K* conservation objective with 50%, 80% or 95% probability. This finding will not necessarily apply if probabilities are assigned to different scenarios, which are then combined (see below).

There is also not much difference between the results (compare Figs 3a through 3f) for different levels of population monitoring (e.g. surveys every 6 or 12 years, or CVs ranging from 0.15 to 0.35 per survey, or whether just the latest abundance estimate or an average of the last three are used). Indeed, the results are slightly more conservative with the higher CV than the lower. This implies that the use of the lower 20%-ile of the population estimate (denoted N_{min} in the PBR context) as the "best estimate" sufficiently accounts for the uncertainty in population estimates.

The 0.8*K* target is harder to meet in the scenario where the population would be increasing in the absence of removals, than when it is stable, because the removals tend to slow the increase, which has a cumulative effect over time. In such scenarios, the performance when population estimates are used is, paradoxically, somewhat better than in the ideal case where the population is known. The reason is that the latest available population estimate tends to be a conservative estimate of current population size, because the population has increased in the meantime. Thus, for the purpose of comparing different removal rates, it is sufficient to focus on Fig. 3b.

The 1% and 1.7% removal rates satisfy the 0.8*K* conservation objective only for the high R_{max}.

The 0.7% removal rate satisfies the conservation objective in the high R_{max} scenarios and in most medium R_{max} scenarios, but not in the low R_{max} scenarios beyond 20 years. In the decaying habitat scenario, where the population would eventually decline to extinction, the population remains above the 0.8*K* level for the first 60 years of the medium R_{max} scenario, during which time the causes of the long-term decline could be addressed. In the low R_{max} scenarios, the population satisfies the conservation objective for the first 20 years, except missing it slightly in the recovering population scenario. It does not satisfy the objective over a longer period, except in the shrinking habitat scenario. In summary, the 0.7% removal rate is largely compatible with the 0.8*K* conservation objective, except in scenarios with low R_{max} and a time horizon beyond 20 years.

The 0.2% removal rate satisfies the conservation objective in all scenarios.

Satisfaction of the conservation objective could be enhanced if instead of a single value, an R_{max} value appropriate for the population in question were used. Fig. 5 shows the results of Fig. 3b when the true R_{max} is used for each population, retaining the Recovery Factor of 0.35. The 0.8*K* objective is satisfied for all R_{max} values, except for the latter years of the decaying habitat scenario. It is important to stress that the results in Fig. 5 do depend on an appropriate choice of R_{max} for each population. If the default R_{max} value of 0.04 is used for all populations, yet some populations have a lower actual R_{max}, the 0.8*K* objective will

not always be satisfied (Fig 3b). Unfortunately, as the discussion in section 2 highlights, the assumption that the true value of R_{max} is known will not usually be realistic.

As noted above, the choice of probability level with which the objective shall be satisfied is unimportant for any given R_{max} value. However, this conclusion will not necessarily hold if the uncertainty in R_{max} is handled probabilistically. For example, Fig. 6 shows the effect of a 0.7% removal rate when the true R_{max} is drawn uniformly from the range 0.02 to 0.08. The incorporation of uncertainty in R_{max} results in a greater spread of the percentiles. The 0.8*K* objective is achieved with a probability of only 80% in the recovering population scenario, but with a probability of 95% or more in the other scenarios, except in the latter years of the decaying habitat scenario.

5 CONCLUSION AND RECOMMENDATIONS

The simulation results show that if an R_{max} value of at least 0.04 can be assumed, then a removal rate of 0.7% of the estimated population size is consistent with achievement of the ASCOBANS conservation objective in virtually all scenarios over most or all of the 20-100-year time horizon. This is not the case for removal rates of 1% or 1.7%. Therefore, there is a case for downward revision of the thresholds specified in Resolution 8.5 (Rev MOP9).

The considerations of section 2.3 suggest that an assumed R_{max} value of 0.04 may not be sufficiently conservative for small cetaceans. If the true value is 0.02, then a removal rate of 0.7% may be too high for achieving the ASCOBANS conservation objective. A removal rate of 0.2% is consistent with the ASCOBANS conservation objective in all the scenarios considered, but to achieve this would involve preventing essentially all removals for populations numbering in the hundreds.

Peripheral or marginal populations of a species are liable to have lower resilience (lower R_{max}) than populations in the main range of a species. Such populations may nevertheless be of considerable regional or national conservation interest if they represent the only cetacean occurring regularly in the waters of some range states, as for example harbour porpoise in the Baltic Sea Proper. A reasonable compromise approach may be to adopt the 0.7% threshold as a target for general use, but with the proviso that lower thresholds be set on a case-by-case basis for populations of suspected low resilience that are nevertheless of high conservation interest.

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Figs. 3-6 on the following pages.

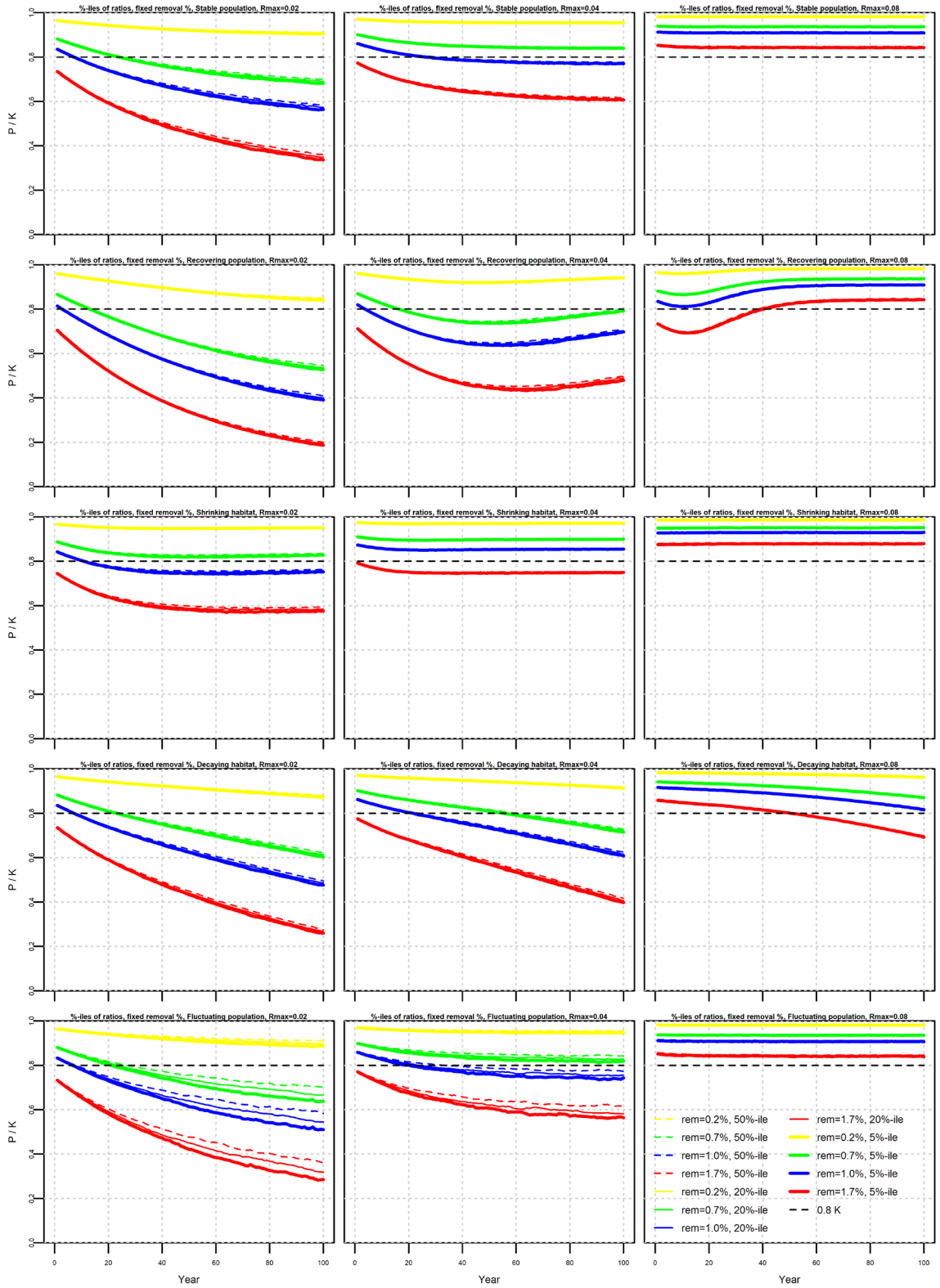


Fig. 3a. Selected percentiles (5th, 20th, 50th) of the distribution of ratios of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population treated as known.

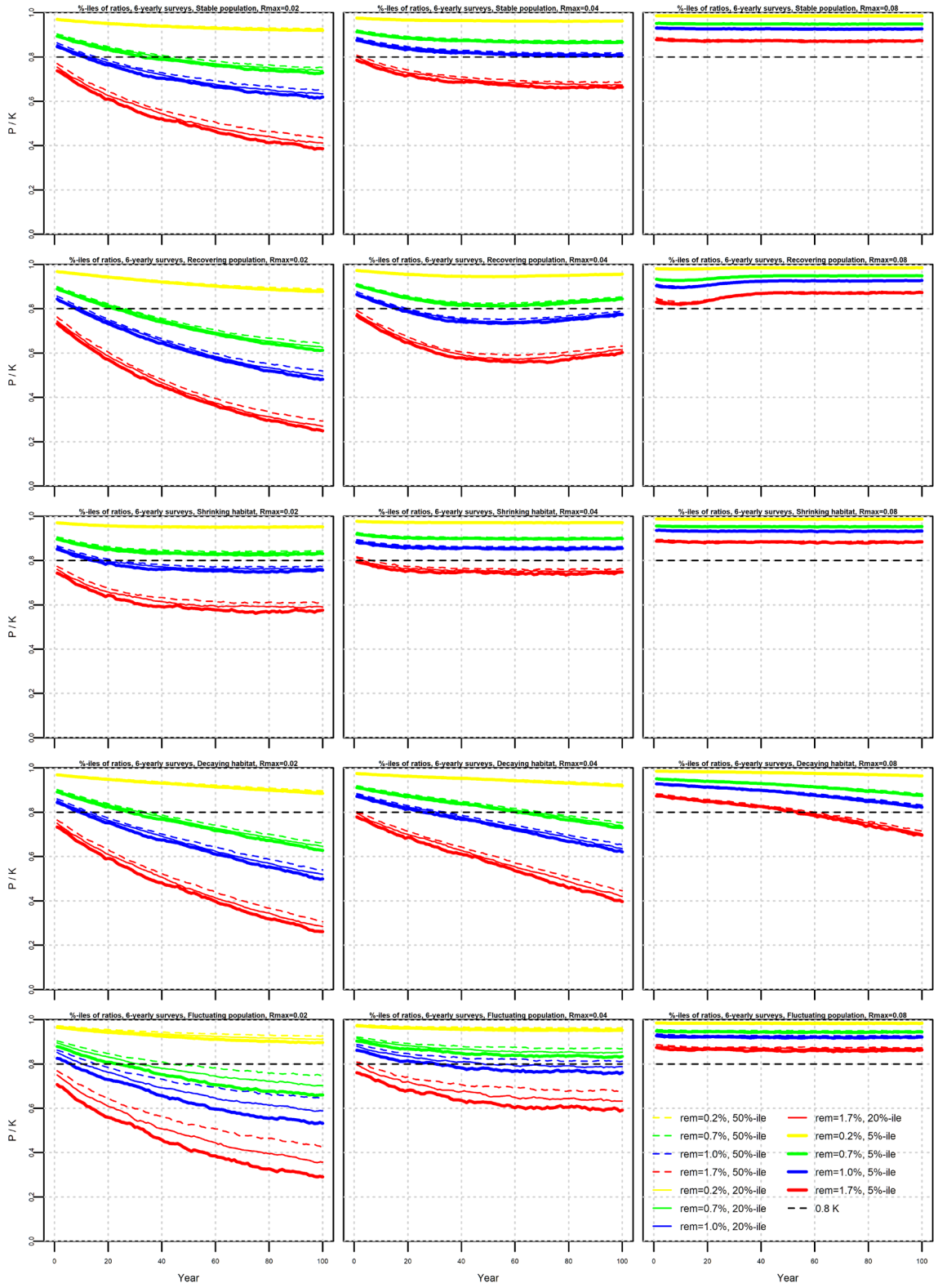


Fig. 3b. Selected percentiles (5^{th}, 20^{th}, 50^{th}) of the distribution of ratios of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population estimates from 6-yearly surveys with CV 0.25.

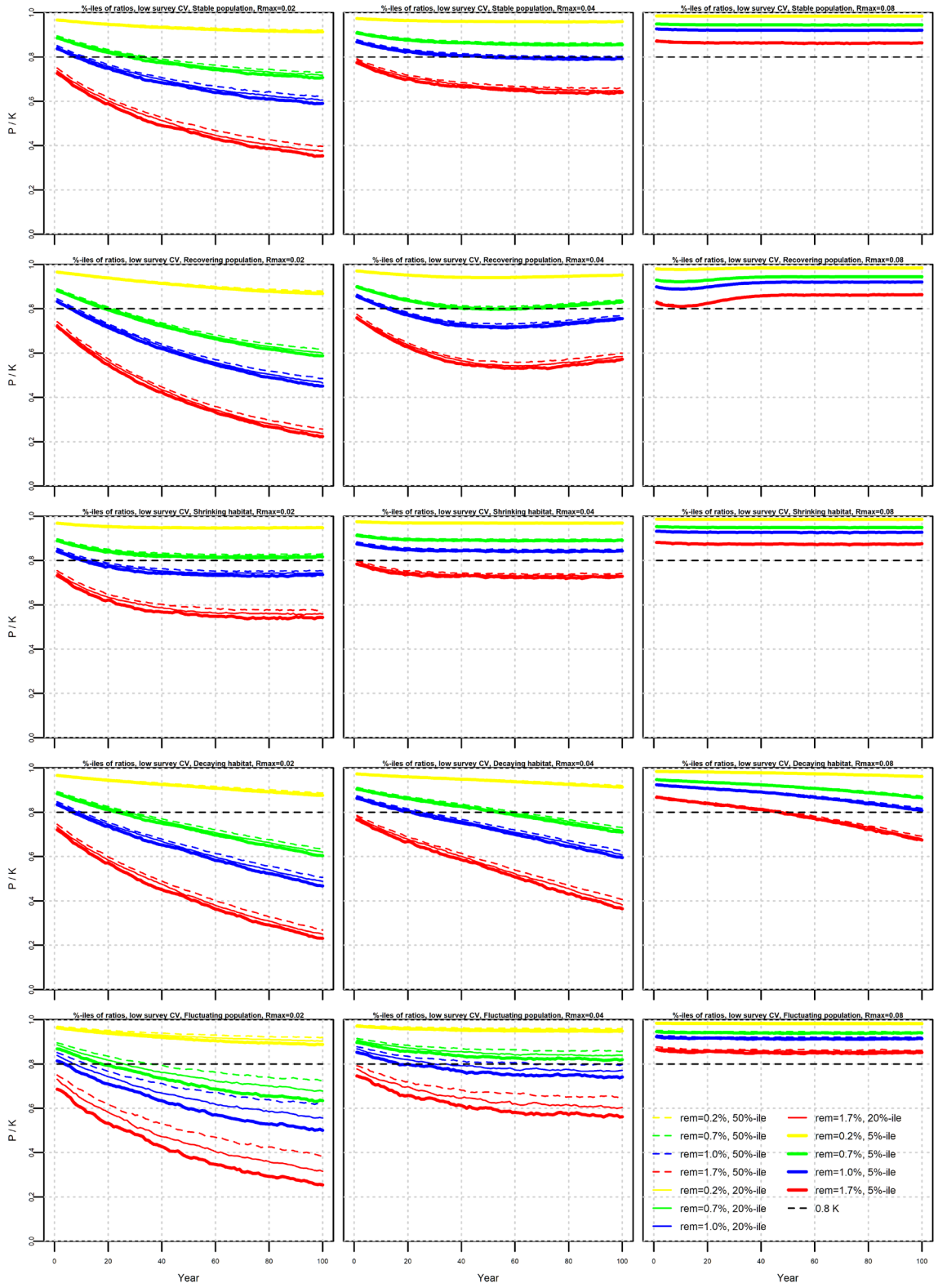


Fig. 3c. Selected percentiles (5th, 20th, 50th) of the distribution of ratios of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population estimated from surveys conducted every 6 years with a CV of 0.15.

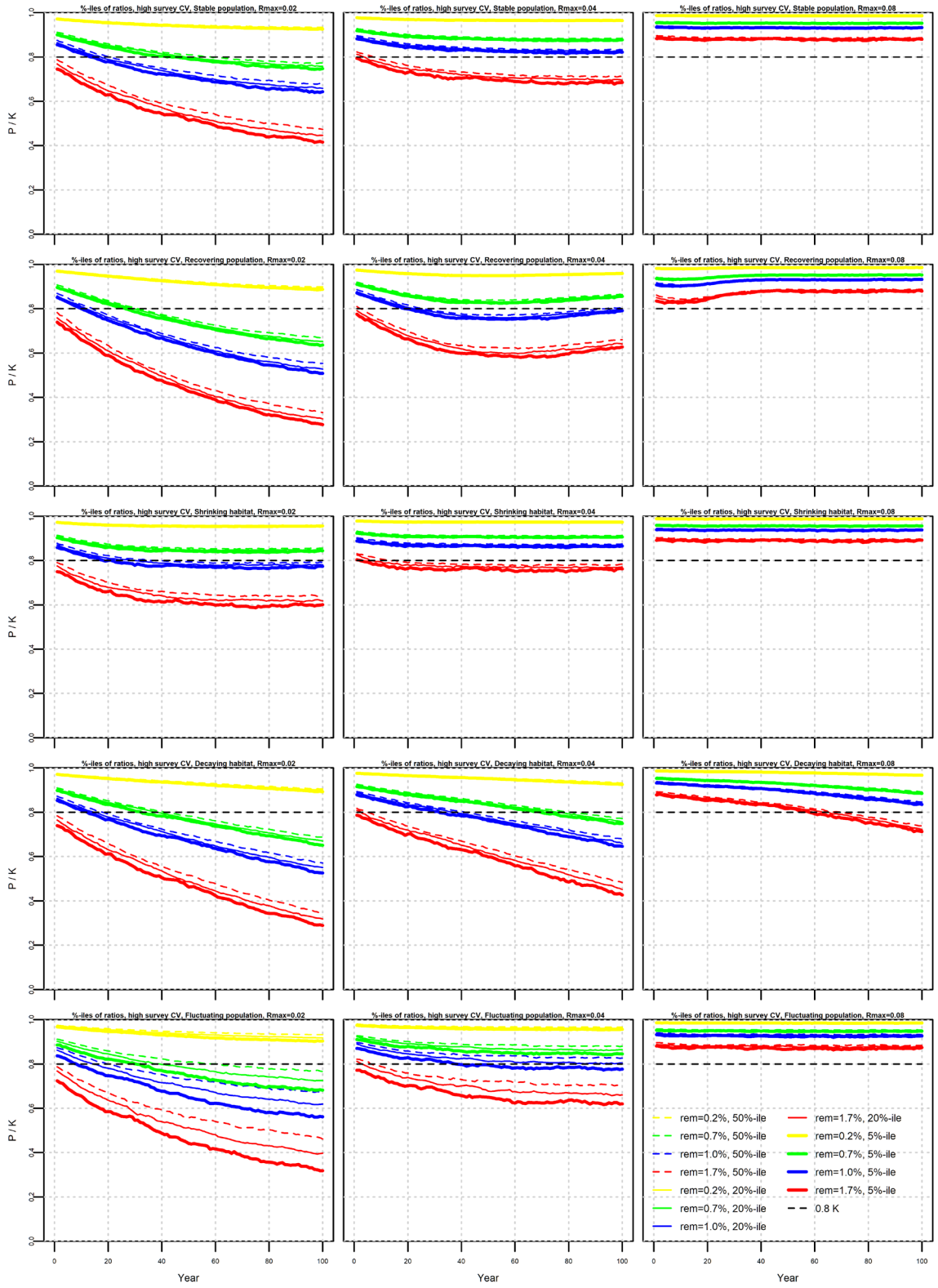


Fig. 3d. Selected percentiles (5th, 20th, 50th) of the distribution of ratios of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population estimated from surveys conducted every 6 years with a CV of 0.35.

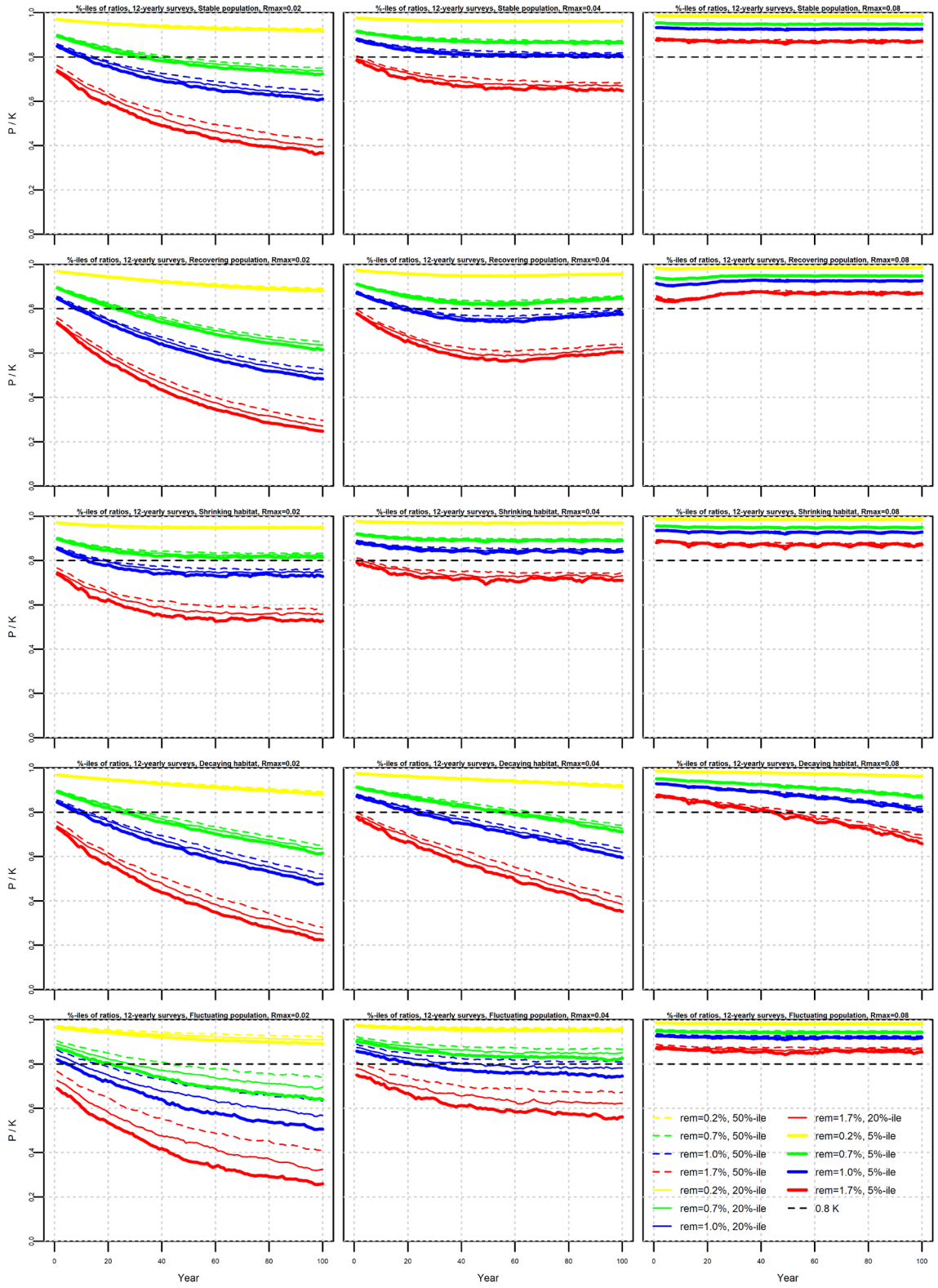


Fig. 3e. Selected percentiles (5th, 20th, 50th) of the distribution of ratios of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population estimated from surveys conducted every 12 years with a CV of 0.25.

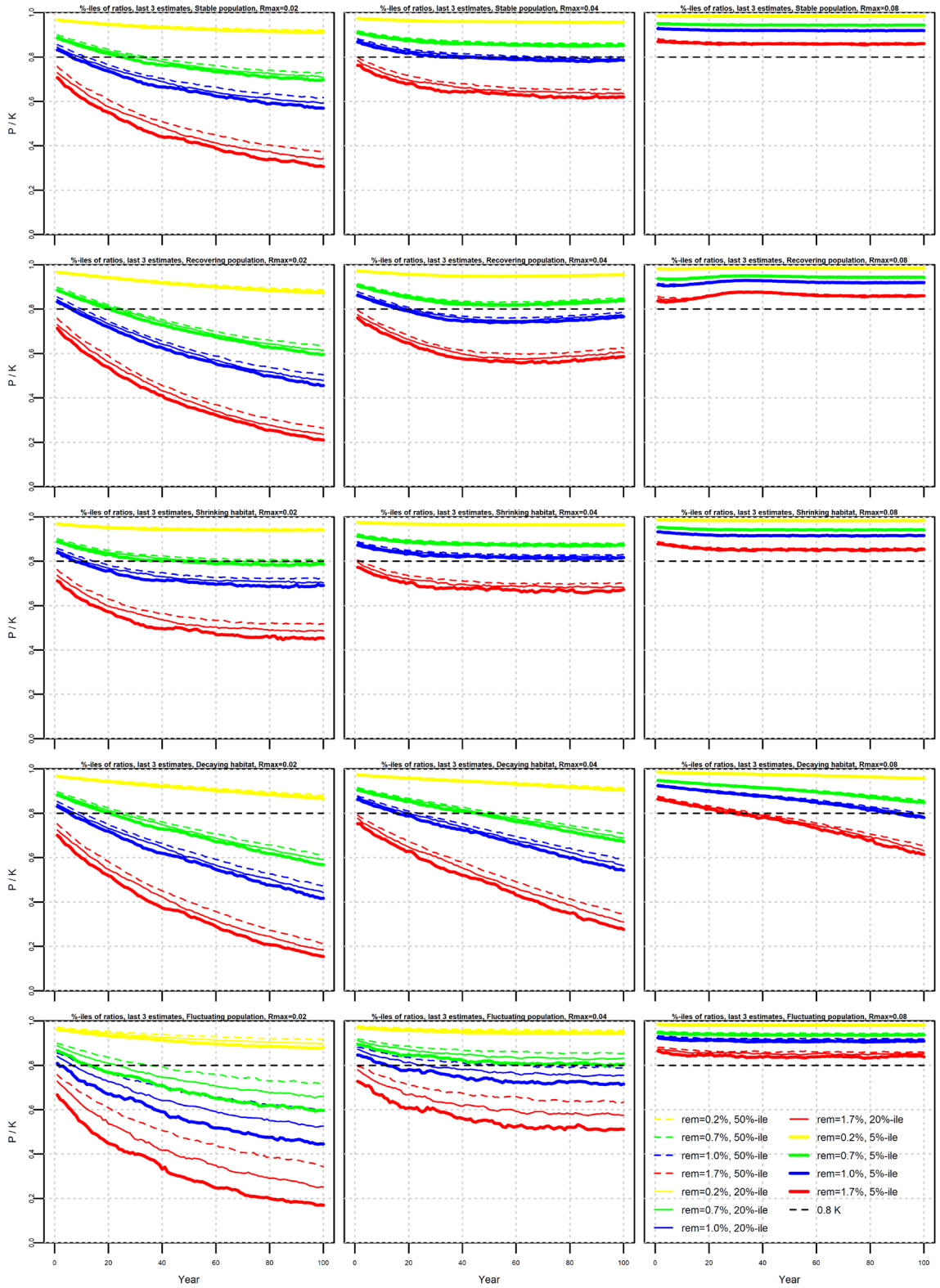


Fig. 3f. Selected percentiles (5th, 20th, 50th) of the distribution of ratios of population sizes with and without removals in various scenarios for four different removal rates three and three R_{max} values. Average of last 3 estimates from surveys conducted every 6 years with a CV of 0.25.

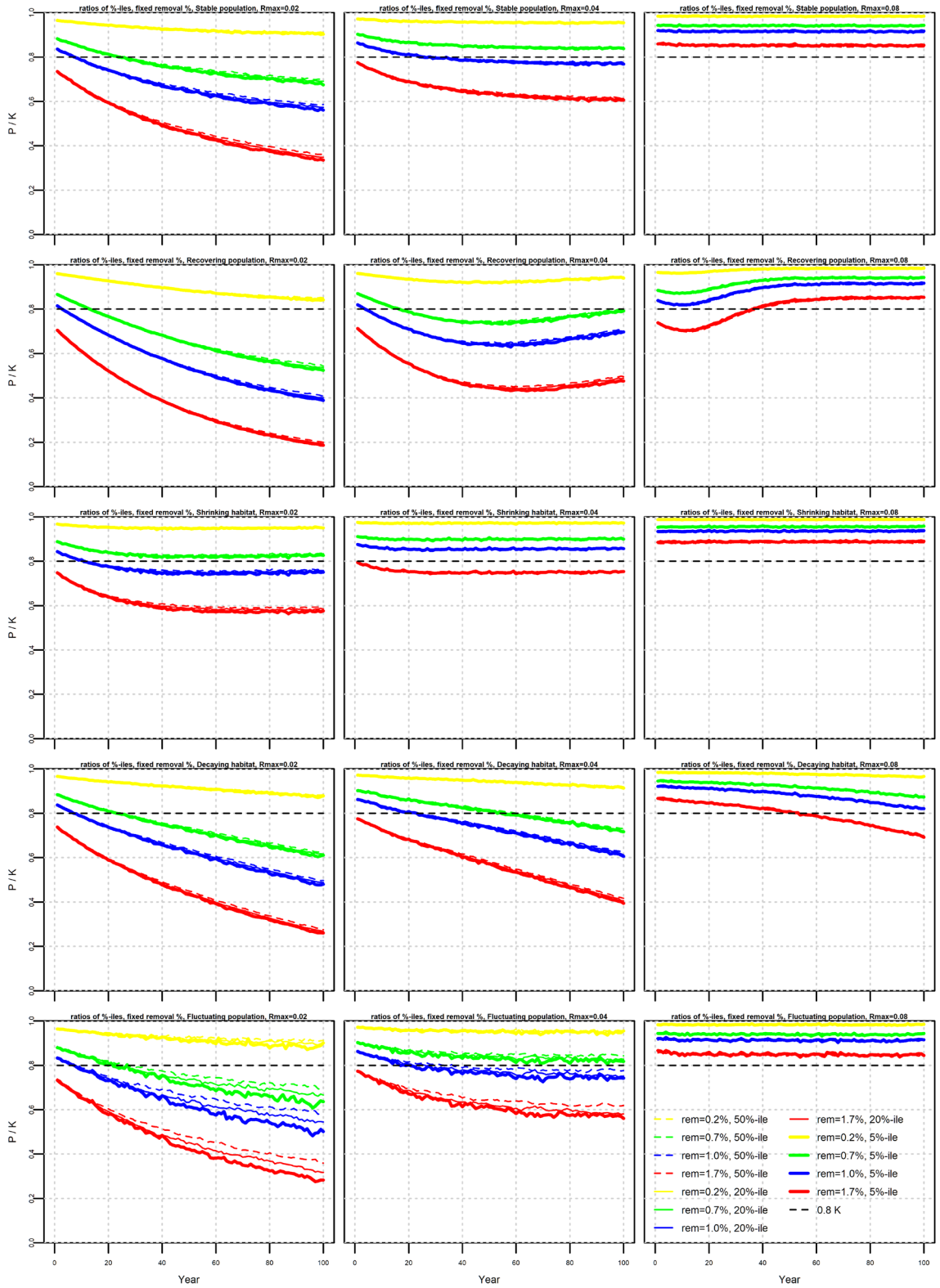


Fig. 4a. Ratios of selected percentiles (5th, 20th, 50th) of the distribution of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population treated as known.

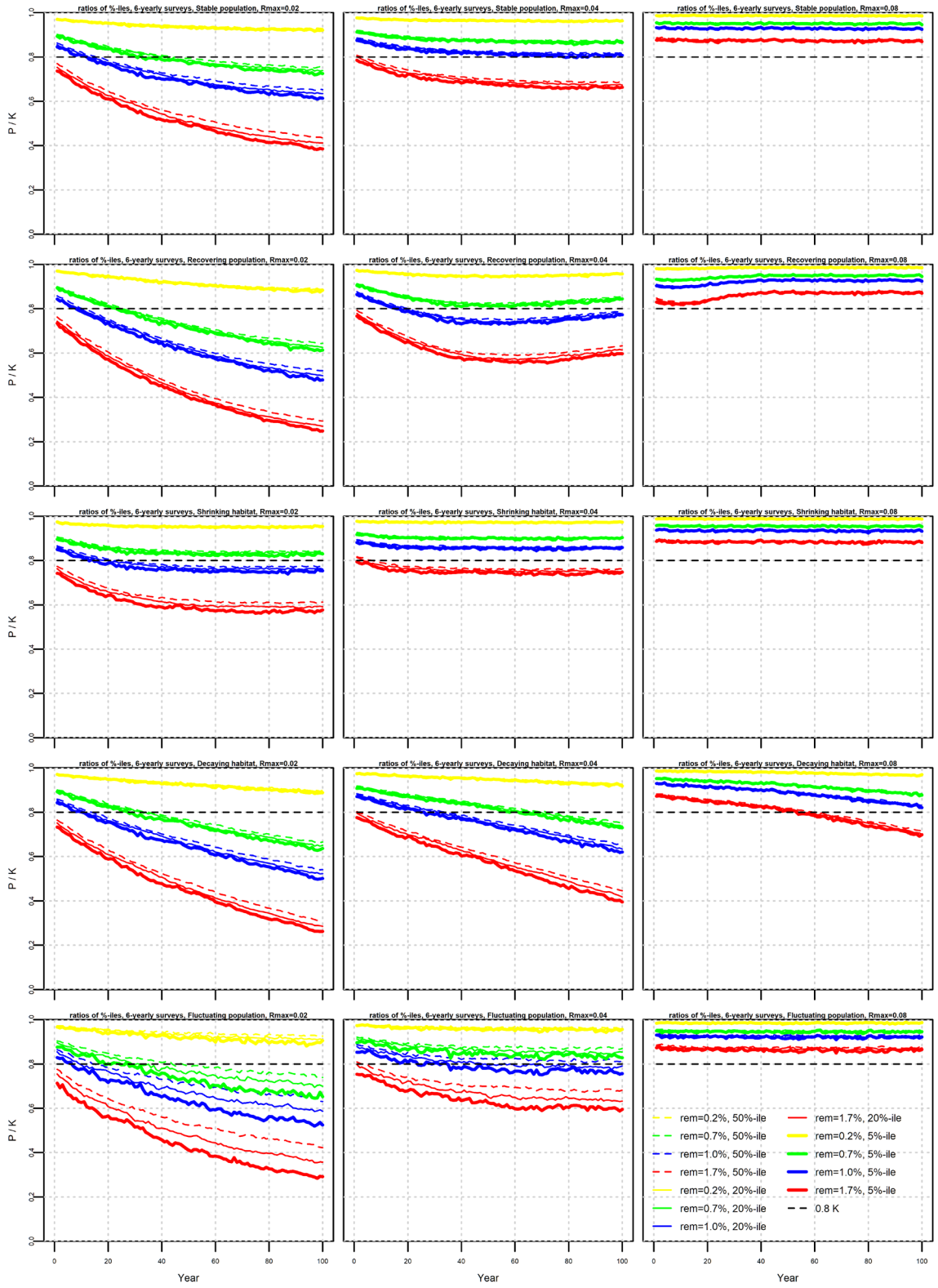
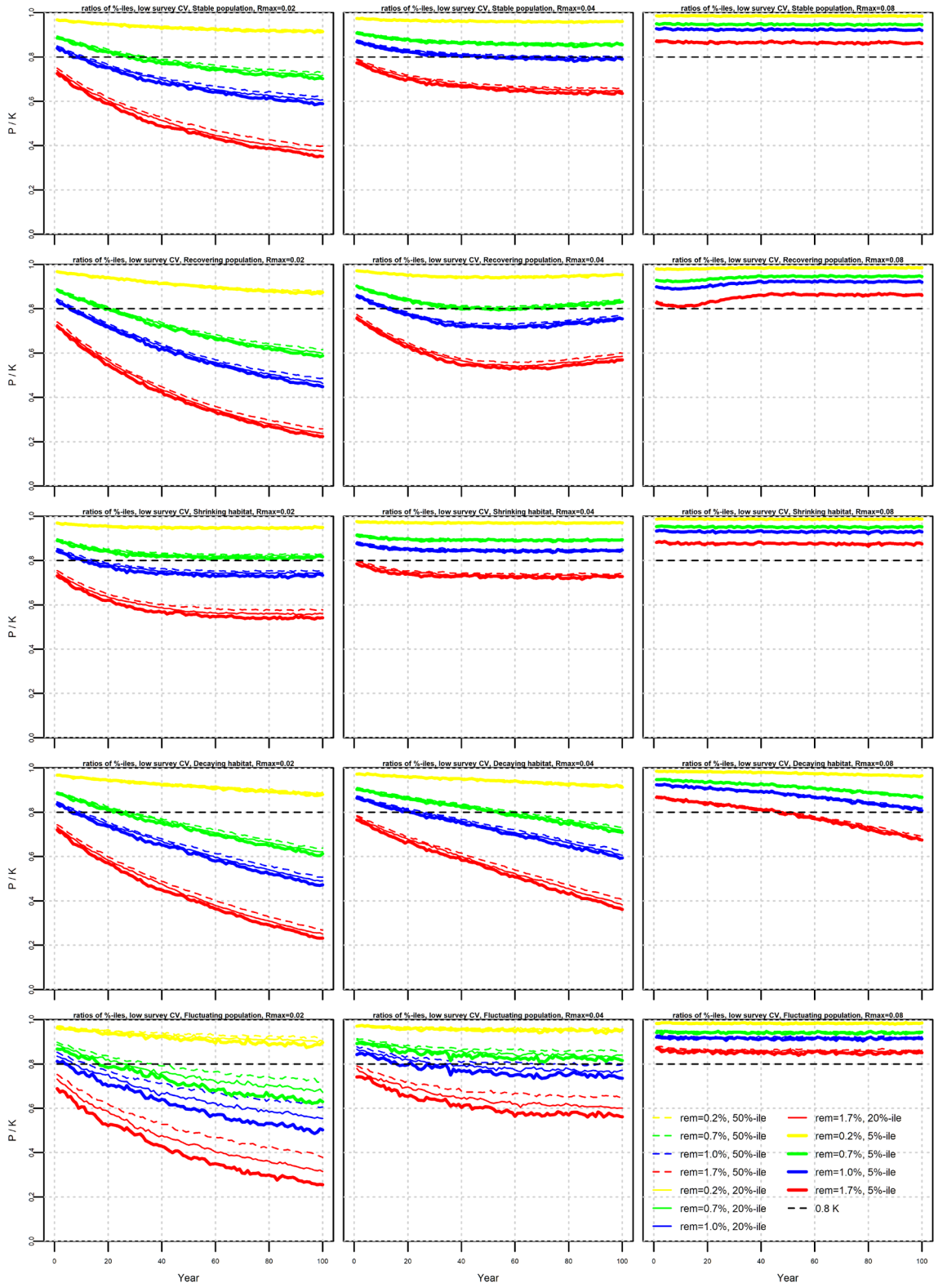


Fig. 4b. Ratios of selected percentiles (5th, 20th, 50th) of the distribution of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population estimated from surveys conducted every 6 years with a CV of 0.25.



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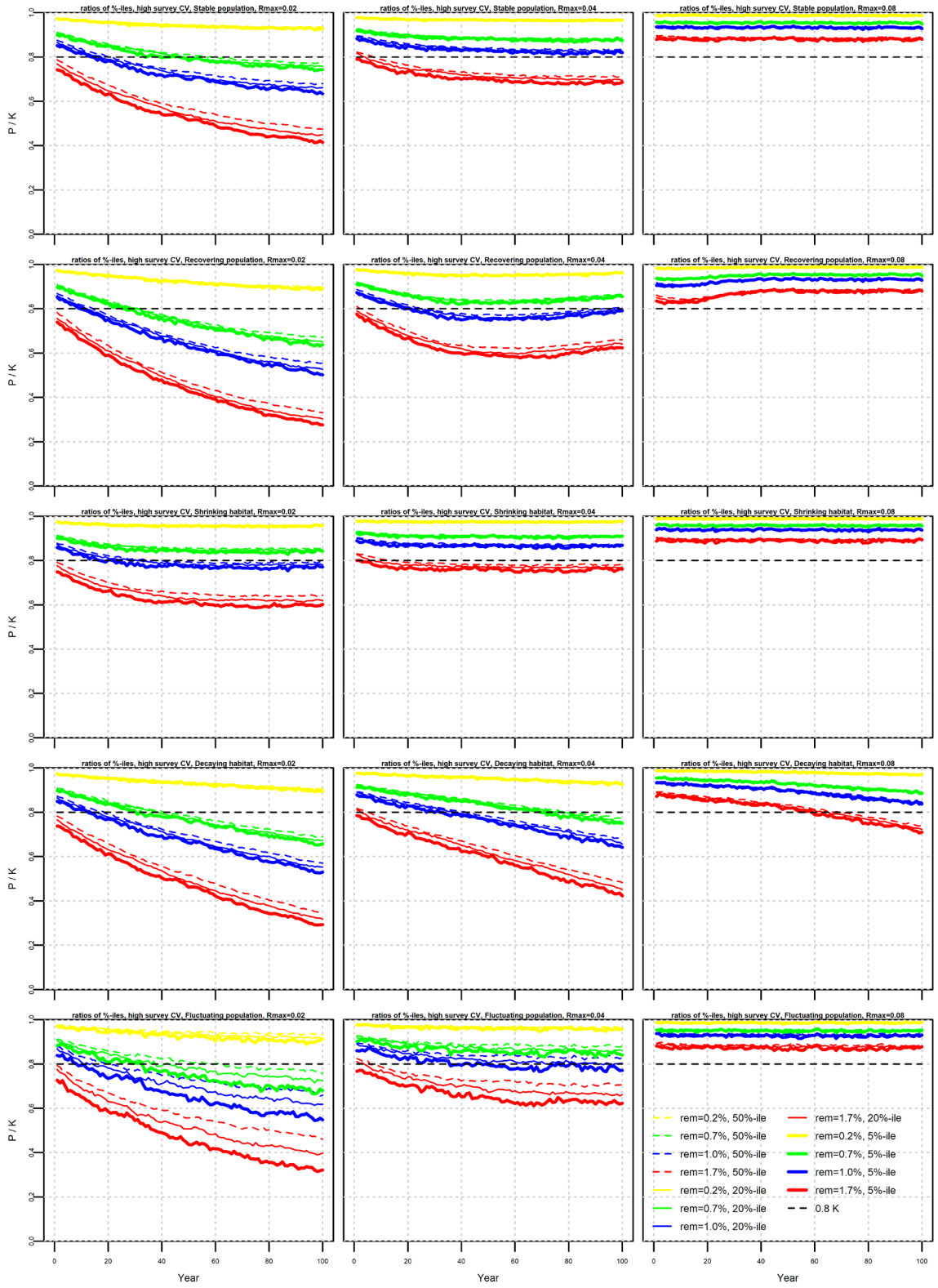

Fig. 4d. Ratios of selected percentiles (5th, 20th, 50th) of the distribution of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population estimated from surveys conducted every 6 years with a CV of 0.35.

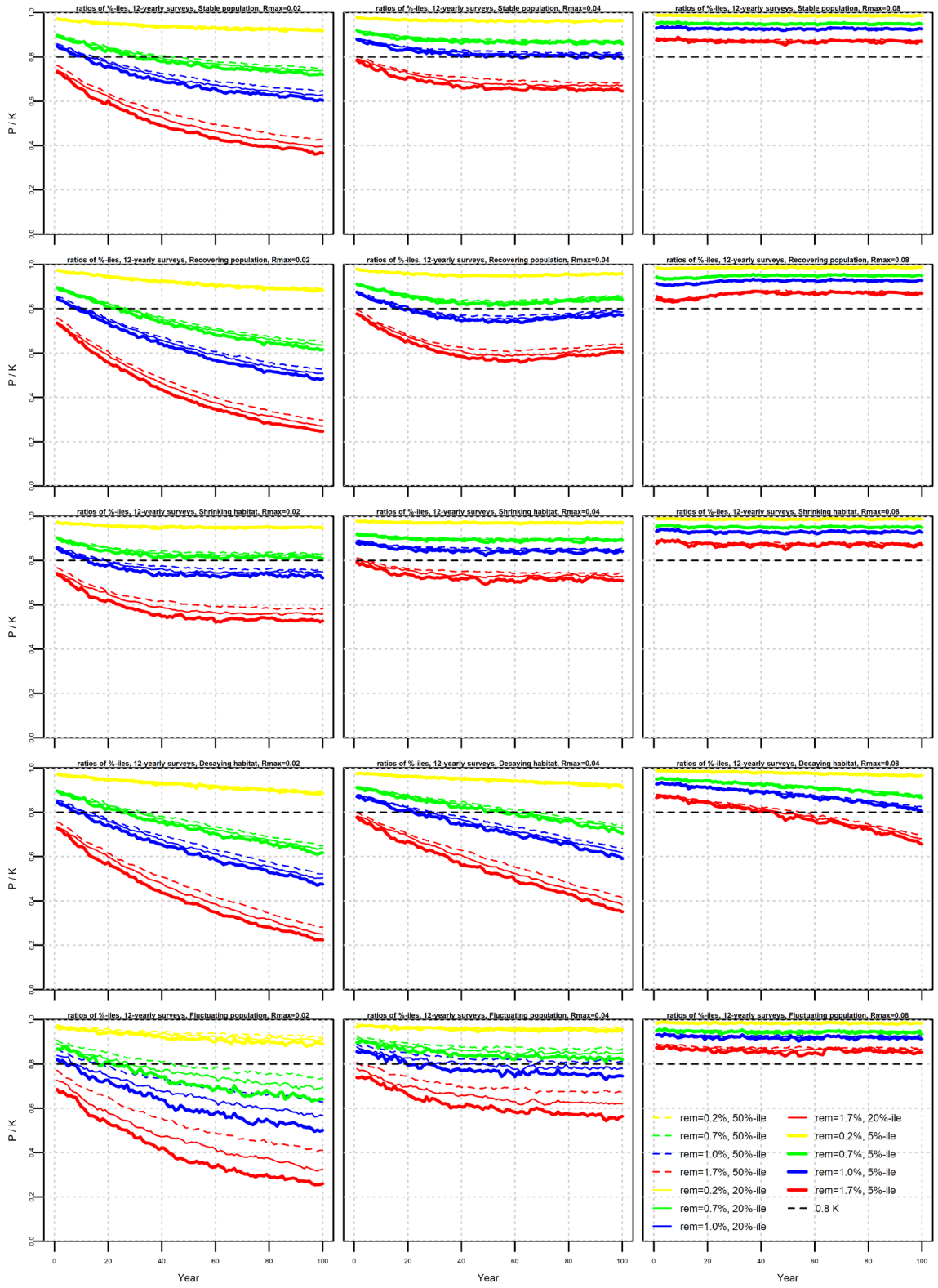

Fig. 4e. Ratios of selected percentiles (5th, 20th, 50th) of the distribution of population sizes with and without removals in various population scenarios for four different removal rates and three R_{max} values. Population estimated from surveys conducted every 12 years with a CV of 0.25.

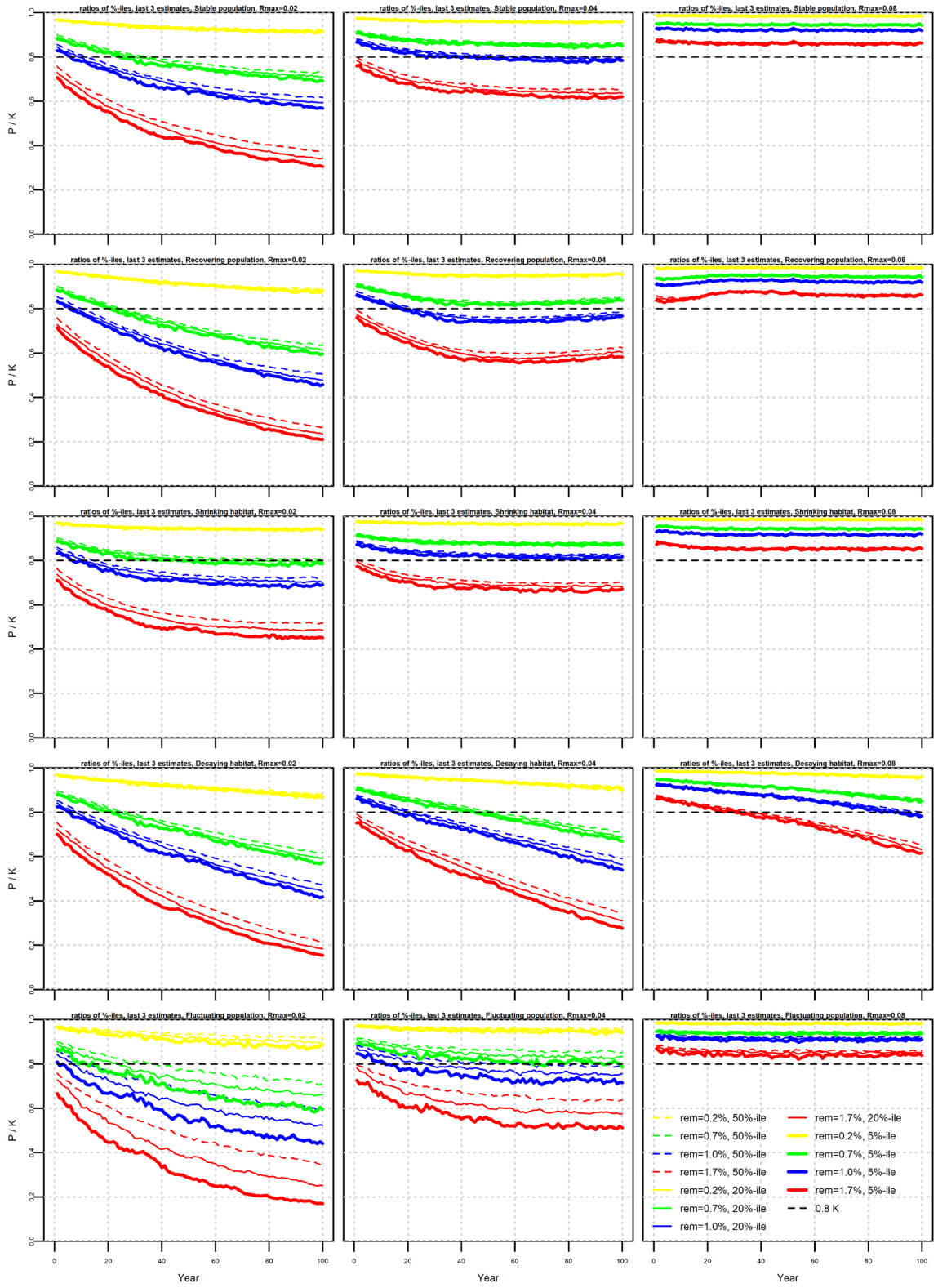

Fig. 4f. Ratios of selected percentiles (5th, 20th, 50th) of the distribution of population sizes with and without removals in various scenarios for four different removal rates three and three R_{max} values. Average of last 3 estimates from surveys conducted every 6 years with a CV of 0.25.

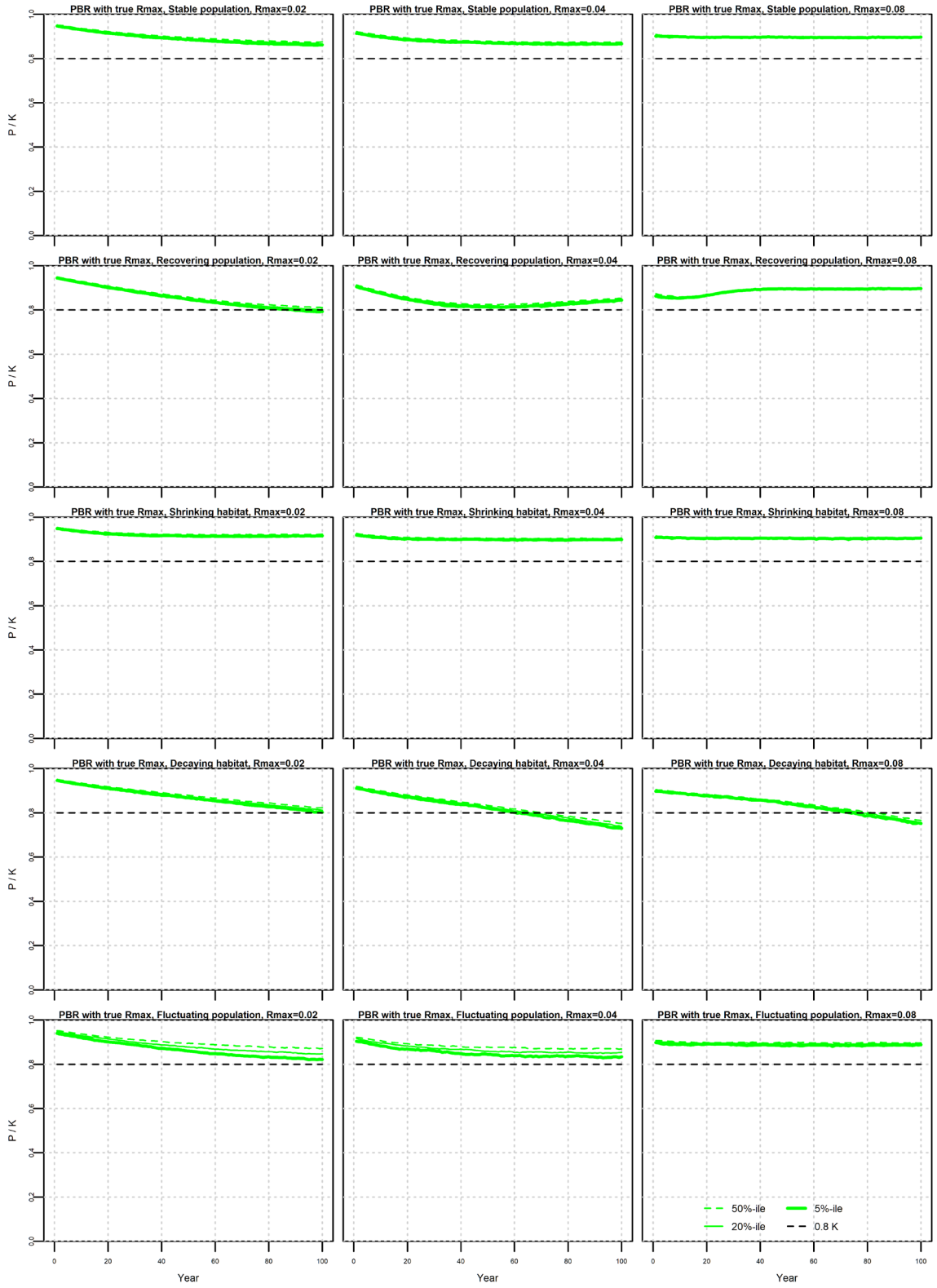

Fig. 5. Selected percentiles (5th, 20th, 50th) of the distribution of ratios of population sizes with and without removals in various scenarios for removals set according to PBR using the true R_{max} value and Recovery Factor 0.35. Surveys every 6 years, with CV of 0.25.

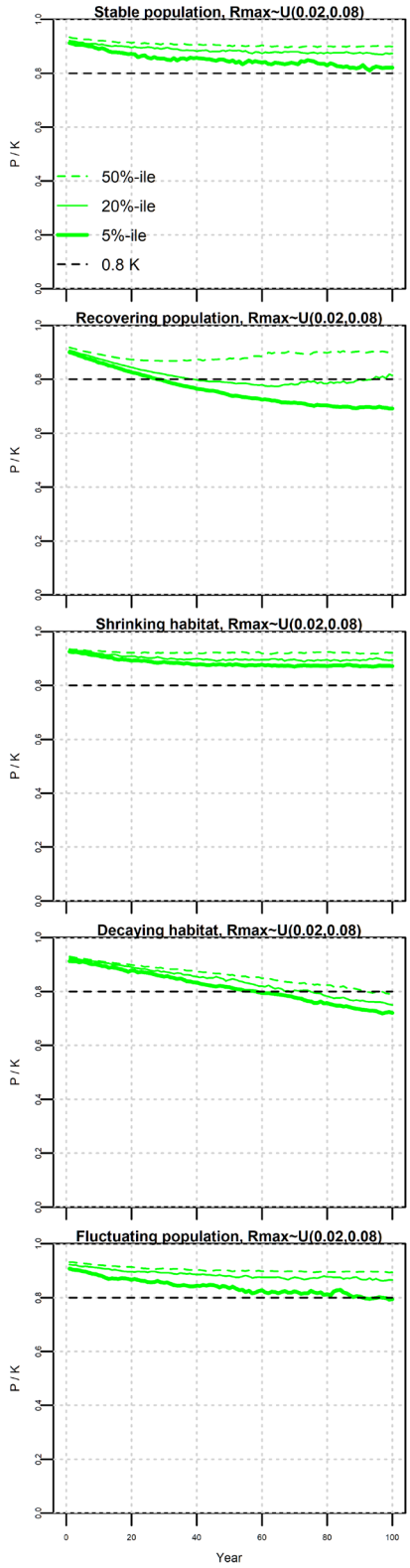

Fig. 6. Selected percentiles (5th, 20th, 50th) of the distribution of ratios of population sizes with and without removals in various population scenarios for a 0.7% removal rate with R_{max} drawn uniformly from the range 0.02-0.08. Surveys every 6 years with CV of 0.25.