Effect of the 2011 oil and soya spill events on rock lobster yields at Inaccessible and Nightingale islands

S.J. Johnston and D.S. Butterworth

Marine Resource Assessment and Management Group (MARAM)
Department of Mathematics and Applied Mathematics
University of Cape Town
Rondebosch 7701, South Africa

Executive Summary

Assessing the effects of the oil and soya spills resulting from the OLIVA incident at Nightingale on the lobster fisheries at the Tristan group of islands is difficult for a number of reasons:

1. the quantification of the impact of the oil spill on settlement and juvenile mortality is not straightforward, both at Nightingale and at Inaccessible islands to which the oil spread;
2. the soya spill, which is restricted to Nightingale island, has certainly had an impact there as evidenced by the poor catch rates experienced for recent experimental catches; however this would have been caused by either or both of a short term migration of the lobsters from the fishing area[1] and an immediate additional mortality on adult lobsters; the quantification of these effects is again difficult, and importantly the consequences of the two possibilities are rather different;
3. there are two alternative models for the growth rate of lobsters at Nightingale island, and results do change appreciably depending upon which of these better approximates reality.

The present basis for management decisions on the annual catch limits for each of the Tristan islands is strongly oriented towards maintaining catch rates at or near to their recent (pre-Oliva incident) levels. The reason is that were abundance to drop, catch rates would become lower, so that more fishing time and effort (costing more in terms of fuel and fishers' salaries) would be needed to harvest the same tonnage of lobsters – perhaps this increase would even be such as to render the fishery uneconomical to pursue. The oil and soya spill effects at Nightingale, and the oil impact at Inaccessible island, will to a greater or lesser extent have the effect of reducing lobster abundance if the catch levels intended before the OLIVA grounding were to be maintained. Thus the scenarios considered here envisage catches being reduced to a level for which, broadly speaking, catch rates are maintained in the medium as well as the long term, and thus the continued economic viability of the fishery is not compromised. This approach is implemented by calculating the catch levels that would result in the same abundance levels in 2016, 2021 and 2031 that would have occurred in the absence of the OLIVA incident under the present harvesting strategy for the resource. The reason that a twenty year period has to be considered

---

[1] Alternatively the lobsters are satiated by the food that the soya provides and hence not attracted to baited traps – the net effect is the same.

is that lobsters are long-lived animals, with relatively slow rates of population increase if reduced in abundance, so that if the soya spill impact at Nightingale island has been such as to cause appreciable mortality to the mature component of the population, it will take more than a decade for the resource to return to its recent level of abundance.

The computations reported here have been carried out for three oil spill scenarios (No effect, Safe case and Worst case) as suggested by consultants for the Nightingale and Inaccessible islands; for Nightingale island these are combined with four scenarios for the impact of the soya spill (No effect, 1-year adult migration out of the area, 3-year adult migration out of the area, and an immediate 70% adult mortality). The results for Nightingale are shown for two possible somatic growth models (the slower "Pollock" and the faster "James Glass" growth models, with the latter regarded as likely a closer representation of the actual situation). A surprising result for the oil spill scenarios is that the impact on the fishery at Nightingale island occurs only a number of years after that for the fishery at Inaccessible island under the "Pollock" model with its slower growth. The reason is that the oil spill scenarios envisage effects on lobsters no older than three years at most, and consequently it takes a few years longer in terms of the "Pollock" model for the cohorts affected to reach the size where they are susceptible to harvest by the fishery.

The results are best summarised in matrix form to illustrate how much (in MT) the catch would need to be reduced in total over the short- to medium-term (the next 20 years) to broadly maintain current catch rates for various combinations of oil spill effects and soya spill impacts (at Nightingale island only).

a) Inaccessible island

		Oil spill effect No effect	Safe case	Worst case
Soya Impact	None	0	270	555

b) Nightingale island (results are for the "Pollock"/"James Glass" growth models)

		Oil spill effect No effect	Safe case	Worst case
Soya Impact	None	0/0	240/350	445/595
	1-yr migration	18/21	257/351	458/595
	3-yr migration	43/51	289/356	478/598
	70% die in 2011	555/390	730/585	850/720

The migration scenarios under the soya spill impact at Nightingale island have relatively little effect on total catches. However this is partly a model artefact of catch losses in the first one to three years being offset by increasing catches over the balance of the period until 2016; in practice operational factors (e.g. vessel scheduling, processing limitations) might render such increases unachievable.

Clearly there is a wide range of cumulative catch losses possible under the range of scenarios considered, and it is difficult to select which of these scenarios is the most likely outcome. However ongoing monitoring at Nightingale island will, over a period whose length would range from a few months to probably about three years, be able to exclude a number of these scenarios. In particular this will throw light on the uncertainty which has the largest impact on the extent of catch losses that are tabulated above, *viz*. the extent of the adult mortality at Nightingale which the soya spill may have caused – for example if monitoring reveals catch rates returning to near pre-OLIVA-incident levels in the short-term, clearly such additional lobster mortality cannot have been very large. There would therefore seem to be an argument to structure ongoing insurance claim negotiations within a framework that equitably allows the results from such future monitoring to be taken into account as they become available. A useful associated initiative would be the organisation of a scientific workshop in the near future to deliberate how such monitoring data would best be utilised to reduce the range of scenarios considered in the Tables above, and concomitantly give guidance on the choices amongst these scenarios that constitute the most appropriate basis upon which to set catch limits in the short term.

Rationale behind the replacement yield calculations

Replacement yields are the catches which maintain resource abundances at their present levels. The reasons they are appropriate to consider here are explained below.

Three possible scenarios associated with the 2011 oil and soya spill event at Nightingale and Inaccessible islands have been identified. These are:

- Safe Case (Oil only)
- Worst case (Oil only)
- Soya impact (Nightingale island only)

The oil spill scenarios assign extra mortalities to both the 2011 settlement (0-year olds) and to the 1-3-year old recently settled juveniles. The degree of mortality expected for each scenario differs for each of the two islands - see table below for details. These scenarios were provided by expert consultants Patrick Franklin and Sue Scott (Franklin and Scott final report, 6 July).

	Oil spill scenario	**2011 Settlement mortality**	**1-3 year olds 2011 mortality**
Inaccessible	Safe Case	18% fails	35% mortality
	Worst Case	35% fails	70% mortality
Nightingale	Safe Case	50% fails	50% mortality
	Worst Case	100% fails	100% mortality

The impact of the soya spill is modelled for Nightingale island assuming the following effects on the adult stock (ages 4+):

i) The adults migrate away from the island/fishery for one year (2011) and then all return.
ii) The adults migrate away from the island/fishery for three years (2011-2013) and then all return.
iii) The adults experience a 70% immediate mortality in 2011.

For options i) and ii) above, this is effected in the modelling by assuming a "zero" catch for either one or three years. The "migration" is thus seen as an absence from the fishery either because the adult lobsters have actually moved away from the island, or because they are not feeding (at least on the bait in the traps) and thus unavailable to the fishery. After one (or three) years these lobster become available to the fishery again. The third option which assumes 70% of adults die in 2011 is fairly extreme and was selected to near "bound" this possibility. Calculations could readily be made for other adult mortality proportions.

Johnston and Butterworth (2011a) have recently developed updated stock assessment models for both the Inaccessible and Nightingale island populations of *Jasus tristanii*. These models keep track of the number of lobsters (male and female separately) of each age group and hence length class over time. They have been developed to encapsulate past catch histories and to reflect catch-per-unit-effort trends, as well as the trends in other data that have been collected from each population (e.g. catch-at-length frequencies, discard proportion rates). Note that there are two assessment models for Nightingale island related to two possible somatic growth models:

i) Pollock and Roscoe (1977) – "Pollock"
ii) James Glass (pers. commn) (2010) – "James Glass"

At present the authors would advise that the James Glass growth rate is likely to be the closer to reality of the two as a number of sources (published and anecdotal) mention that somatic growth rates at Nightingale island are "faster" than those observed at Tristan and Inaccessible islands, whereas the Pollock growth rate model suggests the opposite. Lobsters are also observed to grow to larger sizes at Nightingale island. The Appendix (and Johnston and Butterworth (2011b)) gives further details.

The assessment models provide useful tools to explore the impacts of the various scenarios above on the future productivity of the resource at each island. This is achieved by projecting the population forwards in time under an assumed constant catch (CC) level. The effect of each CC level can then be evaluated by examining the future trajectories for "exploitable biomass" predicted by the assessment. The "exploitable biomass", or B_{exp}, is the mass of lobster (biomass) above the minimum legal carapace length that is available to the fishery for harvesting. It is a combination of the numbers of lobsters, their individual weights, and their availability to the fishery which is called "selectivity".

The rationale used here is to first project the resource at each island ahead into the future under a CC which is equal to the TAC(2011) level ($\text{TAC}_{\text{init}}(2011)$) that has been set initially for each island under the assumption of no oil or soya spill effect. The B_{exp} levels that are predicted for 2016, 2021 and 2061 are recorded and become "target" biomass levels to "achieve" when the same populations are projected ahead under any of the oil spill effect and soya impact scenarios. These are termed the B_{exp}^{target} levels.

For each of the oil spill mortality scenarios ("Safe" and "Worst"), and similarly for these scenarios in combination with a soya impact scenario (i), ii) or iii)), a CC is calculated that is expected to produce the same exploitable biomass level in either 2016, 2021, 2031 or 2061 that is estimated when assuming no oil spill effect and TAC_{init}(2011) being set each year (i.e. the TAC that produces the same eventual biomass as the "target" levels mentioned above). A reason for focusing on such targets is that an important component of the rationale underlying the initial TACs set for 2011 was not to reduce the current CPUE appreciably as this could impact on the financial variability of current catching operations. Hence TACs computed under these alternative oil spill/soya impact scenarios have the broad objective of maintaining these CPUEs. A long time period (50 years) is considered here (although the actual choice of 50 years is somewhat arbitrary), to allow for any past fluctuations in the resource dynamics to work their way through the population so that steady trends become evident. In projecting the populations forwards into the future, a number of assumptions need to be made. Here the following apply:

1) Future recruitment levels: the assessment models **estimate** the recruitment variability for the period 1992-2005. For the period 2006+ it is not possible to estimate recruitment trends from the data and one needs to make an assumption about recruitment level for the 2006+ period. Here it is assumed that the average of the 1998-2005 recruitment level applies to the 2006+ future (before making any adjustments for oil spill/soya impact effects). This is considered a conservative option, as the assessments have estimated a higher recruitment just prior to 1998, which may re-occur in the future. The 1998-2005 average recruitment is thus more conservative as a basis for projections as it excludes these higher recruitments from the average.
2) Future fishing selectivity: the future fishing selectivity is assumed to remain at that estimated for recent years.

Yield calculations assuming Oil spill mortality only

CC Calculations for 2011-2015

Projecting the population forwards under the TAC_{init}(2011) for the "no oil spill effect" scenario provides target exploitable biomass levels at which to aim after five years i.e. in 2016. The CC level for 2011-2015 for both the "Safe Case" and the "Worst Case" that would result in reaching the B_{exp}^{target} (2016) by 2016 can then be determined. The rationale is that the exploitable biomass (and hence CPUE) should desirably reach the same target biomass level in 2016 under any of the three scenarios specified above, i.e. "No oil spill effect", "Safe Case scenario" and "Worst Case scenario".

CC Calculations for 2016-2020

Assuming the catch levels for 2011-2015 were set at the level for which the target biomass in 2016 is reached, one can then ask what the CC level for next five year period (2016-2020) should be that would result in the B_{exp}^{target} (2021) being achieved in 2021. The CC level for 2016-2020 for both the "Safe Case" and the "Worst Case" that would result in reaching this target by 2021 can then be determined. The rationale is that the exploitable biomass should reach the same B_{exp}^{target} in 2021 under any of the three scenarios specified above, for the same reasons as given above.

CC Calculations for 2021-2030

Assuming the catch levels for 2011-2015 were set at the level for which the target biomass in 2016 is reached, and then at the catch levels for which the target biomass in 2021 is reached, one can also then calculate what the CC level for next ten year period (2021-2030) should be that would result in the B_{exp}^{target}(2031) being achieved in 2031. The CC level for 2021-2030 for the various scenarios that would result in reaching this target by 2031 can then be determined. The rationale is, once again, that the exploitable biomass should reach the same B_{exp}^{target} in 2031 under any of the scenarios specified above.

CC Calculations for 2021-2060

One can finally ask what the CC level for the thirty year period (2031-2060) should be that would result in the B_{exp}^{target}(2061) being achieved in 2061. The CC level for 2031-2060 for the various scenarios that would result in reaching this target by 2061 can then be determined. The rationale is, once again, that the exploitable biomass should reach the same B_{exp}^{target} in 2061 under any of the scenarios specified above.

Yield calculations assuming Oil spill mortality and Soya impacts on adult lobsters for Nightingale Island

As discussed above, projecting the population forwards under the TAC_{init}(2011) for the "no oil spill effect" scenario provides target exploitable biomass levels at which to aim after five years, i.e. in 2016, and after ten years, i.e. in 2021. The CC level for 2011-2015 for both the "Safe Case" and the "Worst Case" that would result in reaching the B_{exp}^{target} (2016) by 2016 can then be determined for the various soya impact scenarios on adults in combination with oil spill scenarios.

Results and Conclusions

Inaccessible Island

The TAC_{init}(2011) is 95 MT (this is the initial TAC set for the island under the assumption that no oil spill event occurred in 2011). This provides B_{exp}^{target} values of 337 MT in 2016, 330 MT in 2021, 325 MT in 2031 and 323 MT in 2061. Table 1 shows the CC values for each period that will result in reaching the relevant B_{exp}^{target} values under each of the two oil spill scenarios (“Safe Case” and “Worst Case”).

Figure 1a shows a plot of the Inaccessible island B_{exp} trajectory where the population has been projected ahead until 2066 at a CC of 95 MT (TAC_{init}(2011) value) – under the assumption that the oil spill event which occurred in 2011 had no effect. The vertical line shows the current (2011) time. Figure 1b plots the B_{exp} trajectory for each of the three specified oil spill scenarios under the corresponding CC that results in the B_{exp}^{target} for 2016 being attained where this target as well as those for 2021, 2031 and 2061 are shown by circles. Figure 1b also shows the corresponding CC values for as well as the historic catch values (shown as solid dots).

Table 3a summarises the total loss expected (in MT) to the Inaccessible island fishery over various periods for each of the oil spill impact scenarios.

Nightingale Island

The “Pollock” growth model

The TAC_{init}(2011) is 65 MT. For the “Pollock growth” model, this provides B_{exp}^{target} values of 252 MT in 2016, 262 MT in 2021 and 273 MT in 2061. Table 2a shows the CC values for each period that will result in reaching the B_{exp}^{target} values under each of the various oil spill and soya impact scenarios using this “Pollock” growth model.

Table 3b summarises the total loss expected (in MT) to the Nightingale island fishery over various periods for each of the two oil spill scenarios specified in isolation, and then in combination with various soya impact scenarios.

Table 4a reports the series of catches at Nightingale island that are estimated to result in the B_{exp}^{target} values under each of the various oil spill and soya impact scenarios using the “Pollock” growth model.

Figure 2a shows a plot of the Nightingale island B_{exp} (Pollock) trajectory where the population has been projected ahead till 2061 at a CC of 65 MT. The vertical line shows the current (2011) time.

Figure 2b plots the B_{exp} trajectory for each of the three specified oil spill scenarios under the corresponding CC that results in the B_{exp}^{target} values being attained where these targest (for 2016, 2021, 2031 and 2061) are shown by circles. Figure 2b also shows the corresponding CC values as well as the historic catch values (shown as solid dots).

Figure 2c plots the B_{exp} trajectory for each of the three specified oil spill scenarios under the corresponding CC that results in the B_{exp}^{target} values being attained under the assumption of 1 year adult migration . Figure 2c also shows the corresponding CC values as well as the historic catch values (shown as solid dots). Figure 2d is similar to Figure 2c but where the assumption of 3 year adult migration is made. Similarly, Figure 2e is for the assumption that 70% of all adults die in 2011.

The "James Glass" growth model

The "James Glass" growth model similarly provides B_{exp}^{target} values: these being of 234 MT in 2016, 242 MT in 2021 and 250 MT in 2061. Table 2b shows the CC values for each period that will result in reaching the B_{exp}^{target} values under the various oil spill and soya impact scenarios using this "James Glass" growth model.

Table 3c summarises the total loss expected (in MT) to the Nightingale island fishery over various periods for each of the two oil spill scenarios specified in isolation, and then in combination with various soya impact scenarios.

Table 4b reports the series of catches at Nightingale island that are estimated to result in the B_{exp}^{target} values under each of the various oil spill and soya impact scenarios using the "James Glass" growth model.

Figure 3a shows a plot of the Nightingale island B_{exp} (James Glass) trajectory where the population has been projected ahead till 2061 at a CC of 65 MT. The vertical line shows the current (2011) time.

Figure 3b plots the B_{exp} trajectory for each of the three specified oil spill scenarios under the corresponding CC that results in the B_{exp}^{target} values being attained, where these targets (for 2016, 2021, 2031 and 2061) are shown by circles. Figure 3b also shows the corresponding CC values as well as the historic catch values (shown as solid dots).

Figure 3c plots the B_{exp} trajectory for each of the three specified oil spill scenarios under the corresponding CC that results in the B_{exp}^{target} values being attained under the assumption of 1 year adult migration . Figure 3c also shows the corresponding CC values as well as the historic catch values (shown as solid dots). Figure 3d is similar to Figure 3c but where the assumption of 3 year adult migration is made. Similarly, Figure 3e is for the assumption that 70% of all adults die in 2011.

Implications of setting future TACs at the TAC_{init}(2011) level

Figure 4 shows future projections at Inaccessible island assuming a CC= TAC_{init}(2011)=95 MT is applied from 2011 and into the future. The plot compares the implications of this CC under all three future oil spill scenarios considered.

Figure 5a shows future projections at Nightingale island assuming a CC= TAC_{init}(2011)=65 MT is applied from 2011 and into the future. The plot compares the implications of this CC under all three future oil spill scenarios considered. Here the “Pollock” growth model is used. Figure 5b shows similar trajectories, but for the “James Glass” growth model.

Nightingale island results: “Pollock” vs “James Glass” growth models

Figure 6 compares the Nightingale island trajectories for the various CC calculated in this report between the “Pollock” and the “James Glass” growth models.

General Comments

Note that there are clear differences in the future dynamics for the Inaccessible, Nightingale (Pollock) and Nightingale (James Glass) island models. These differ in the short and in the medium term in part because of different past fishing levels and assessed different patterns of recruitment at the two islands. More importantly though, the growth rate of the lobsters at the two islands differ (see Figure 7), and there are two possible growth curves available for Nightingale island. The growth rate at Nightingale island according to the James Glass growth model is higher than at Inaccessible or at Nightingale island assuming Pollock’s growth model. These differences in growth rates result in the inference that for any given age, lobsters will be largest at Nightingale island according to the James Glass growth model, but largest at Inaccessible island if one assumes the Pollock growth model for Nightingale island. The two islands also have slightly different minimum legal carapace lengths of 68mm CL at Inaccessible and 70mm CL at Nightingale island. What this means is that legal sized lobsters (lobsters in the exploitable biomass and hence the legal catch) at Inaccessible island are around 6+ years of age, whereas the legal sized lobsters at Nightingale island are either 5.5 years (according to the James Glass growth model) or around 9 years+ of age according to the Pollock growth curve. These differences are a direct result of the different growth rates.

Figure 8 shows a plot of numbers-at-age for Inaccessible (left side), Nightingale (Pollock) (central) and Nightingale (James Glass) (right side) islands for every two years starting in 2011, under the assumption that the “Worst Case” oil spill scenario at Nightingale occurred at both islands (i.e. 100% mortality in 2011 of ages 0-3) – though the “Worst Case” scenario for Inaccessible island is not as severe, the larger effect is assumed here for illustrative purposes to aid the graphical comparison. As a result of the differing growth rates, the full effect of the oil spill can be seen to impact the exploitable portion of the Inaccessible island stock over 2014-2017. The vertical arrows in the plots show the ages which correspond to the minimum legal carapace length (and hence the age above which lobsters enter the exploitable biomass). In contrast, assuming the “Pollock” growth model, the full impact of the oil spill will only be felt at Nightingale island some 4-5 years hence, around 2019-2021, due to the slower growth rate – i.e. it takes a while before the "oil spill effected" lobsters grow into the exploitable component of the stock. If, however, the "James Glass" growth model is assumed correct, then one can expect to see the impact of the oil spill in the exploitable portion of the stock much sooner (around 2013-2017) as a result of the faster growth rate.

To summarise, if the "Pollock" growth model is assumed for Nightingale island, the worst of the oil spill impact will be felt more immediately at Inaccessible island because of the different growth rates and minimum carapace lengths, while the full effect will be felt at Nightingale island only some 8-9 years hence. Assuming the "James Glass" growth model for Nightingale island leads to the prediction that the oil spill impact will be felt far sooner.

Results for the consequences of a soya impact at Nightingale island vary substantially depending on whether this causes a short term "migration" away from the fishery or an immediate additional mortality on adult lobsters. For the former, results differ little from the case where there is no soya impact. The reason is that over the first five years, an initial zero catch resulting from the migration can be offset by near equivalent increases in catches in the years which immediately follow the lobsters return for the same net longer term impact on the stock.

However the consequences of an immediate 70% adult mortality as a result of the soya spill is larger, with a greater impact on catch loss for the "Pollock" than for the "James Glass" growth model (the relative effects for the oil spill scenarios are in the opposite order: there losses are greater for the "James Glass" growth model). The reason for this is evident from Figure 9 which projects B_{exp} values for the 70% adult mortality scenario under a constant annual catch of 65MT. Because of the slower "Pollock" growth, recovery of the biomass is slower in that case, so that greater catch sacrifices are needed to restore catch rates to pre-OLIVA levels quickly.

Comparison of losses across scenarios

As computed, the various scenarios considered can lead to losses in catch for up to 20 years. Table 5 provides an overall summary for this 2011-2030 period for both Inaccessible and Nightingale islands, where for the latter, results for various combinations of oil spill effects and soya impacts are shown.

For Nightingale island the results differ depending on the growth model assumed. The oil spill effects are greater for the faster "James Glass" growth model because the high initial losses in that case correspond to lesser later losses under the slower "Pollock" growth rate (see Tables 3 and 4 – the reasons that these later losses are lower are complex, related in part to the different historical abundance trends estimated for the two alternative growth models). These results change only slightly if the soya spill causes migration of the lobsters out of the fishery for a 1-3 year period. (Note though that result might be misleading: it assumes that a catch loss over the first few years can be compensated by a near equivalent increase in the balance of the period until 2016; operational considerations for the fishery – e.g. vessel scheduling and processing limitations – might render such increases impossible to achieve.) However, if instead the soya spill results in a substantial immediate mortality of adult lobster, results differ appreciably. First the resultant catch loss could be appreciably higher, and secondly this effect is larger for the "Pollock" growth rate because the reduced abundance takes longer to recover if growth rates are lower.

A difficulty is that even given future monitoring data, it could prove difficult to distinguish in due course what combination of oil spill and soya effects on juvenile and adult rock lobsters did in fact take place. Nevertheless these monitoring data should, over a period whose length would range from a few months to probably about three years, be able to exclude a number of these scenarios. This could assist considerably in reducing the range of possible losses in future catches that is summarised in Table 5. In particular this will throw light on the uncertainty which has the largest impact on the extent of catch losses that are tabulated above, *viz*. the extent of the adult mortality at Nightingale which the soya spill may have caused – for example if monitoring reveals catch rates returning to near pre-OLIVA incident levels in the short-term, clearly such additional lobster mortality cannot have been very large. There would therefore seem to be an argument to structure ongoing insurance claim negotiations within a framework that equitably allows the results from such future monitoring to be taken into account as they become available. A useful associated initiative would be the organisation of a scientific workshop in the near future to deliberate how such monitoring data would best be utilised to reduce the range of scenarios considered in Table 5, and consequently give guidance on the choices amongst these scenarios that constitute the most appropriate basis upon which to set catch limits in the short term.

References

Johnston, S.J. and D.S. Butterworth. 2011a. Updates to the 2011 Tristan da Cunha group of islands assessment models and final assessment results. MARAM document, MARAM/TRISTAN/2011/Jun/08.

Johnston, S.J. and D.S Butterworth. 2011b. Summary of growth rate data and analyses for the Tristan da Cunha group of islands. MARAM document, MARAM/TRISTAN/2011/Jun/09.

Table 1: Inaccessible island CC values for the periods 2011-2015, 2016-2020, 2021-2030 and 2031-2060 that will result in the various B_{exp}^{target} values being reached under various oil spill effect scenarios.

Oil spill scenario	**CC 2011-2015**	**CC 2016-2020**	**CC 2021-2030**	**CC 2031-2060**
	$B_{exp}^{target}(2016) = 337$ MT	$B_{exp}^{target}(2021) = 330$ MT	$B_{exp}^{target}(2031) = 325$ MT	$B_{exp}^{target}(2061) = 323$ MT
No effect	95 MT	95 MT	95 MT	95 MT
Safe case	53 MT	83 MT	95 MT	95 MT
Worst case	9 MT	70 MT	95 MT	95 MT

Table 2a: Nightingale island CC values for the periods 2011-2015, 2016-2020, 2021-2030 and 2031-2060 that will result in the various B_{exp}^{target} values being reached, assuming the "Pollock growth" model under various combinations of oil spill and soya impact scenarios.

Oil spill scenario	**Soya impact**	**CC 2011-2015**	**CC 2016-2020**	**CC 2021-2030**	**CC 2031-2060**
		$B_{exp}^{target}(2016) = 252$ MT	$B_{exp}^{target}(2021) = 262$ MT	$B_{exp}^{target}(2031) = 270$ MT	$B_{exp}^{target}(2061) = 273$ MT
No effect	None	65 MT	65 MT	65 MT	65 MT
Safe case	None	64 MT	20 MT	64 MT	65 MT
Worst case	None	57 MT	0 MT	57 MT	65 MT
None	1 yr migration	78 MT (2012-2015))	64 MT (2012-2020)	65 MT	65 MT
Safe case	1 yr migration	77 MT (2012-2015))	19 MT (2012-2020)	64 MT	65 MT
Worst case	1 yr migration	68 MT (2012-2015))	0 MT (2012-2020)	57 MT	65 MT
No effect	3 yr migration	146 MT (2014-2015)	63 MT (2014-2015)	65 MT	65 MT
Safe case	3 yr migration	143 MT (2014-2015)	17 MT (2014-2015)	64 MT	65 MT
Worst case	3 yr migration	126 MT (2014-2015)	0 MT (2014-2015)	57 MT	65 MT
No effect	70% die in 2011	0 MT	23 MT	63 MT	65 MT
Safe case	70% die in 2011	0 MT	0 MT	57 MT	65 MT
Worst case	70% die in 2011	0 MT	0 MT	45 MT	64 MT

Table 2b: Nightingale island CC values for the periods 2011-2015, 2016-2020, 2021-2030 and 2031-2060 that will result in the various B_{exp}^{target} values being reached, assuming the "James Glass growth" model under various combinations of oil spill and soya impact scenarios.

Oil spill scenario	**Soya impact**	**CC 2011-2015**	**CC 2016-2020**	**CC 2021-2030**	**CC 2031-2060**
		$B_{exp}^{target}(2016) = 234$ MT	$B_{exp}^{target}(2021) = 242$ MT	$B_{exp}^{target}(2031) = 248$ MT	$B_{exp}^{target}(2061) = 250$ MT
No effect	None	65 MT	65 MT	65 MT	65 MT
Safe case	None	10 MT	50 MT	65 MT	65 MT
Worst case	None	0 MT	11 MT	65 MT	65 MT
No effect	1 yr migration	76 MT (2012-2015))	65 MT (2012-2020)	65 MT	65 MT
Safe case	1 yr migration	11 MT (2012-2015))	51 MT (2012-2020)	65 MT	65 MT
Worst case	1 yr migration	0 MT (2012-2015))	11 MT (2012-2020)	65 MT	65 MT
No effect	3 yr migration	137 MT (2014-2015)	65 MT (2014-2015)	65 MT	65 MT
Safe case	3 yr migration	22 MT (2014-2015)	50 MT (2014-2015)	65 MT	65 MT
Worst case	3 yr migration	0 MT (2014-2015)	11 MT (2014-2015)	65 MT	65 MT
No effect	70% die in 2011	0 MT	52 MT	65 MT	65 MT
Safe case	70% die in 2011	0 MT	13 MT	64 MT	65 MT
Worst case	70% die in 2011	0 MT	0 MT	58 MT	65 MT

Table 3a: Summary of total loss expected (in MT) to the Inaccessible island fishery over various periods for each of the two oil spill scenarios specified.

Oil spill scenario	**5-year period 2011-2015**	**5-year period 2016-2020**	**10-year period 2021-2030**	**30-year period 2031-2060**	**Total**
No effect	0	0	0	0	0
Safe case	210 (5 x 42)	60 (5 x 12)	0	0	270
Worst case	430 (5 x 86)	125 (5 x 25)	0	0	555

Table 3b: Summary of total loss expected (in MT) to the Nightingale island fishery over various periods for each of the two oil spill scenarios specified in isolation and then in combination with various soya impact scenarios – "Pollock growth" model.

Oil spill scenario	Soya impact	5-year period 2011-2015	5-year period 2016-2020	10-year period 2021-2030	30-year period 2031-2060	Total
No effect	None	0	0	0	0	0
Safe case	None	5 (5 x 1)	225 (5 x 45)	10 (10 x 1)	0 (30 x 0)	240
Worst case	None	40 (5 x 8)	325 (5 x 65)	80 (10 x 8)	0 (30 x 0)	445
No effect	1 yr migration	13 (65+ 4 x -13)	5 (5 x 1)	0 (10 x 0)	0 (30 x 0)	18
Safe case	1 yr migration	17 (65 + 4 x -12)	230 (5 x 46)	10 (10 x 1)	0 (30 x 0)	257
Worst case	1 yr migration	53 (65 + 4 x -3)	325 (5 x 65)	80 (10 x 8)	0 (30 x 0)	458
No effect	3 yr migration	33 (3 x 65, 2 x -81)	10 (5 x 2)	0 (10 x 0)	0 (30 x 0)	43
Safe case	3 yr migration	39 (3 x 65, 2 x -78)	240 (5 x 48)	10 (10 x 1)	0 (30 x 0)	289
Worst case	3 yr migration	73 (3 x 65, 2 x -61)	325 (5 x 65)	80 (8 x 10)	0 (30 x 0)	478
No effect	70% die in 2011	325 (5 x 65)	210 (5 x 42)	20 (10 x 2)	0 (30 x 0)	555
Safe case	70% die in 2011	325 (5 x 65)	325 (5 x 65)	80 (10 x 8)	0 (30 x 0)	730
Worst case	70% die in 2011	325 (5 x 65)	325 (5 x 65)	200 (10 x 20)	0 (30 x 0)	850

Table 3c: Summary of total loss expected (in MT) to the Nightingale island fishery over various periods for each of the two oil spill scenarios specified in isolation and then in combination with various soya impact scenarios – "James Glass growth" model.

Oil spill scenario	Soya impact	5-year period 2011-2015	5-year period 2016-2020	10-year period 2021-2030	30-year period 2031-2060	Total
No effect	None	0	0	0	0	0
Safe case	None	275 (5 x 55)	75 (5 x 15)	0 (10 x 0)	0 (30 x 0)	350
Worst case	None	325 (5 x 65)	270 (5 x 54)	0 (10 x 0)	0 (30 x 0)	595
No effect	1 yr migration	21 (65+ 4 x -11)	0 (5 x 0)	0 (10 x 0)	0 (30 x 0)	21
Safe case	1 yr migration	281 (65 + 4 x 54)	70 (5 x 14)	0 (10 x 0)	0 (30 x 0)	351
Worst case	1 yr migration	325 (65 + 4 x 65)	270 (5 x 54)	0 (10 x 0)	0 (30 x 0)	595
No effect	3 yr migration	51 (3 x 65, 2 x -72)	0 (5 x 0)	0 (10 x 0)	0 (30 x 0)	51
Safe case	3 yr migration	281 (3 x 65, 2 x -43)	75 (5 x 15)	0 (10 x 0)	0 (30 x 0)	356
Worst case	3 yr migration	325 (3 x 65, 2 x 65)	270 (5 x 54)	0 (10 x 0)	0 (30 x 0)	595
No effect	70% die in 2011	325 (5 x 65)	65 (5 x 13)	0 (10 x 0)	0 (30 x 0)	390
Safe case	70% die in 2011	325 (5 x 65)	260 (5 x 52)	0 (10 x 0)	0 (30 x 0)	585
Worst case	70% die in 2011	325 (5 x 65)	325 (5 x 65)	70 (10 x 7)	0 (30 x 0)	720

Table 4a: Catches (MT) at Nightingale island associated with each oil spill/soya impact scenario combinations. Values as calculated assuming the "Pollock growth" model.

	TAC$_{init}$											
Oil spill scenario	No effect	Safe	Worst	No effect	Safe	Worst	No effect	Safe	Worst	No effect	Safe	Worst
Soya impact	none	none	none	1 yr migration	1 yr migration	1 yr migration	3 yr migration	3 yr migration	3 yr migration	70% adults die	70% adults die	70% adults die
2011	65	64	57	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2012	65	64	57	78	77	68	**0**	**0**	**0**	**0**	**0**	**0**
2013	65	64	57	78	77	68	**0**	**0**	**0**	**0**	**0**	**0**
2014	65	64	57	78	77	68	146	143	126	0	0	0
2015	65	64	57	78	77	68	146	143	126	0	0	0
Total 2011-2015	*325*	*320*	*285*	*312*	*308*	*272*	*292*	*286*	*252*	*0*	*0*	*0*
2016	65	20	0	64	19	0	63	17	0	23	0	0
2017	65	20	0	64	19	0	63	17	0	23	0	0
2018	65	20	0	64	19	0	63	17	0	23	0	0
2019	65	20	0	64	19	0	63	17	0	23	0	0
2020	65	20	0	64	19	0	63	17	0	23	0	0
Total 2016-2020	*325*	*100*	*0*	*320*	*95*	*0*	*315*	*85*	*0*	*115*	*0*	*0*
2021-2030	65	64	57	65	64	57	65	64	57	63	57	45
Total 2021-2030	*650*	*640*	*570*	*650*	*640*	*570*	*650*	*640*	*570*	*630*	*570*	*450*
Total 2011-2030	*1300*	*1060*	*855*	*1282*	*1043*	*842*	*1257*	*1011*	*822*	*745*	*570*	*450*

Table 4b: Catches (MT) at Nightingale island associated with each oil spill/soya impact scenario combinations. Values as calculated assuming the “James Glass” growth model.

	TAC$_{\text{init}}$											
Oil spill scenario	No effect	Safe	Worst	No effect	Safe	Worst	No effect	Safe	Worst	No effect	Safe	Worst
Soya impact	none	none	none	1 yr migration	1 yr migration	1 yr migration	3 yr migration	3 yr migration	3 yr migration	70% adults die	70% adults die	70% adults die
2011	65	10	0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2012	65	10	0	76	11	0	**0**	**0**	**0**	**0**	**0**	**0**
2013	65	10	0	76	11	0	**0**	**0**	**0**	**0**	**0**	**0**
2014	65	10	0	76	11	0	137	22	0	0	0	0
2015	65	10	0	76	11	0	137	22	0	0	0	0
Total 2011-2015	*325*	*50*	*0*	*304*	*44*	*0*	*274*	*44*	*0*	*0*	*0*	*0*
2016	65	50	11	65	51	11	65	50	11	52	13	0
2017	65	50	11	65	51	11	65	50	11	52	13	0
2018	65	50	11	65	51	11	65	50	11	52	13	0
2019	65	50	11	65	51	11	65	50	11	52	13	0
2020	65	50	11	65	51	11	65	50	11	52	13	0
Total 2016-2020	*325*	*250*	*55*	*325*	*255*	*55*	*325*	*250*	*55*	*260*	*65*	*0*
2021-2030	65	65	65	65	65	65	65	65	65	65	65	58
Total 2021-2030	*650*	*650*	*650*	*650*	*650*	*650*	*650*	*650*	*650*	*650*	*650*	*580*
Total 2011-2030	*1300*	*950*	*705*	*1179*	*949*	*705*	*1249*	*944*	*705*	*910*	*715*	*580*

Table 5: Overall summary of losses expected (in MT) over the 2011-2030 period for the various combinations of oil spill and soya impact scenarios considered.

a) Inaccessible island

		Oil spill effect		
		No effect	Safe case	Worst case
Soya Impact	None	0	270	555

b) Nightingale island (results are for the “Pollock”/”James Glass” growth models)

		Oil spill effect		
		No effect	Safe case	Worst case
Soya Impact	None	0/0	240/350	445/595
	1-yr migration	18/21	257/351	458/595
	3-yr migration	43/51	289/356	478/598
	70% die in 2011	555/390	730/585	850/720

Figure 1a: Inaccessible island B_{exp} trajectory under the “no oil spill effect” scenario and a 2011+ constant catch of 95 MT (the TAC_{init}(2011) value). The vertical line indicates the year 2011.

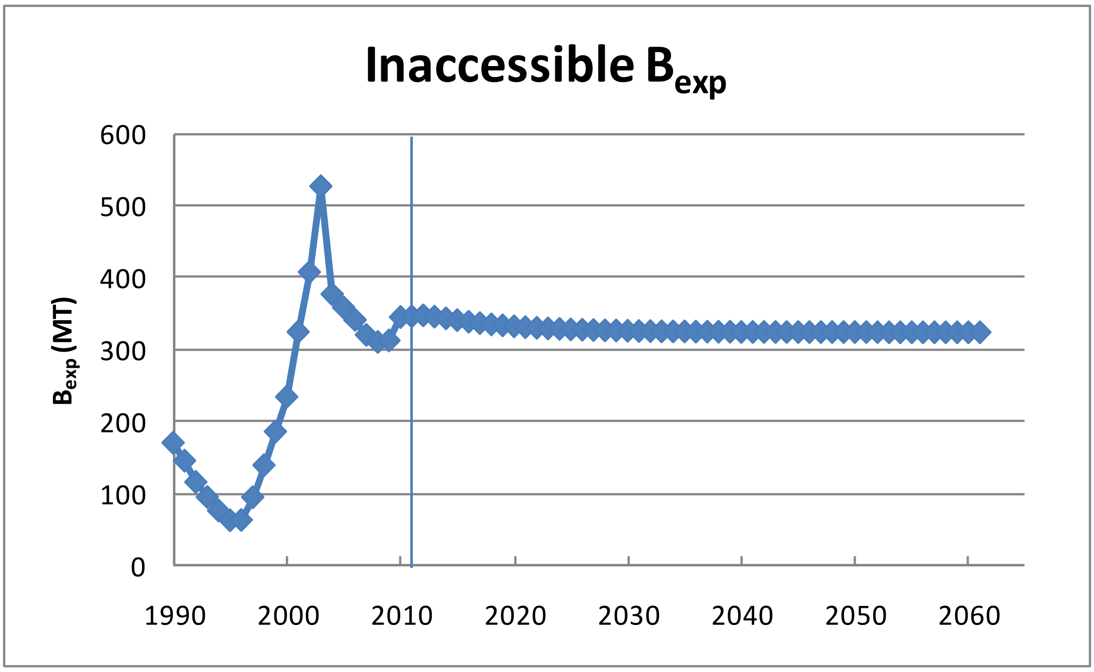


Figure 1b: Inaccessible island B_{exp} trajectories (top plot) for the three oil spill effect scenarios and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} levels (shown as circles) in either 2016, 2021, 2031 or 2061.

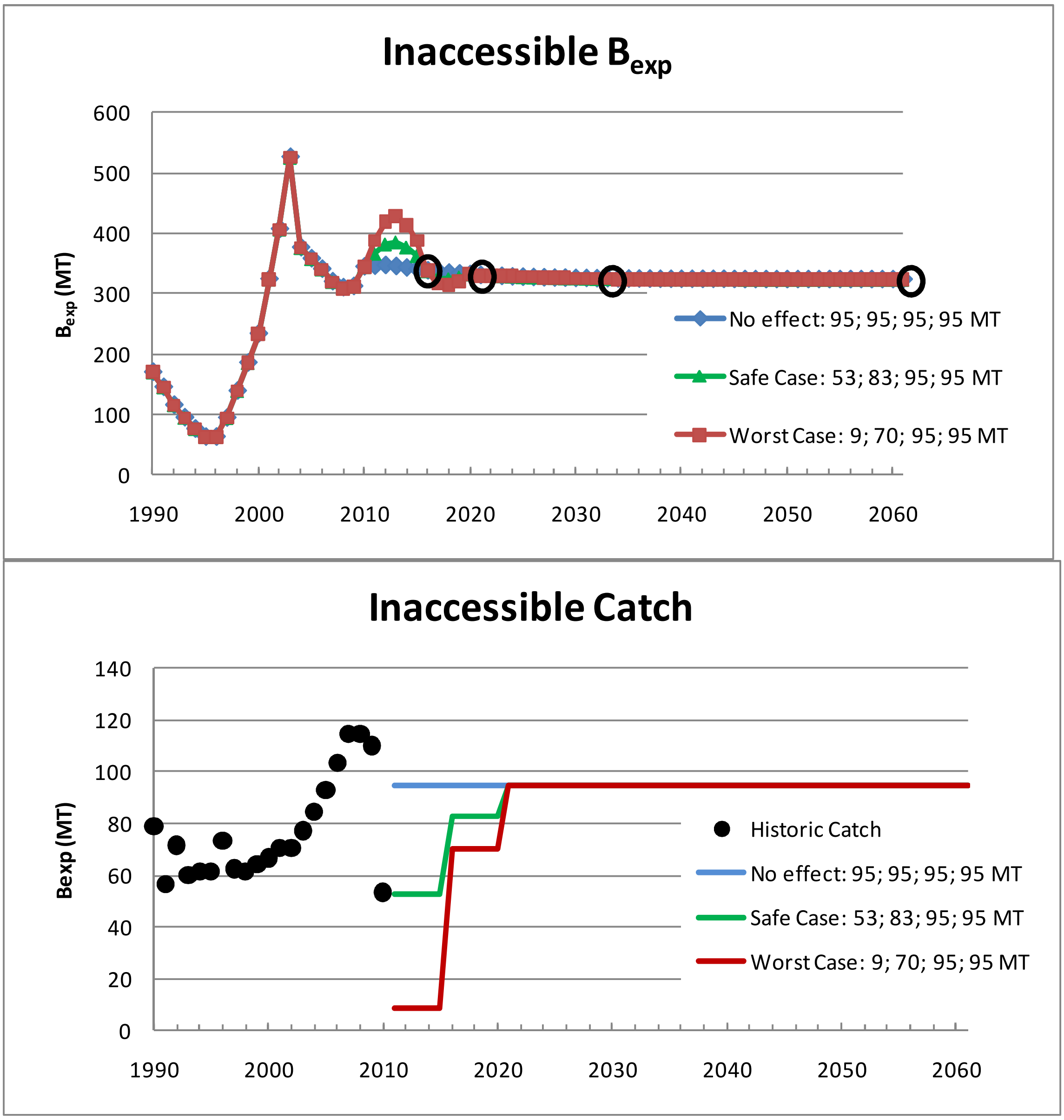


Figure 2a: Nightingale (Pollock growth) island B_{exp} trajectory under the “no oil spill” effect scenario and a 2011+ constant catch of 65 MT (the TAC_{init}(2011) value). The vertical line indicates the year 2011.

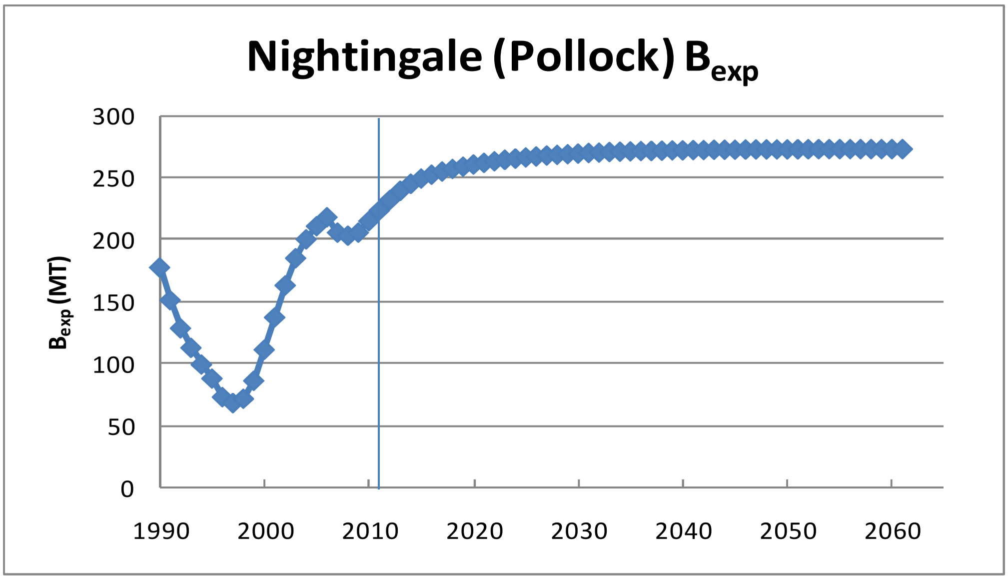
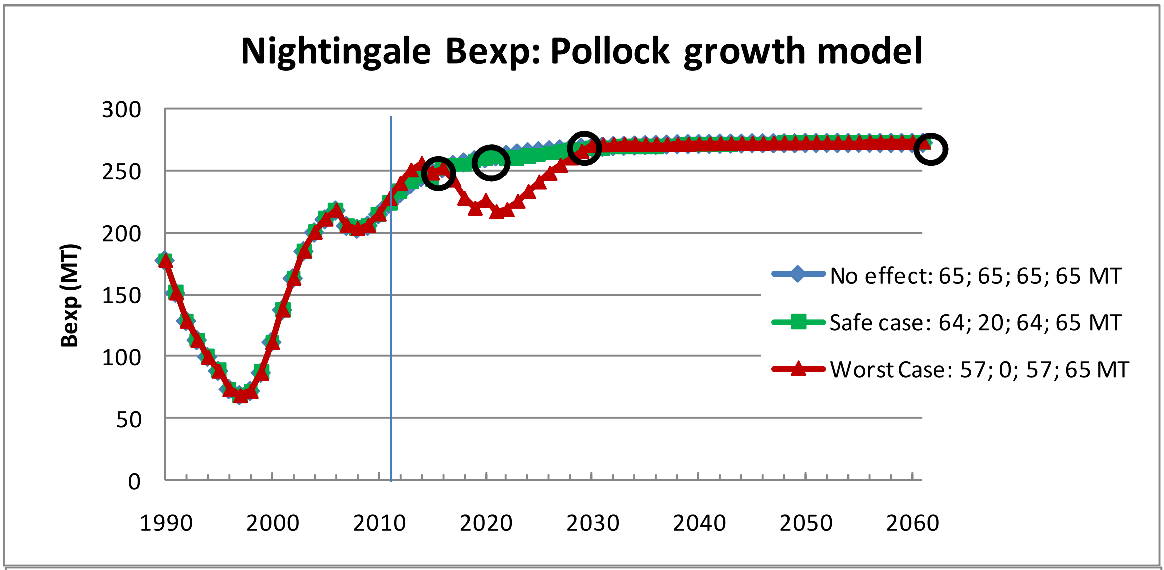


Figure 2b: Nightingale (Pollock growth) island B_{exp} trajectories (top plot) for the three **oil spill effect only** scenarios and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} (shown by circles) levels in either 2016, 2021, 2031 or 2061.



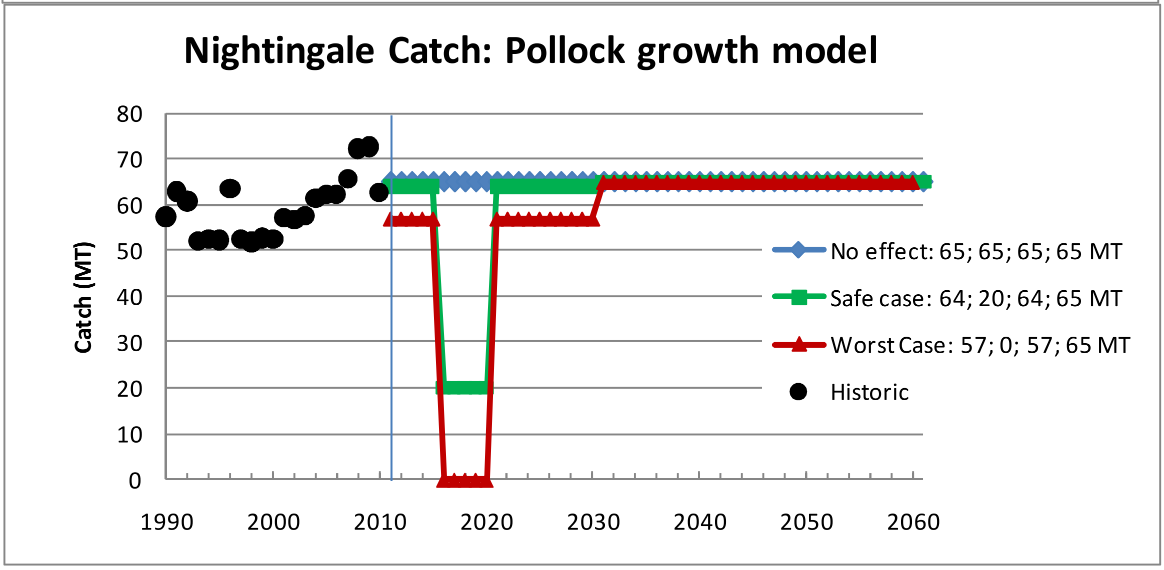
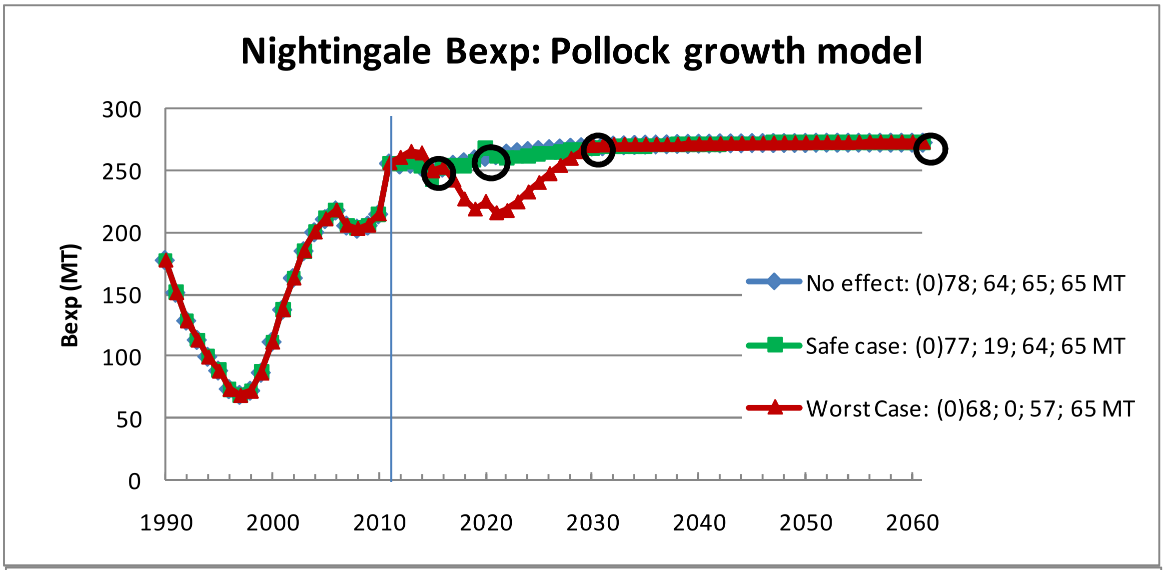


Figure 2c: Nightingale (Pollock growth) island B_{exp} trajectories (top plot) for the soya impact scenarios which assume **1 year adult migration** in addition to alternative oil spill effects, and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} levels (shown by circles) in either 2016, 2021, 2031 or 2061.



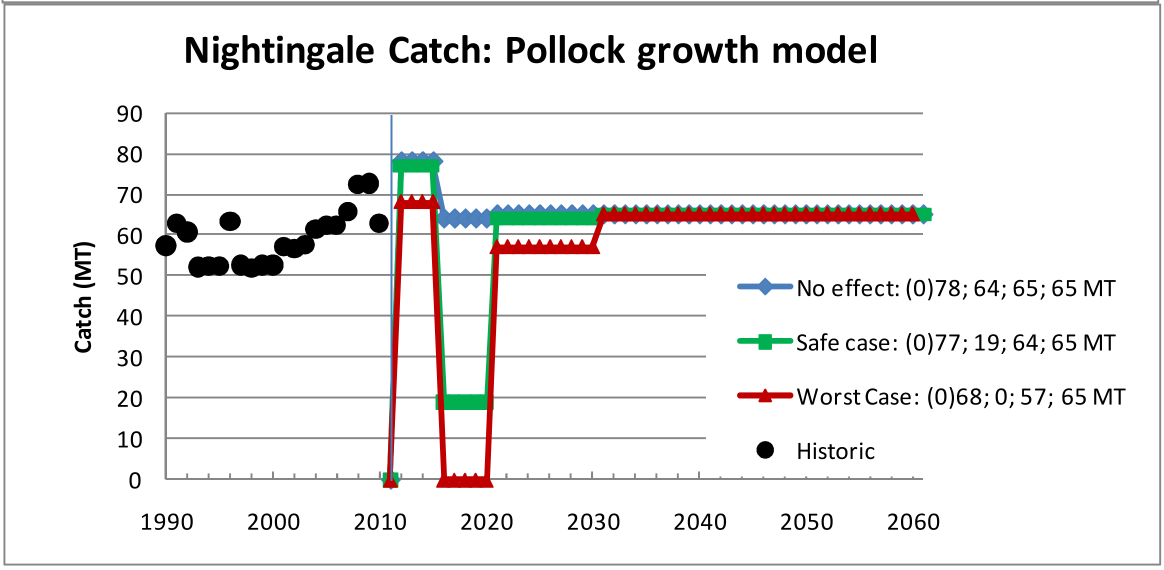
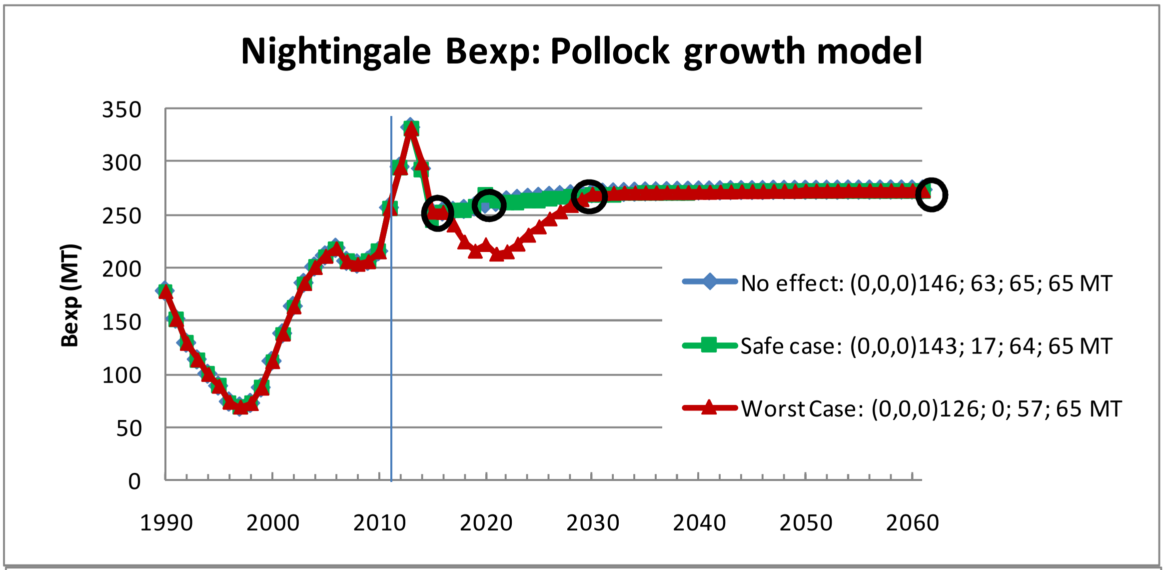


Figure 2d: Nightingale (Pollock growth) island B_{exp} trajectories (top plot) for the soya impact scenarios which assume **3 years adult migration** in addition to alternative oil spill effects, and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} levels (shown by circles) in either 2016, 2021, 2031 or 2061.



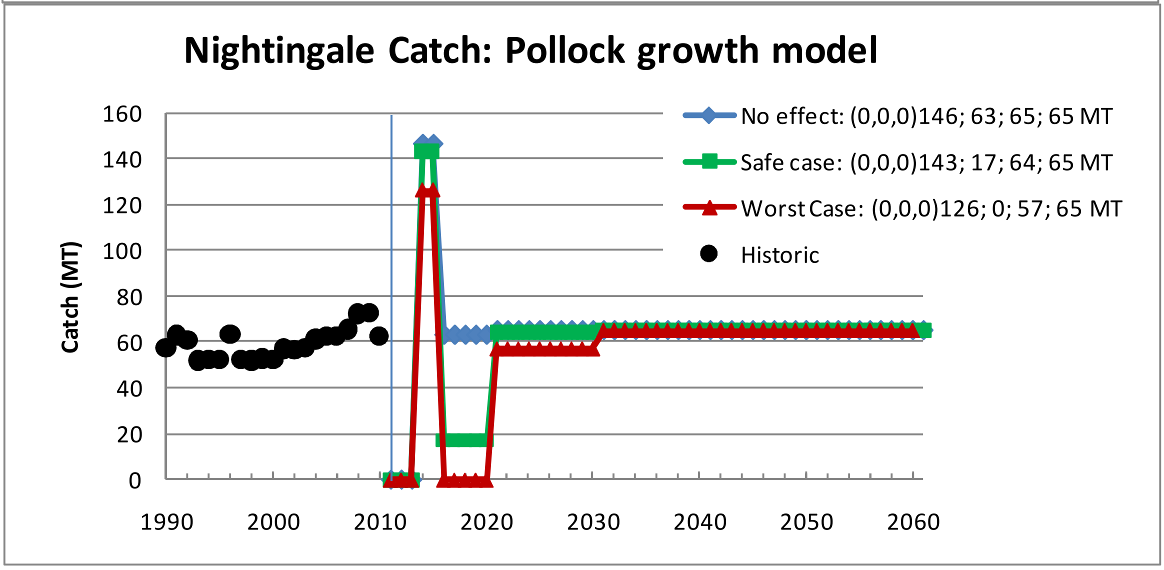
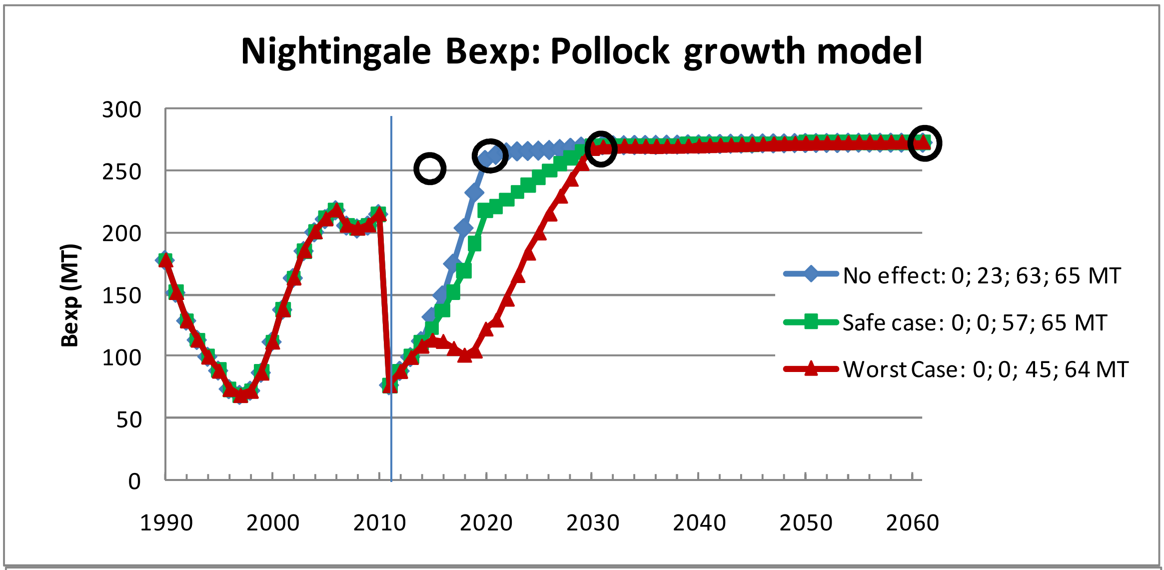


Figure 2e: Nightingale (Pollock growth) island B_{exp} trajectories (top plot) for the soya impact scenarios which assume **70% of adults die** in 2011 in addition to alternative oil spill effects, and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} levels (shown by circles) in either 2016, 2021, 2031 or 2061.



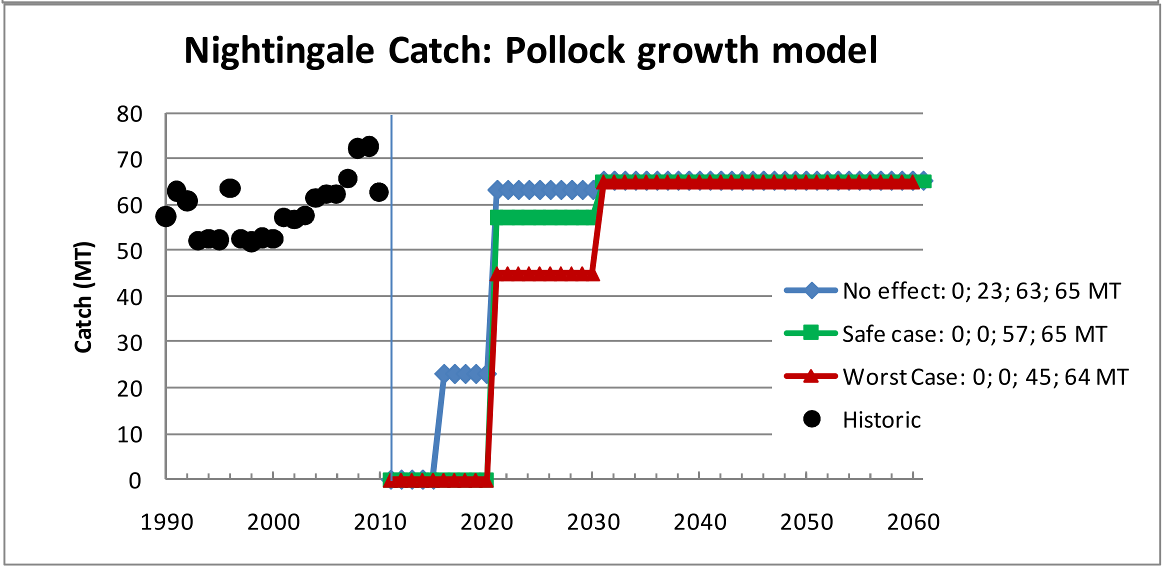


Figure 3a: Nightingale (James Glass growth) island B_{exp} trajectory under the "no oil spill" effect scenario and a 2011+ constant catch of 65 MT (the TAC_{init}(2011) value). The vertical line indicates the year 2011.

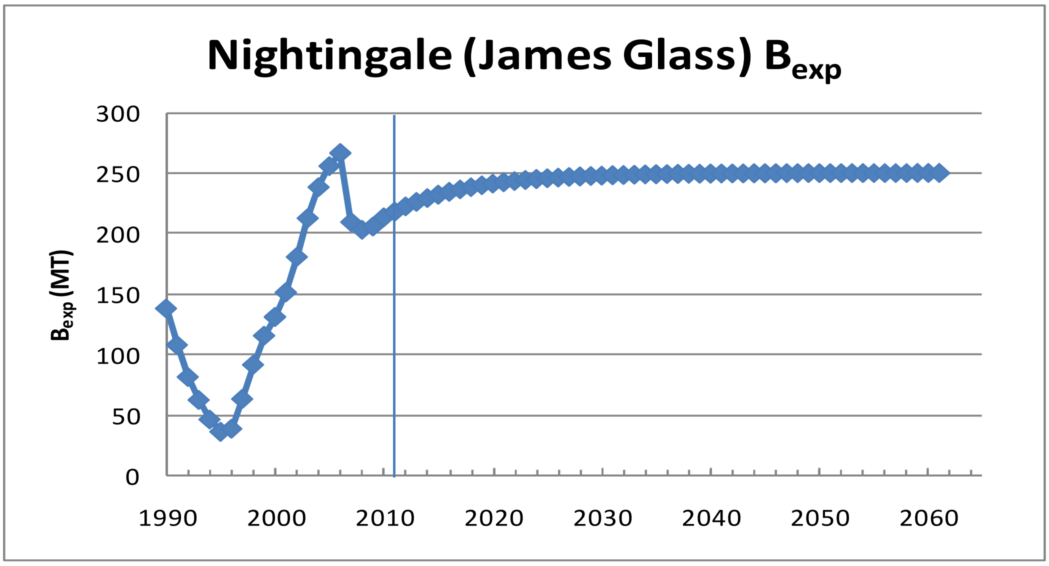


Figure 3b: Nightingale (James Glass growth) island B_{exp} trajectories (top plot) for the three **oil spill effect only** scenarios and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} (shown by circles) levels in either 2016, 2021, 2031 or 2061.

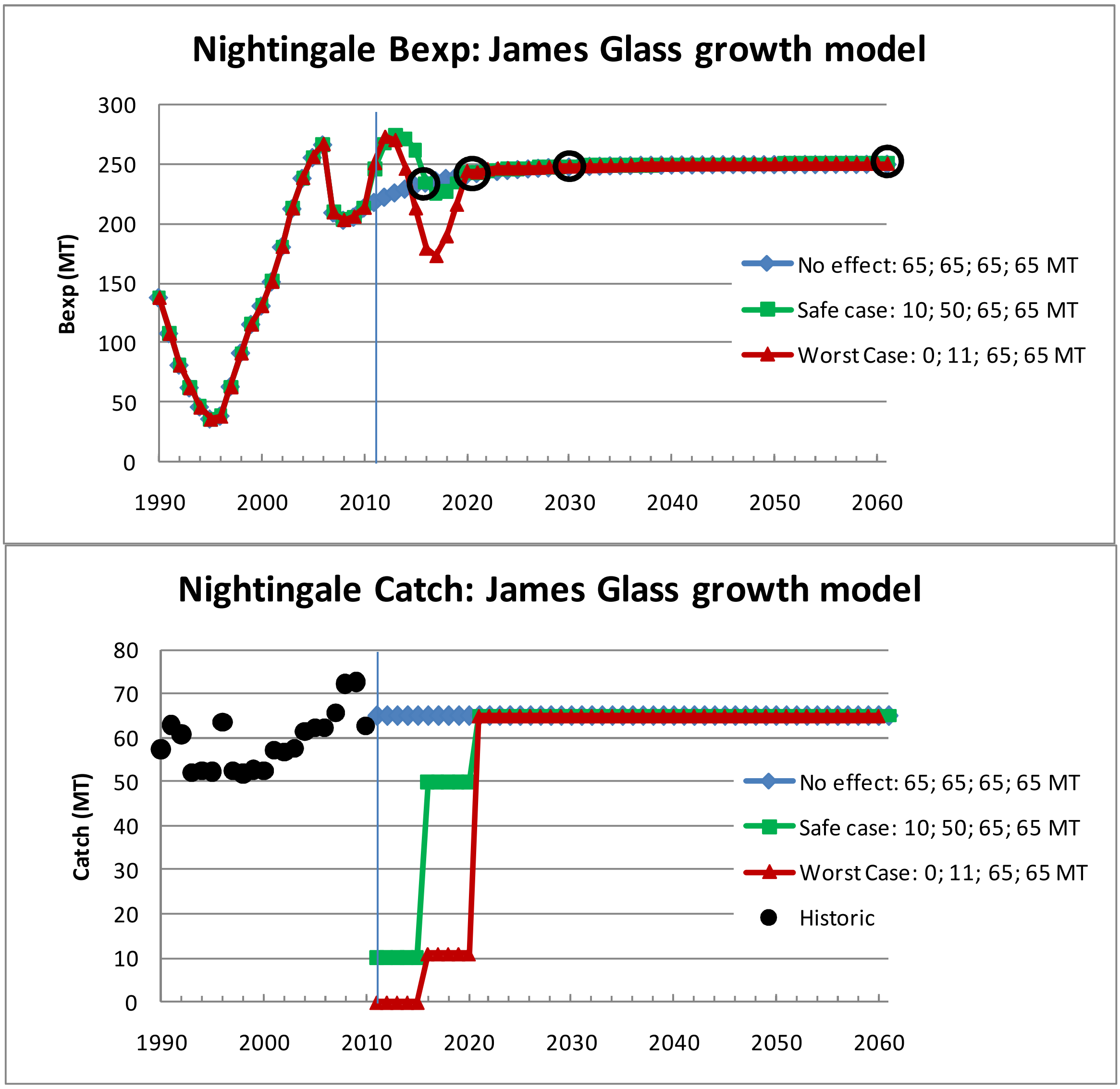
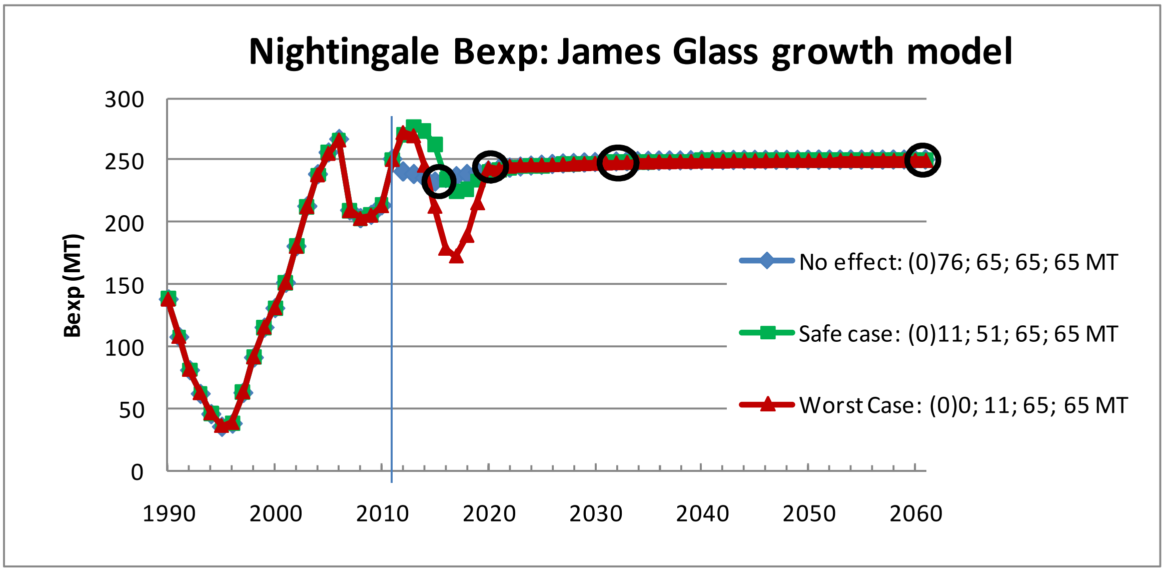


Figure 3c: Nightingale (James Glass growth) island B_{exp} trajectories (top plot) for the soya impact scenarios which assume **1 year adult migration** in addition to alternative oil spill effects, and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} levels (shown by circles) in either 2016, 2021, 2031 or 2061.



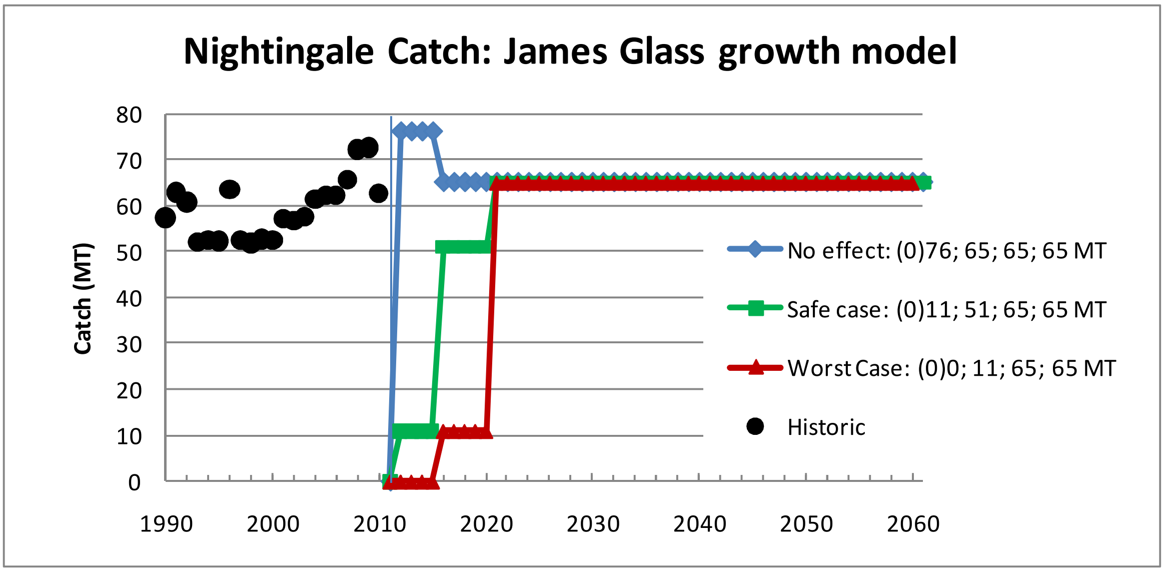
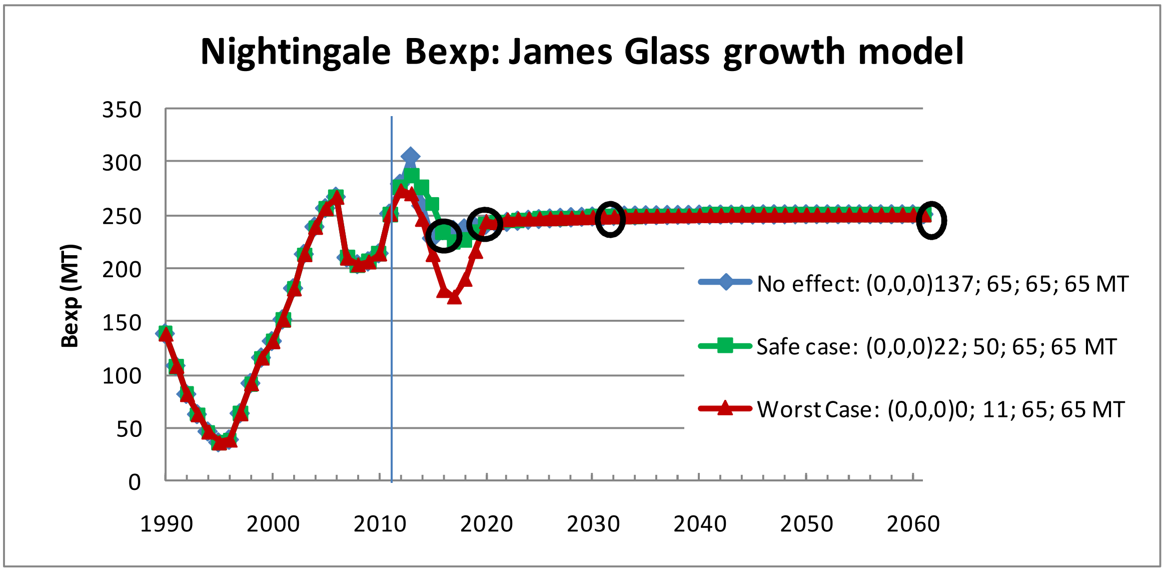


Figure 3d: Nightingale (Pollock growth) island B_{exp} trajectories (top plot) for the soya impact scenarios which assume **3 years adult migration** in addition to alternative oil spill effects, and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} levels (shown by circles) in either 2016, 2021, 2031 or 2061.



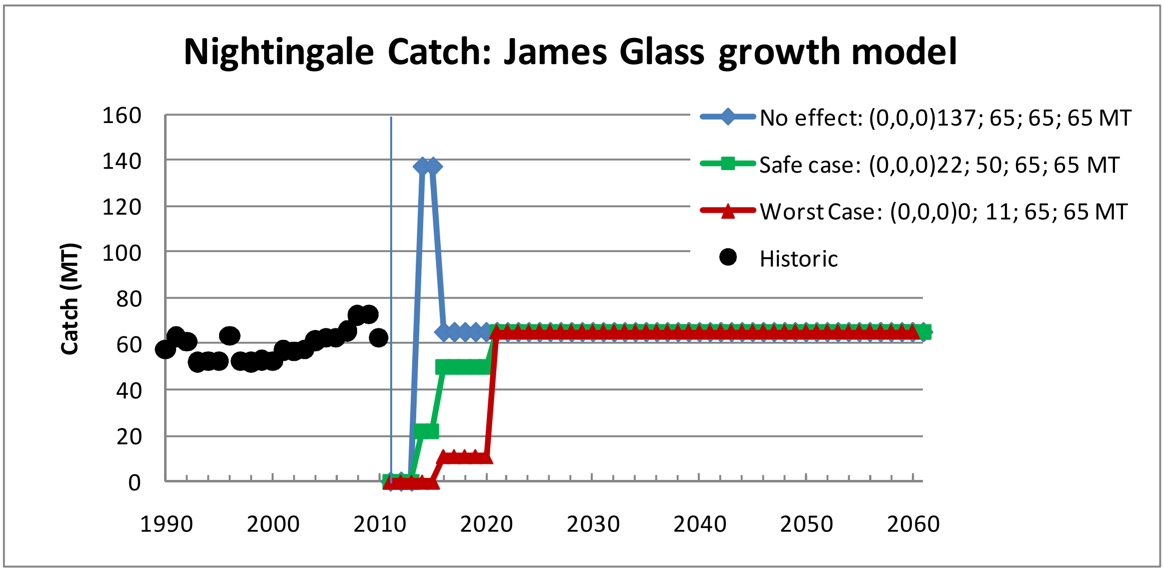
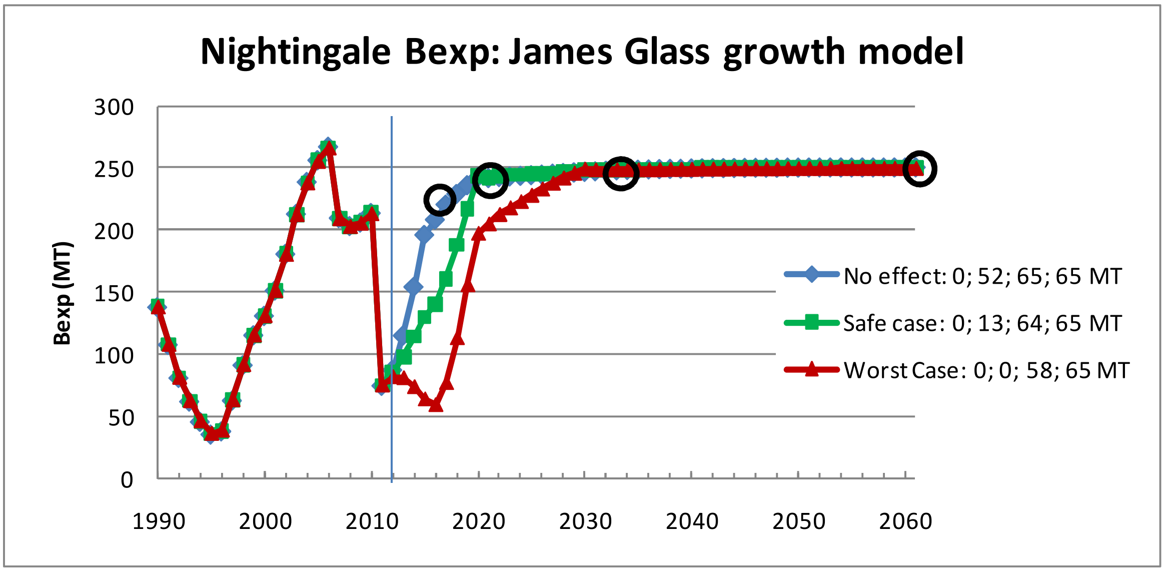


Figure 3e: Nightingale (James Glass growth) island B_{exp} trajectories (top plot) for the soya impact scenarios which assume **70% of adults die** in 2011 in addition to alternative oil spill effects, and the associated catch trajectories (bottom plot) required to reach the equivalent target B_{exp} levels (shown by circles) in either 2016, 2021, 2031 or 2061.



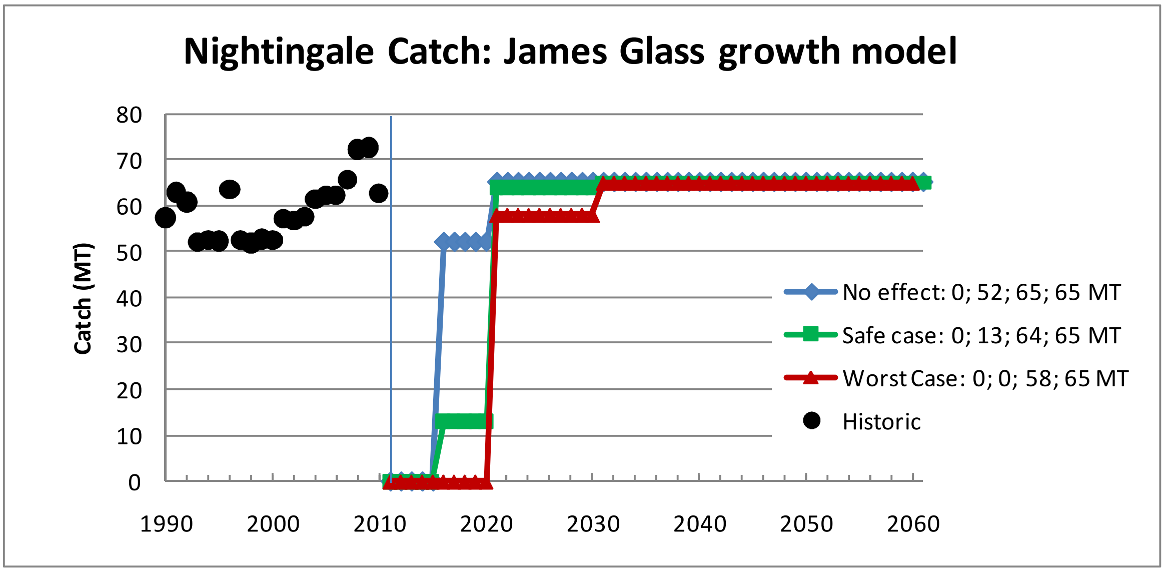


Figure 4: Comparison of the Inaccessible island future B_{exp} trajectories under a constant catch of 95 MT (the TAC_{init}(2011) value) assuming either the “No oil spill effect”, “Safe Case” or “Worst Case” scenario eventuates.

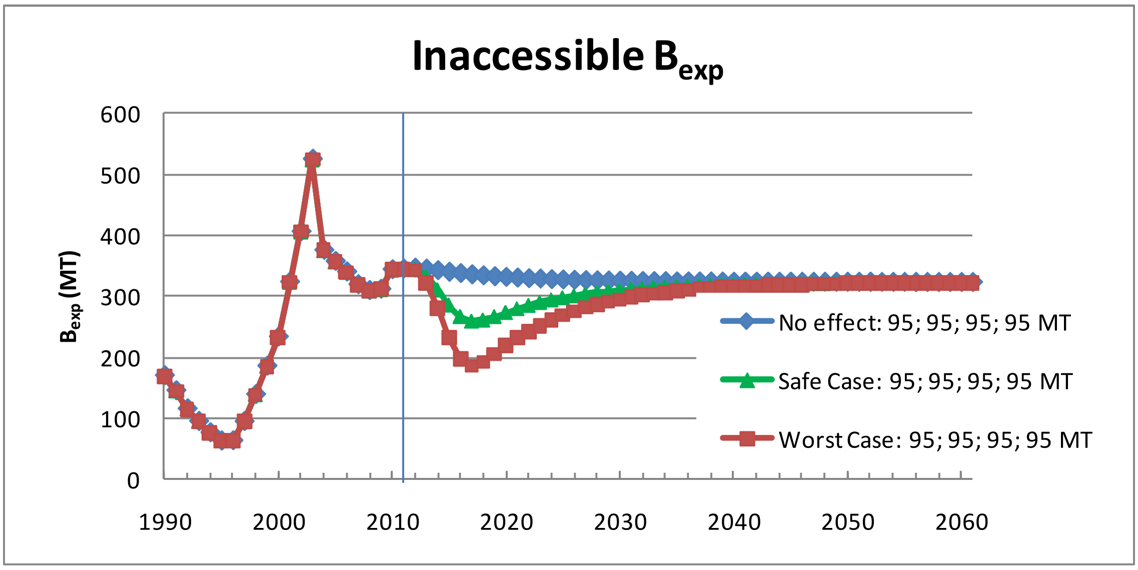


Figure 5a: Comparison of the Nightingale (Pollock growth) island future B_{exp} trajectories under a constant catch of 65 MT (the TAC_{init}(2011) value) assuming either the “No oil spill effect”, “Safe Case” or “Worst Case” scenario eventuates.

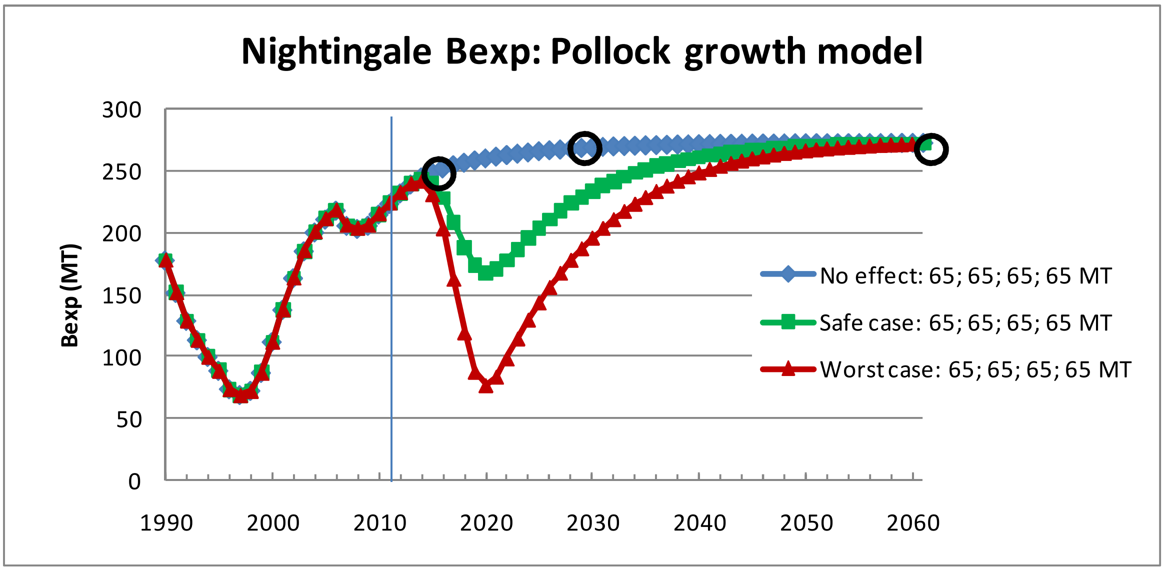


Figure 5b: Comparison of the Nightingale (James Glass growth) island future B_{exp} trajectories under a constant catch of 65 MT (the TAC_{init}(2011) value) assuming either the “No oil spill effect”, “Safe Case” or “Worst Case” scenario eventuates.

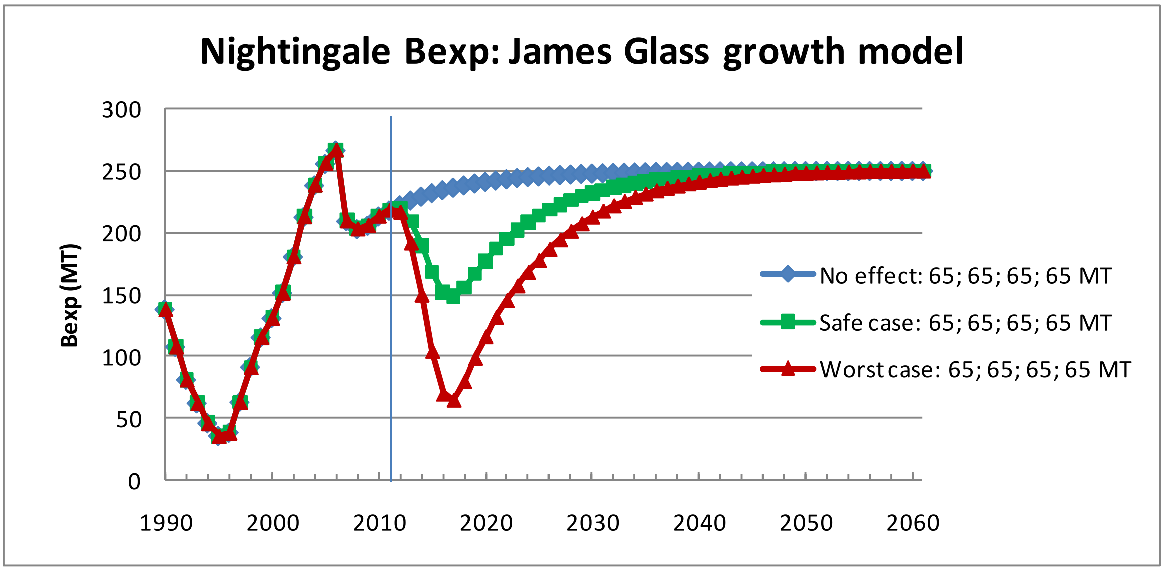


Figure 6: Comparisons between the “Pollock” and “James Glass” growth Nightingale island B_{exp} trajectories under a future constant catch of 65 MT for the three alternate oil spill effect scenarios.

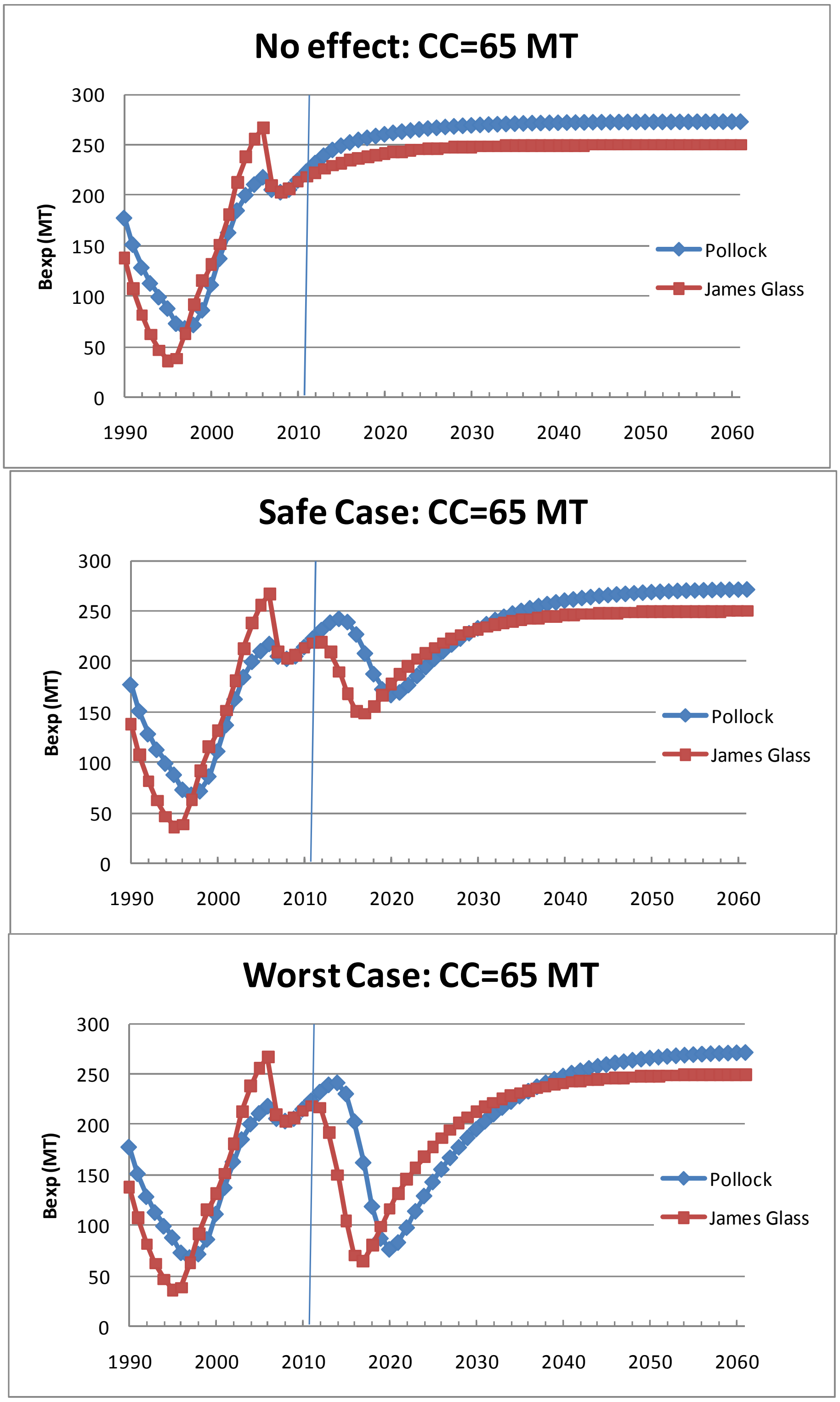
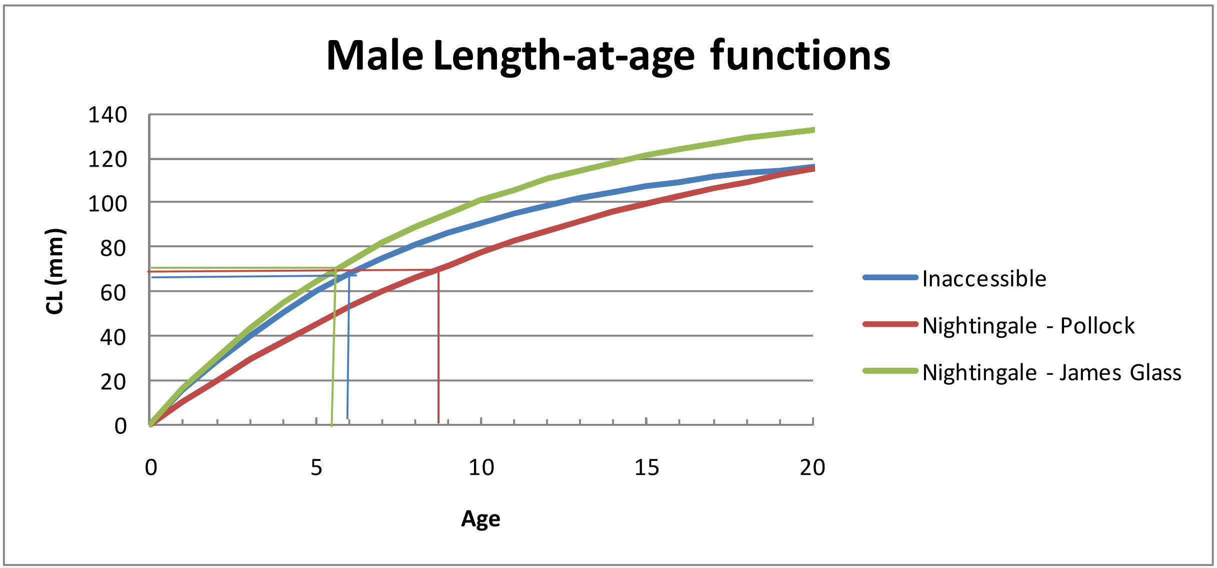


Figure 7: Length-at-age plots for Inaccessible and Nightingale islands. The thin lines show ages and lengths which correspond to current minimum legal carapace lengths. Note that there are two alternate growth functions for Nightingale island – Pollock and James Glass.



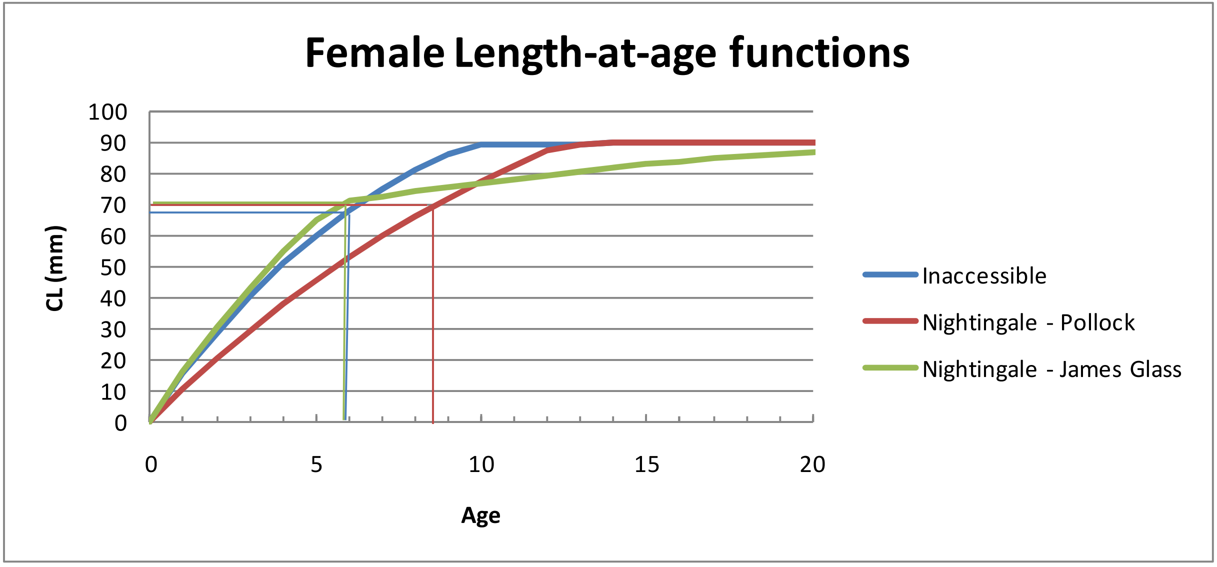


Figure 8: Numbers-at-age plots for Inaccessible (left hand plots), Nightingale (Pollock growth) (central plots) and Nightingale (James Glass growth) (right hand plots) islands assuming the "Worst Case" Nightingale island oil spill effect scenario in 2011 (and projections for the TAC_{init}(2011) values). The arrows indicate the ages which correspond to the minimum legal carapace lengths for each island.

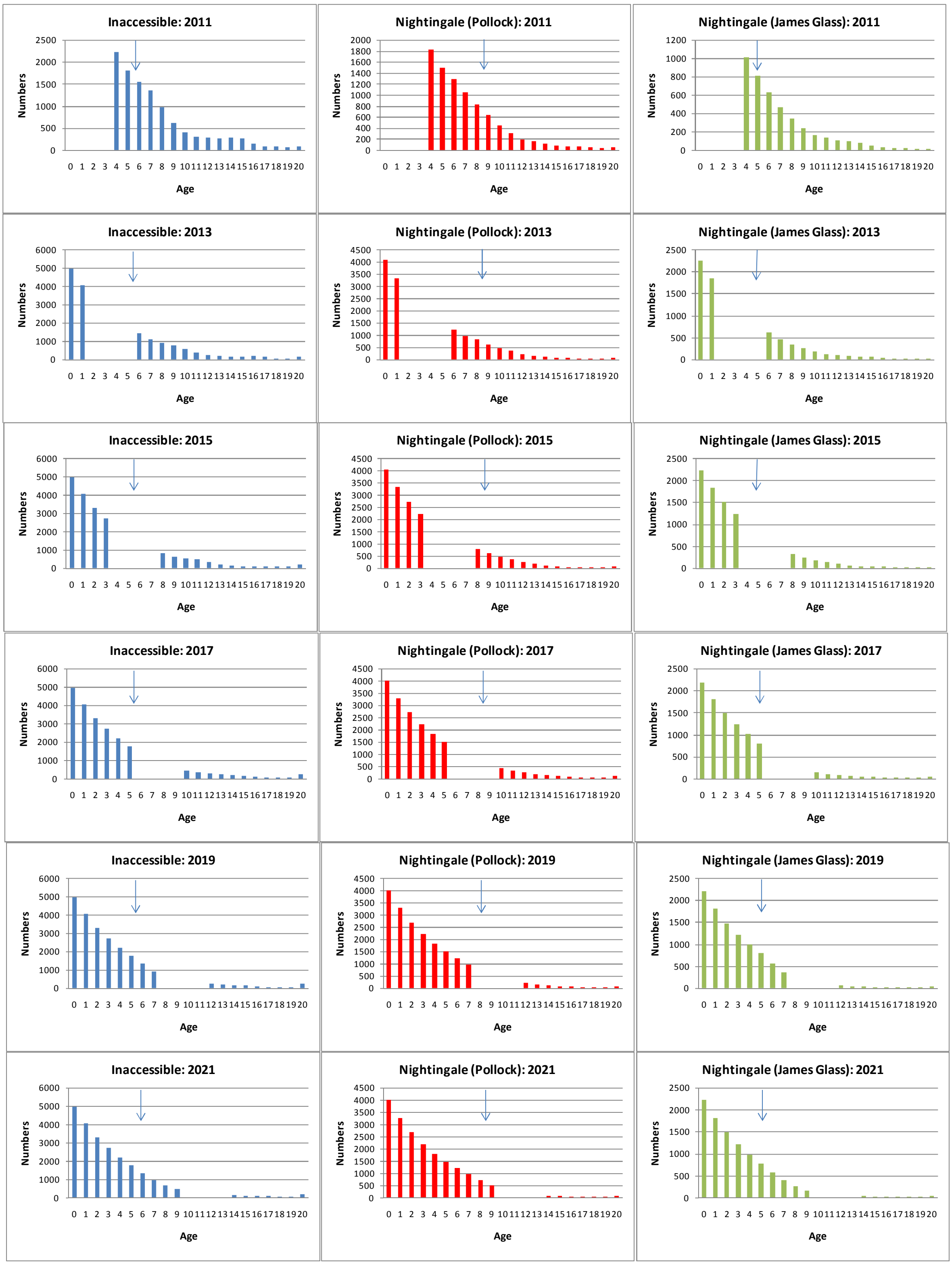
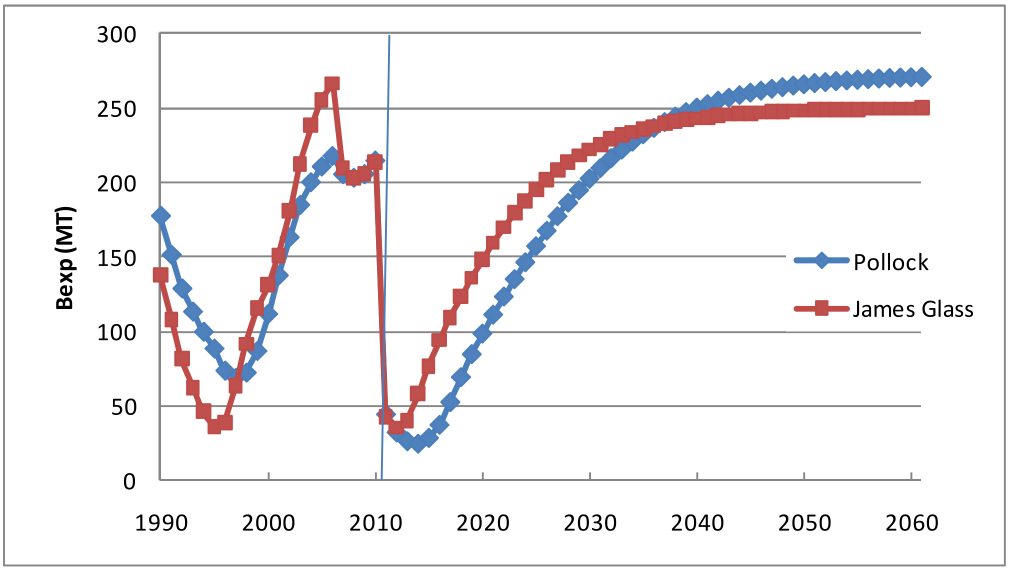


Figure 9: Comparison between “Pollock” and “James Glass” growth Nightingale island B_{exp} trajectories under a future constant catch of 65 MT for the case of no oil spill effect but a soya impact resulting in 70% of adults dieing in 2011.



Appendix: Published references related to somatic growth rates at Inaccessible and Nightingale islands

1) Pollock,D.E. and M.J.Rosoce (1977). The gowth at moulting of crawfish *Jasus tristani* at Tristan da Cunha, South Atlantic. J. Cons. Int. Explor. Mer, 37(2):144-416.

"… limited data for male *J. tristani* from Inaccessible Island suggest that the mean increment may be less than that for Tristan or Nightingale crawfish. Roscoe found in 1971-73 that the mode of the size frequency distribution for Inaccessible males was markedly lower than for Tristan or Nightingale males, and Rowan (unpublished) noted that Inaccessible crawfish were smaller when exploitation commended in 1949. "

2) Pollock, D.E. 1991. Spiny lobsters at Tristan da Cunha, South Atlantic: inter-island variations in growth and population structure. S. AFr. J. mar. Sci. 10:1-12.

" Ever since the inception of the trap fishery at Inaccessible and Nightingale islands, fishermen have been aware that rock lobsters at Inaccessible were smaller than those from Nightingale, an observation confirmed by Rowan (unpublished, in Pollock and Roscoe 1977). Pollock and Roscoe (op. cit.) and Pollock (1981) showed clearly that significantly smaller mount increments of lobsters at Inaccessible island were responsible for the observed differences in the size composition of catches from the two islands, …"

" From Table I it is evident that mean increments are some 40-65 per cent larger at Nightingale than at Inaccessible for the size classes shown. "

3) Pollock, D.E. 1981. Population dynamics of rock lobster Jasus tristani at the Tristan da Cunha group of islands.

" … it would appear that male (growth) increments are larger at Gough and Nightingale than at the remaining islands"