# ESTIMATING EFFECTIVE STRIP WIDTH IN SCANS-III AERIAL SURVEYS

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## BACKGROUND

The “tandem” aerial survey technique, later modified as “racetrack”, was designed to estimate the total number of harbour porpoises in a specified region using data collected from a ‘plane flying random transects across the region. It uses the frequency distribution of perpendicular distance y to sightings left and right of the transect to estimate the “sighting function” g(y) with the number of resightings made from the trailing ‘plane or during the trailing section of a “racetrack” flight pattern used to estimate g(0). g(y) then gives the effective strip width (ESW) which in turn estimates of the number of porpoises in the region from the total number of sightings.

The tandem ‘planes separation or racetrack pattern is designed for the trailing section to overfly the position of a porpoise sighting 3 minutes after the sighting occurred. We assume that the probability a porpoise is at the surface at any given moment is independent of whether it was at the surface 3 minutes earlier. It is impossible to monitor the position of a porpoise during those 3 minutes and porpoises are not distinctively marked so classifying a porpoise seen during the trailing section as a resighting of one seen 3 minutes earlier depends entirely on its observed location relative to where we expect to see it. Continuous gps recording during the flights combined with the observer’s estimates of y and the swim direction of each porpoise seen allows us to calculate the expected location of a trailing sighting.

In very low density regions a trailing sighting anywhere near its expected location is almost certain to be a resighting but restricting potential resightings to very low density regions would not provide enough data. We therefore accept all trailing sightings as potential resightings of porpoises seen about 3 minutes earlier. Instead of classifying any of them as definite resightings we consider all configurations of the trailing as possible resightings of the leading sightings (including none of them being resightings) and assign a probability to each configuration. Those configurations form an exhaustive set of mutually exclusive events so the probability of the observed trailing sighting locations is the sum of the probabilities of each possible configuration. The probabilities are calculated using a model for displacement over the interval between the leading and trailing sections in combination with the sighting function g(y). The displacement model moves the porpoise in the direction recorded by the observer followed by diffusion from the resulting location to allow for differences in swimming speeds/durations and measurement error (with diffusion only in the case of “milling” behaviour).

The parameters of the displacement are unknown and are estimated along with the sighting function parameters by maximising the sum of the configuration probabilities. That means that the data are used to estimate the parameters of a model that is itself used to affect the relative probabilities of the observed configurations. Intuitively the displacement model selects the “correct” configurations which in turn generate the displacements used to estimate the parameters of the displacement model.

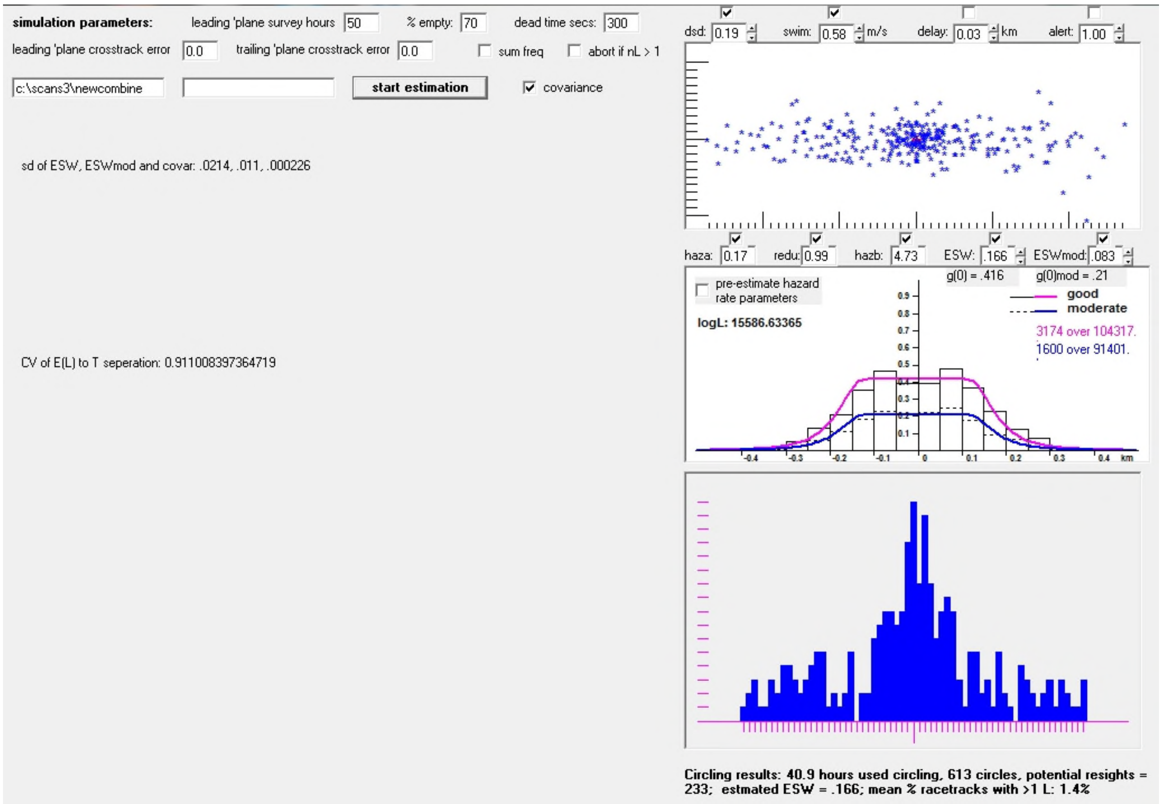
## PARAMETERS RELATED TO THE PORPOISES AND TO THE OBSERVERS

The parameters of the displacement model ("swimming speed" and the standard deviation of the bivariate normal distribution used to model diffusion) relate to porpoise behaviour which might be expected not to differ between surveys. The parameters of the hazard rate sighting function g(y) relate to observer behaviour and that might be expected to change between surveys, as might g(0) and the reduction in the scale parameter of the hazard rate in "moderate" as compared to "good" conditions. One approach is therefore to combine all available data to estimate the displacement model parameters and use those as fixed values for the individual surveys with the hazard rate and g(0) parameters re-estimated for each survey. An alternative more restrictive approach is to combine data and introduce the survey team as a covariate affecting one of the observer-related parameters, for example g(0).

Two further parameters we have considered concern possible difference in observer behaviour during a trailing section. Observers may be more alert during a trailing racetrack section resulting in a higher probability of seeing a porpoise and a reduced delay in recording the sighting. A 0.03 km (equivalent to 0.6 seconds) reduction in that delay on trailing sections was measured using voice recordings made during earlier surveys and that is used as a fixed value for the current surveys. However previous attempts to estimate an increase in the sighting probability on trailing sections more than doubled the CV of the ESW estimate and the current analyses assume that any increase in alertness is limited to the reduced delay mentioned above.

## COMBINING ALL AVAILABLE AERIAL SURVEY DATA

Data from all seven SCANS-III aerial surveys were combined with the aerial survey data used to estimate ESW in SCANS-II and subsequent surveys in German and Netherlands coastal waters. By combining the "leg" and "sig" files only data already corrected for problems encountered during the flights were used. The following screenshot displays the results:




The upper picturebox shows the location of the trailing sighting relative to its expected location for all leading/trailing pairs where the trailing sighting occurred within 60s of the expected time for a duplicate sighting. Because the expected location allows for the initial displacement mentioned above the locations shown vary with the value in the "swim" textbox. The horizontal axis minor tick marks refer to a 2 second difference between observed and expected time equivalent to a distance separation of 100 metres so the entire axis spans 6 km.

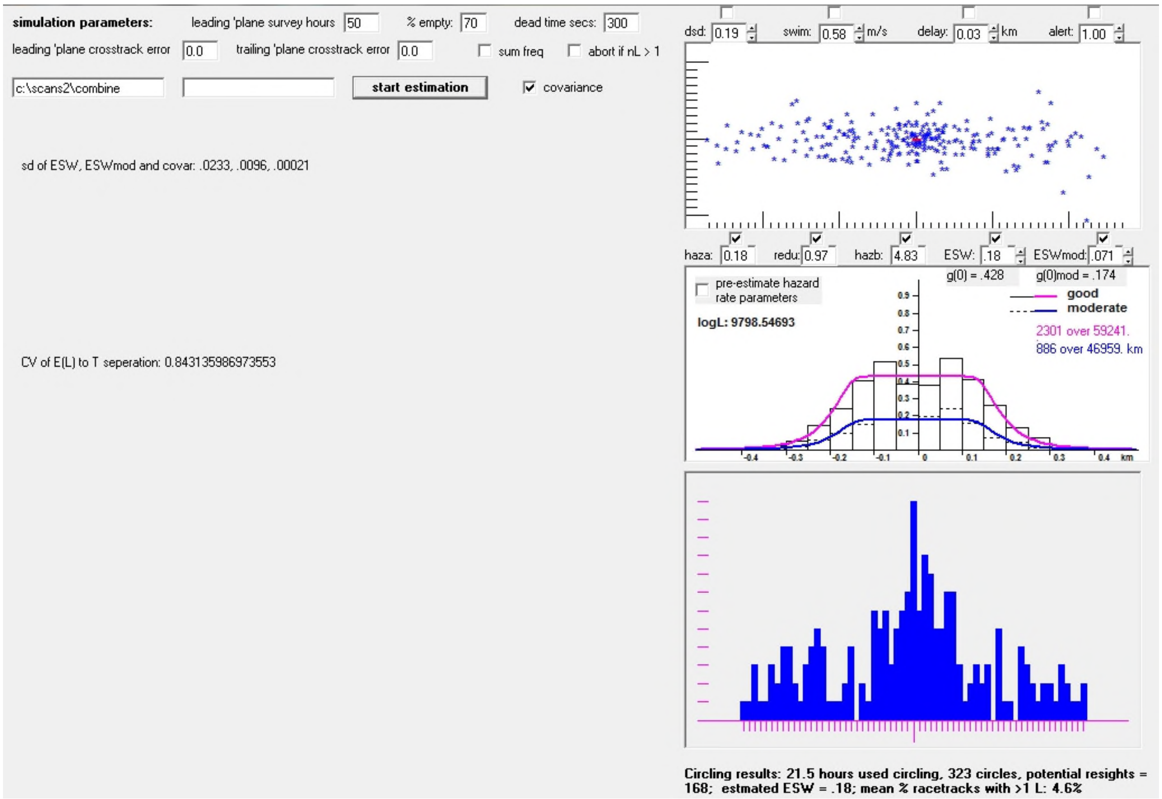
In the lower plot time differences under 30s are shown as a frequency distribution. Duplicate sightings of the same porpoise should occur within a few seconds of the expected time. The plot thus shows a peak around the middle superimposed on a uniform distribution of differences resulting from sightings of different porpoises.

The textboxes surrounding the upper picturebox display the ML parameter values where the checkbox is checked or fixed values otherwise. So the ML estimates for swim speed and for the standard deviation of the normal distribution resulting from diffusion (dsd), to be used as fixed values for the individual surveys, are 0.58 and 0.19 km. The maximum likelihood estimate for swimming speed is much less that would be expected from telemetry studies because it is applied during the whole leading to trailing section interval. We could equivalently assume a maximum swimming speed and introduce a free parameter for its duration.

If the same effective strip width was assumed to apply for all surveys it would be estimated at 0.166 km and 0.083 km under good and moderate conditions, corresponding to g(0) of 0.416 and 0.21 respectively. The coefficient of variation (CV) for ESW under good conditions is 0.13 and for ESW under moderate conditions is also 0.13. “Moderate” as compared to “good” conditions have almost no affect on the scale parameter of the hazard rate function and thus the distance out to which porpoises are seen but a marked affect on g(0).

## COMBINING PRE-SCANS-III AERIAL SURVEY DATA

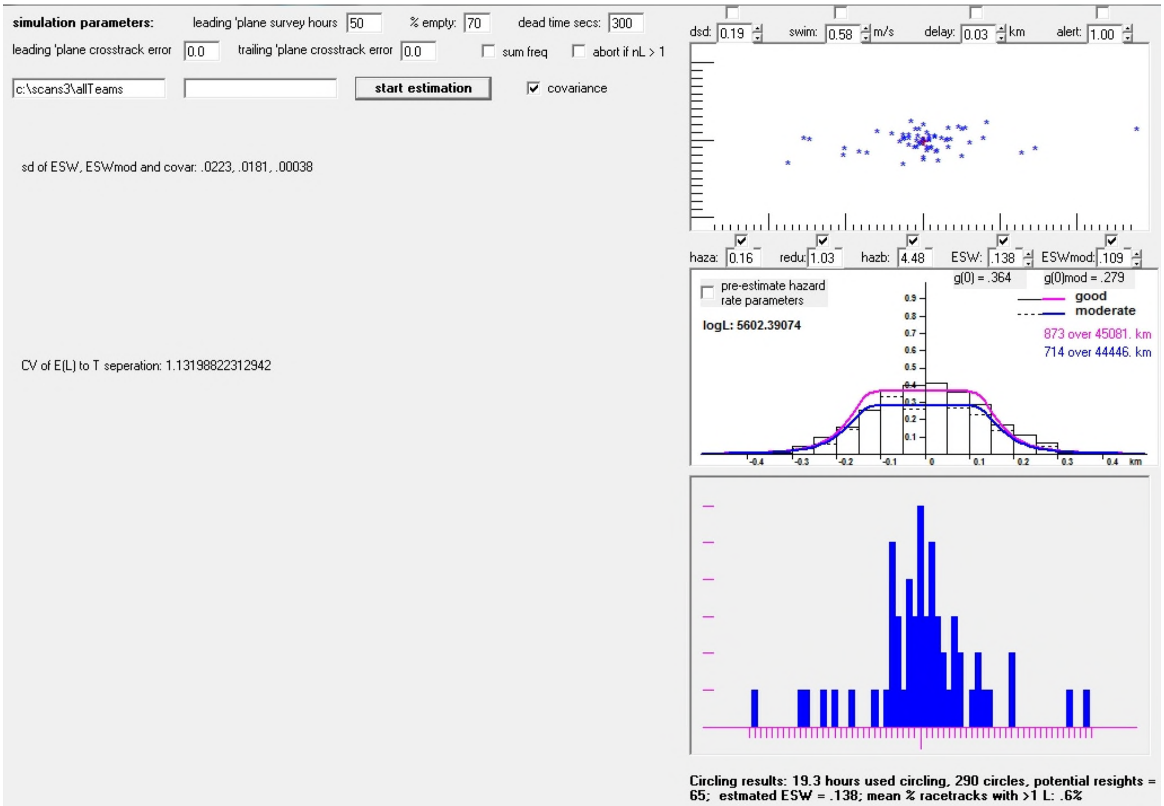
The aerial survey data used to estimate ESW in SCANS-II and subsequent surveys in German and Netherlands coastal waters were combined. The following screenshot displays the results:




If the same effective strip width was assumed to apply for all surveys it would be estimated at 0.18 km and 0.071 km under good and moderate conditions, corresponding to g(0) of 0.428 and 0.174 respectively. The coefficient of variation (CV) for ESW under good conditions is 0.13 and for ESW under moderate conditions is 0.14. “Moderate” as compared to “good” conditions have little effect on the scale parameter of the hazard rate function and thus the distance out to which porpoises are seen but a marked effect on g(0).

## COMBINING SCANS-III AERIAL SURVEY DATA

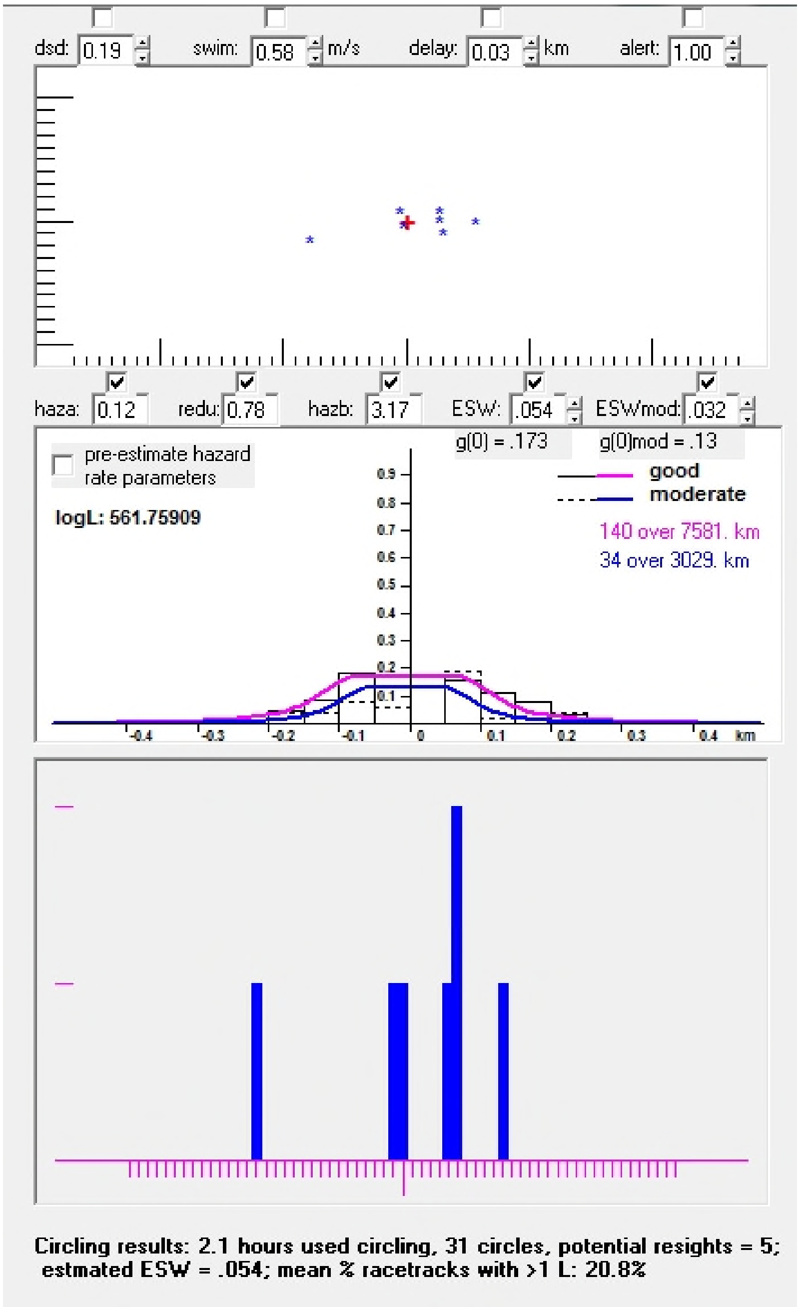
The aerial survey data from all seven SCANS-III teams were combined. The following screenshot displays the results:



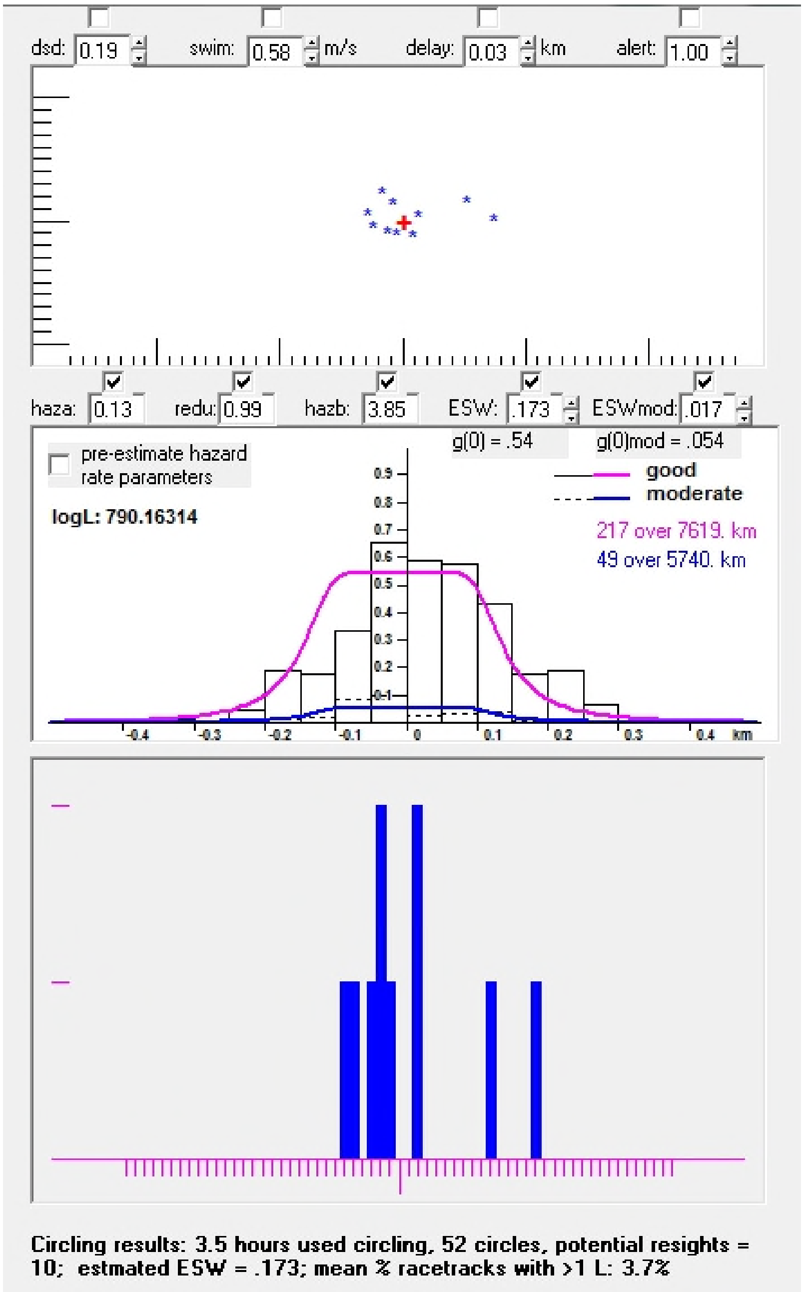

If the same effective strip width was assumed to apply for all surveys it would be estimated at 0.138 km and 0.109 km under good and moderate conditions, corresponding to g(0) of 0.364 and 0.279 respectively. The coefficient of variation (CV) for ESW under good conditions is 0.16 and for ESW under moderate conditions is 0.17. Again "moderate" as compared to "good" conditions have little effect on the scale parameter of the hazard rate function and thus the distance out to which porpoises are seen (actually a slight increase).

The obvious difference between the SCANS-III and pre- SCANS-III results is a much reduced effect of recorded subjective conditions on ESW and g(0). As a result ESW is now reduced under good and increased under moderate conditions.

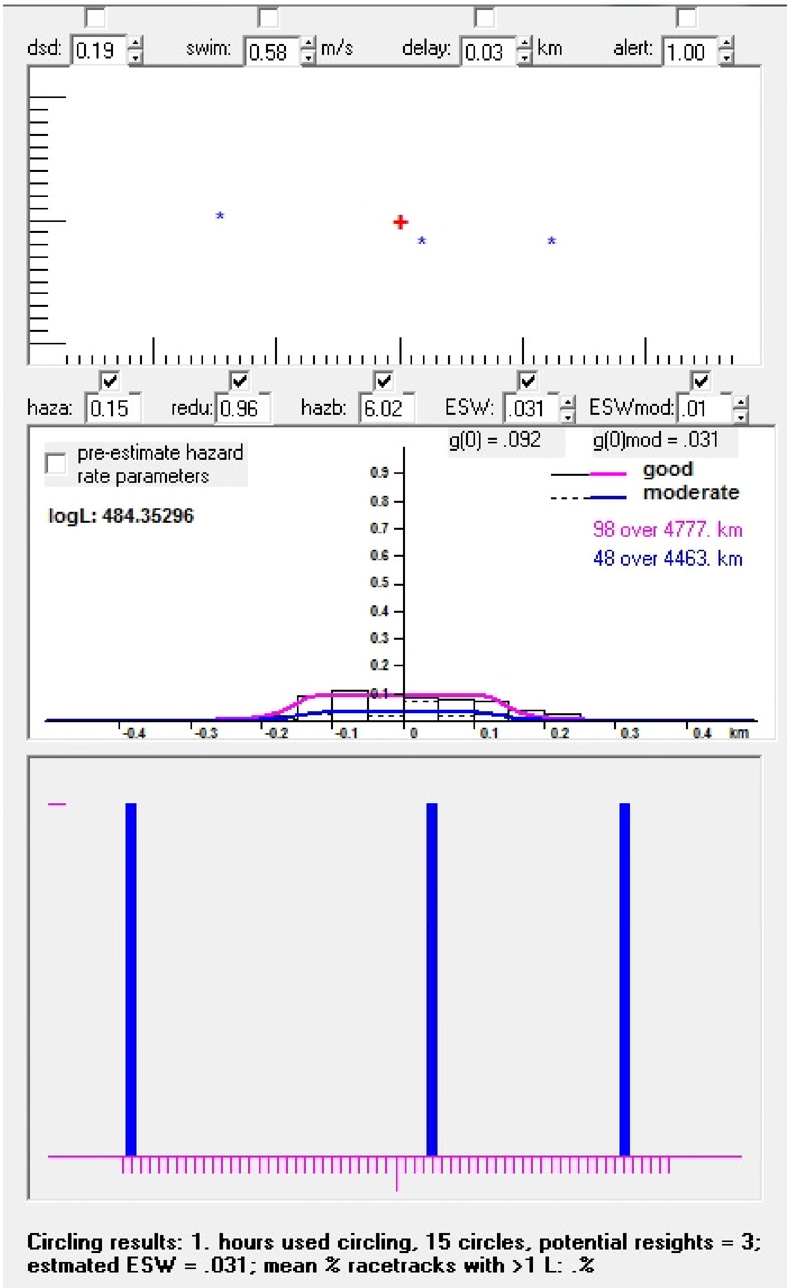
Team 1


dsd: 0.19
swim: 0.58 m/s
delay: 0.03 km
alert: 1.00
haza: 0.12
redu: 0.78
hazb: 3.17
ESW: .054
ESWmod: .032
g(0) = .173
g(0)mod = .13
pre-estimate hazard rate parameters
logL: 561.75909
good
moderate
140 over 7581. km
34 over 3029. km
km
Circling results: 2.1 hours used circling, 31 circles, potential resights = 5;
estmated ESW = .054; mean % racetracks with >1 L: 20.8%

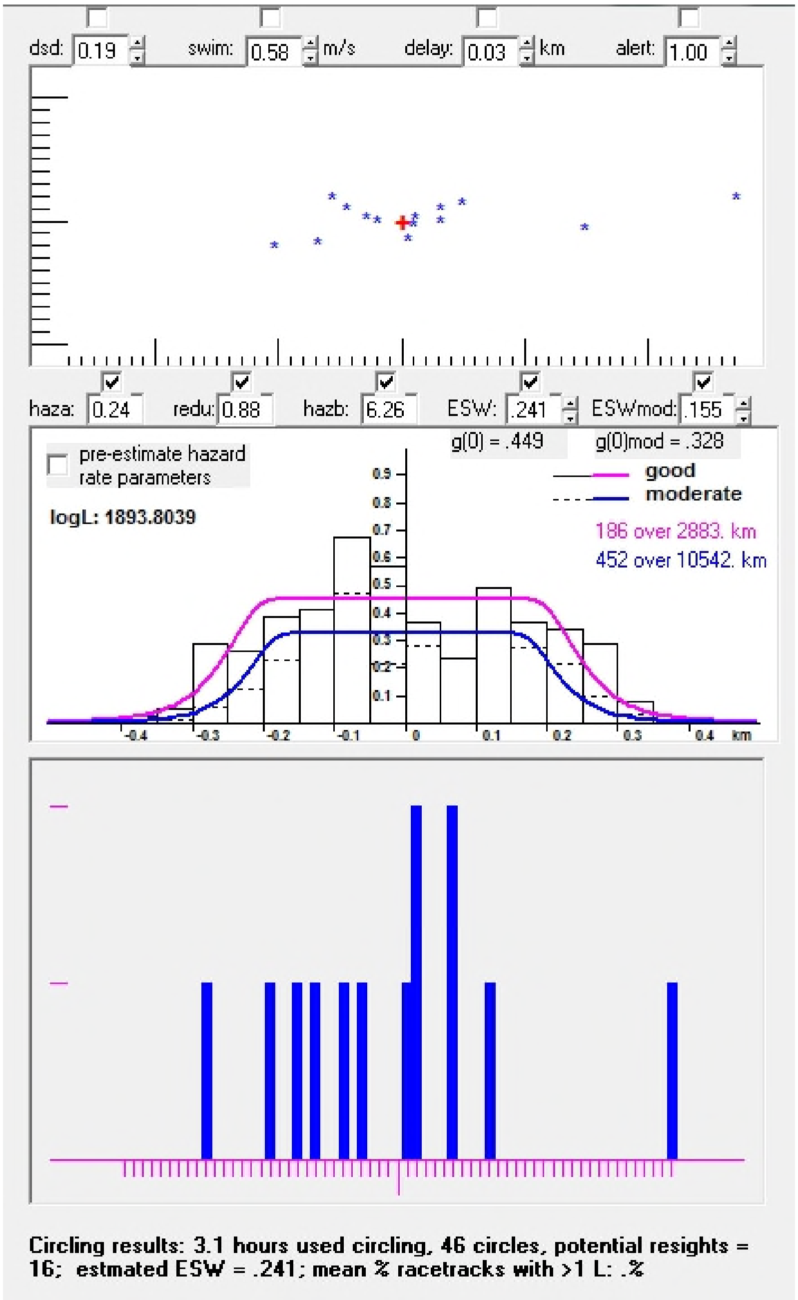
Team 2


dsd: 0.19
swim: 0.58 m/s
delay: 0.03 km
alert: 1.00
haza: 0.13
redu: 0.99
hazb: 3.85
ESW: .173
ESWmod: .017
pre-estimate hazard rate parameters
g(0) = .54
g(0)mod = .054
good
moderate
logL: 790.16314
217 over 7619. km
49 over 5740. km
km
Circling results: 3.5 hours used circling, 52 circles, potential resights = 10; estmated ESW = .173; mean % racetracks with >1 L: 3.7%

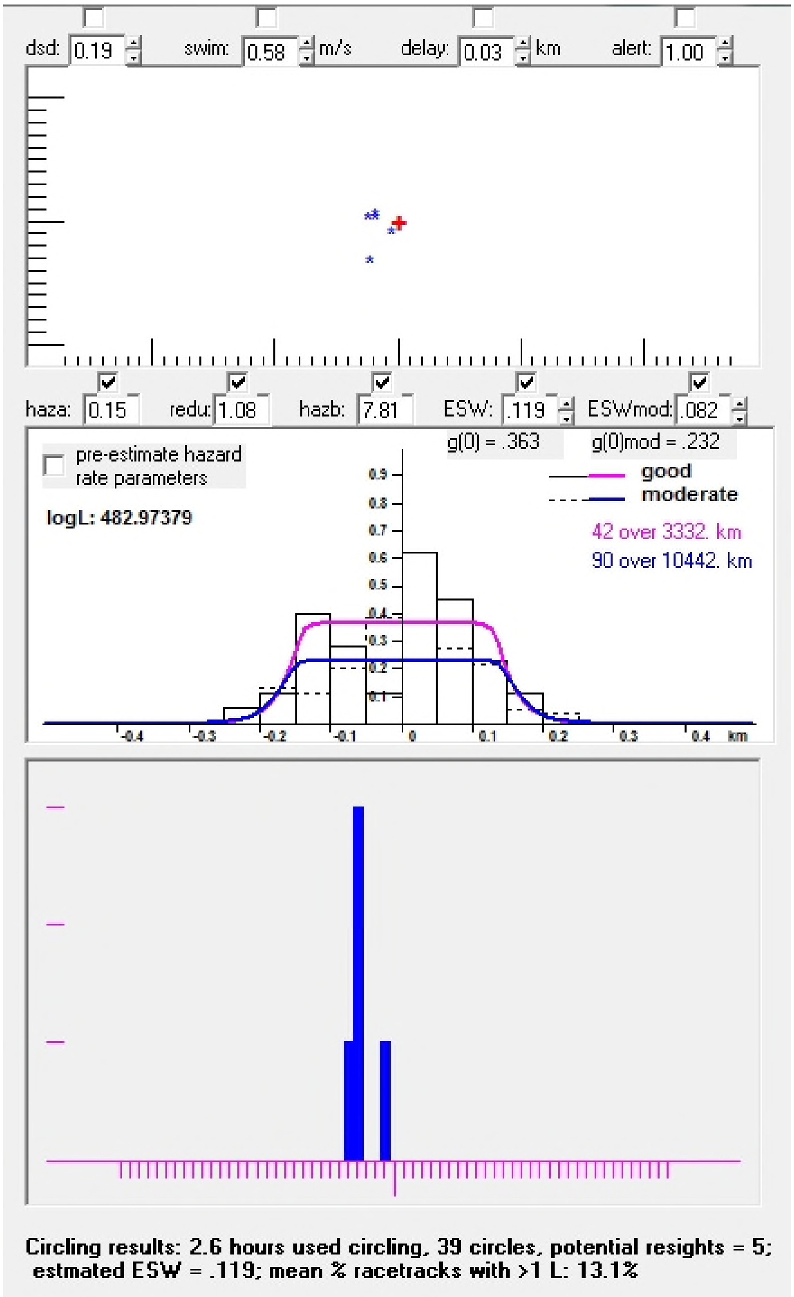
Team 3


dsd: 0.19
swim: 0.58 m/s
delay: 0.03 km
alert: 1.00
haza: 0.15
redu: 0.96
hazb: 6.02
ESW: .031
ESWmod: .01
g(0) = .092
g(0)mod = .031
pre-estimate hazard rate parameters
logL: 484.35296
good
moderate
98 over 4777. km
48 over 4463. km
Circling results: 1. hours used circling, 15 circles, potential resights = 3; estmated ESW = .031; mean % racetracks with >1 L: .%

Team 4

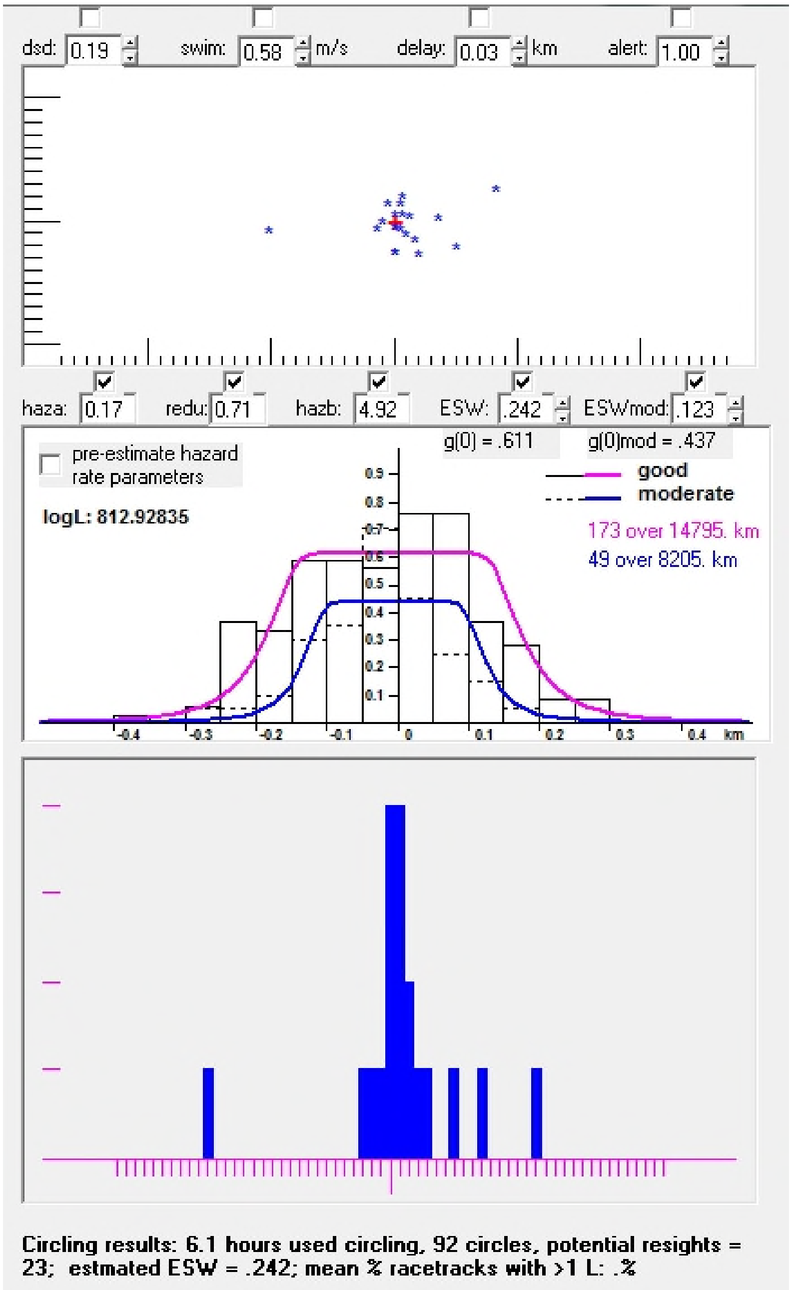

dsd: 0.19
swim: 0.58 m/s
delay: 0.03 km
alert: 1.00
haza: 0.24
redu: 0.88
hazb: 6.26
ESW: .241
ESWmod: .155
g(0) = .449
g(0)mod = .328
pre-estimate hazard rate parameters
logL: 1893.8039
good
moderate
186 over 2883. km
452 over 10542. km
km
Circling results: 3.1 hours used circling, 46 circles, potential resights = 16; estmated ESW = .241; mean % racetracks with >1 L: .%

Team 5



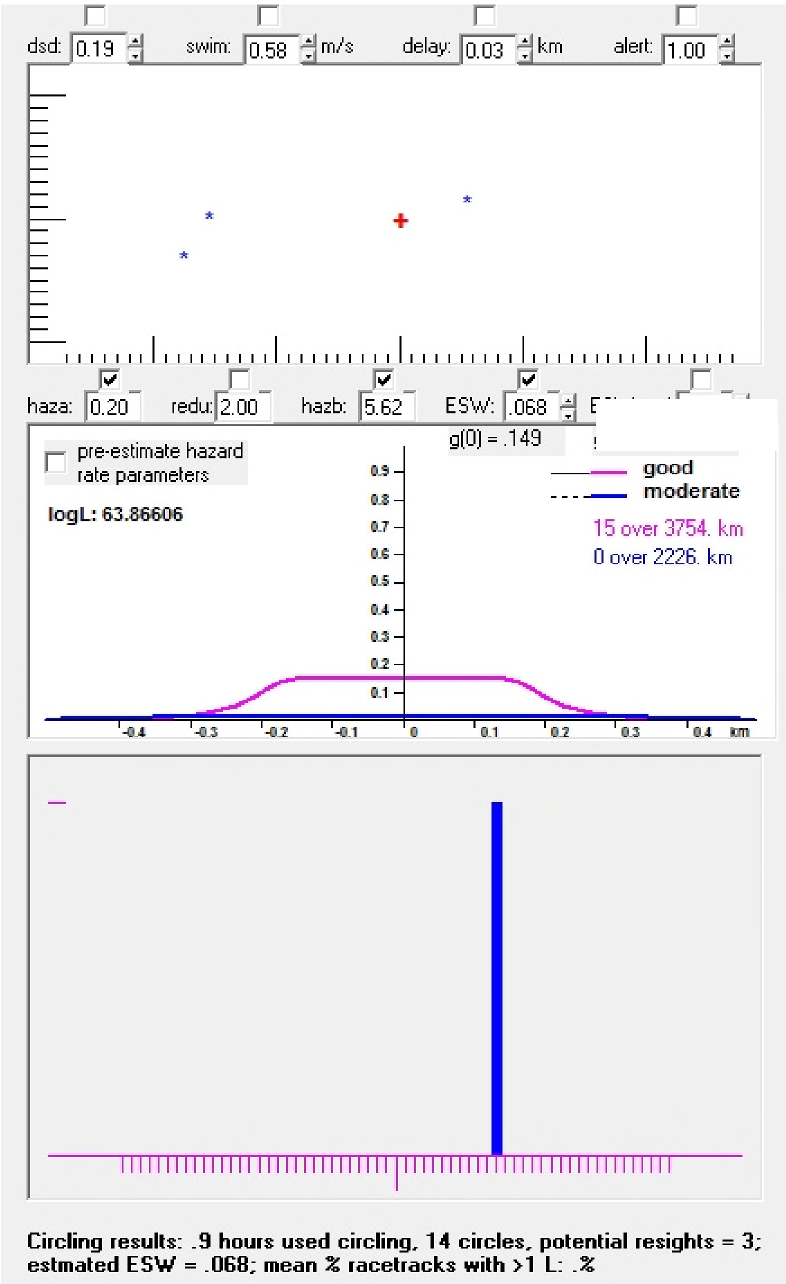
dsd: 0.19
swim: 0.58 m/s
delay: 0.03 km
alert: 1.00
haza: 0.15
redu: 1.08
hazb: 7.81
ESW: .119
ESWmod: .082
g(0) = .363
g(0)mod = .232
pre-estimate hazard rate parameters
logL: 482.97379
good
moderate
42 over 3332. km
90 over 10442. km
km
Circling results: 2.6 hours used circling, 39 circles, potential resights = 5; estmated ESW = .119; mean % racetracks with >1 L: 13.1%

Team 6



dsd: 0.19
swim: 0.58 m/s
delay: 0.03 km
alert: 1.00
haza: 0.17
redu: 0.71
hazb: 4.92
ESW: .242
ESWmod: .123
g(0) = .611
g(0)mod = .437
pre-estimate hazard rate parameters
logL: 812.92835
good
moderate
173 over 14795. km
49 over 8205. km
km
Circling results: 6.1 hours used circling, 92 circles, potential resights = 23; estmated ESW = .242; mean % racetracks with >1 L: .%

Team 7




## SCANS-III INDIVIDUAL SURVEY RESULTS SUMMARY

The number of “circles” (i.e. racetracks) shown in the “Circling results” above include those flown on species other than porpoises. The summary table below is for porpoise sightings only. The second column shows the number of “Leading” sightings that initiated racetracks and the third column the number seen on the trailing section (between “rejoin” and “circle”). Occasionally there was more than one porpoise sighting before the ‘plane broke off from the track so the number of racetracks may be slightly less than the number of Leading sightings. The penultimate column shows the Trailing sightings as a fraction of the Leading sightings and in the final column compares that to the average g(0) estimate over good and moderate conditions.

Intuitively, as some potential resights may be “new” porpoises rather than resightings of the Leading porpoises, we would expect the potential resight fraction to be greater than the true g(0) but on the other hand the risk that the Leading porpoise may move out of visible range suggests that the potential resight fraction will be less than g(0).

| Team | Leading porpoise sightings | Trailing porpoise sightings | ESW_good (CV) | g(0)_good | ESW_mod (CV) | g(0)_mod | Potential resight fraction | Average g(0) |
|---|---|---|---|---|---|---|---|---|
| 1 | 28 | 5 | .054 | .173 | .032 | .13 | .179 | .152 |
| 2 | 45 | 10 | .173 (.33) | .54 | .017 (.45) | .054 | .22 | .297 |
| 3 | 16 | 3 | .031 | .092 | .01 | .031 | .188 | .062 |
| 4 | 34 | 16 | .241 (.38) | .449 | .155 (.38) | .328 | .471 | .389 |
| 5 | 18 | 5 | .119 | .363 | .082 | .232 | .278 | .298 |
| 6 | 41 | 23 | .242 (.20) | .611 | .123 (.30) | .437 | .561 | .524 |
| 7 | 6 | 3 | .068 | .149 | N/A | N/A | .5 | .068 |

Actually the values in the last two columns are quite similar. For teams 3 and 7 average g(0) is much less than the potential resight fraction but in each case 2 of the 3 trailing sightings occurred more than 30 seconds from the expected time for a resighting or almost 30 seconds from that time so those were hardly potential resights. Thus, the g(0) estimates are generally in line with what would be expected intuitively.

## DISCUSSION

In common with any mark-recapture experiment the tandem/racetrack technique needs a large number of "recaptures" to estimate the capture probability (in this case g(0) and therefore ESW) reliably. The 65 trailing sightings collected by the seven SCANS-III teams provide reasonably reliable estimates of ESW under good and moderate conditions (CV 0.16 and 0.17) and if all those data had been collected by the same team we would now have a reasonable measure of that team's ESWs. That measure would be even more accurate if the same team had collected all the previous racetrack data.

There is obviously a limit to the size of the region a single team can survey which creates a dilemma: most of the teams cooperating to survey a large region will not collect individually sufficient trailing sightings to estimate their individual ESWs reliably. Of the seven SCANS-III teams only three collected 10 or more trailing sightings to give feasible ESW estimates. Even those have large CVs. The individual results were based on the displacement parameter values estimated by combining all the data but similar results would have been produced by introducing a team covariate.

Thus we have to assume that the actual ESWs are sufficiently similar for the estimates from the SCANS-III data combined to be used for each team. That solution seems appropriate for deriving a total abundance estimate but less appropriate if the objective is to derive a spatial density distribution because the actual ESWs may differ between teams.

A possible solution might be to use as a standard measure the ESW for a single team that has collected over time a large sample of trailing sightings and have that team and the other teams fly (under the same conditions and without circling) a transect across a high density region. The standard ESW times the ratio of sightings by each team to sightings by the standard team would then be the ESW for that team. The transect could be divided into sections to assess the reliability of the ratios.

## ADDENDUM, 12.12.2016

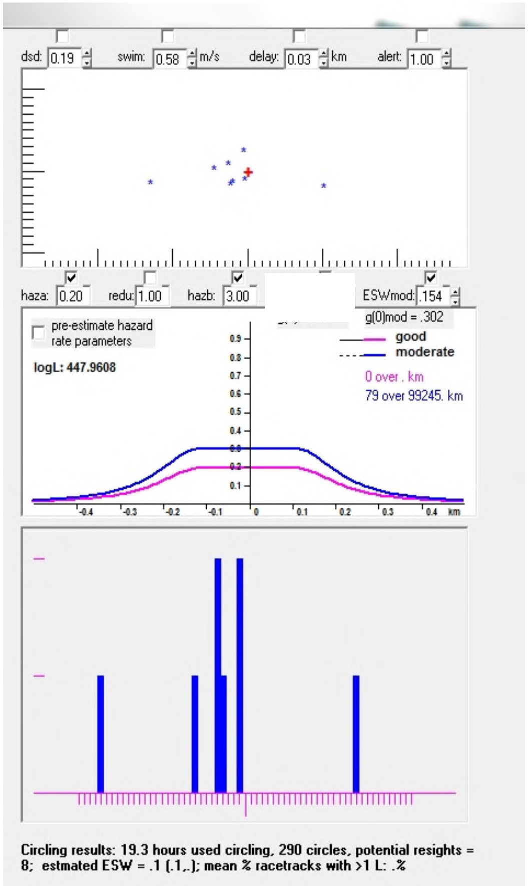
**BY ANITA GILLES**

During SCANS-III we also used the racetrack method to estimate esw for other species than the harbour porpoise, like the minke whale and some dolphin species. We made sure that the racetracks should only be performed with sightings of small groups (≤10) since the method is probably unfeasible for species occurring in larger groups.

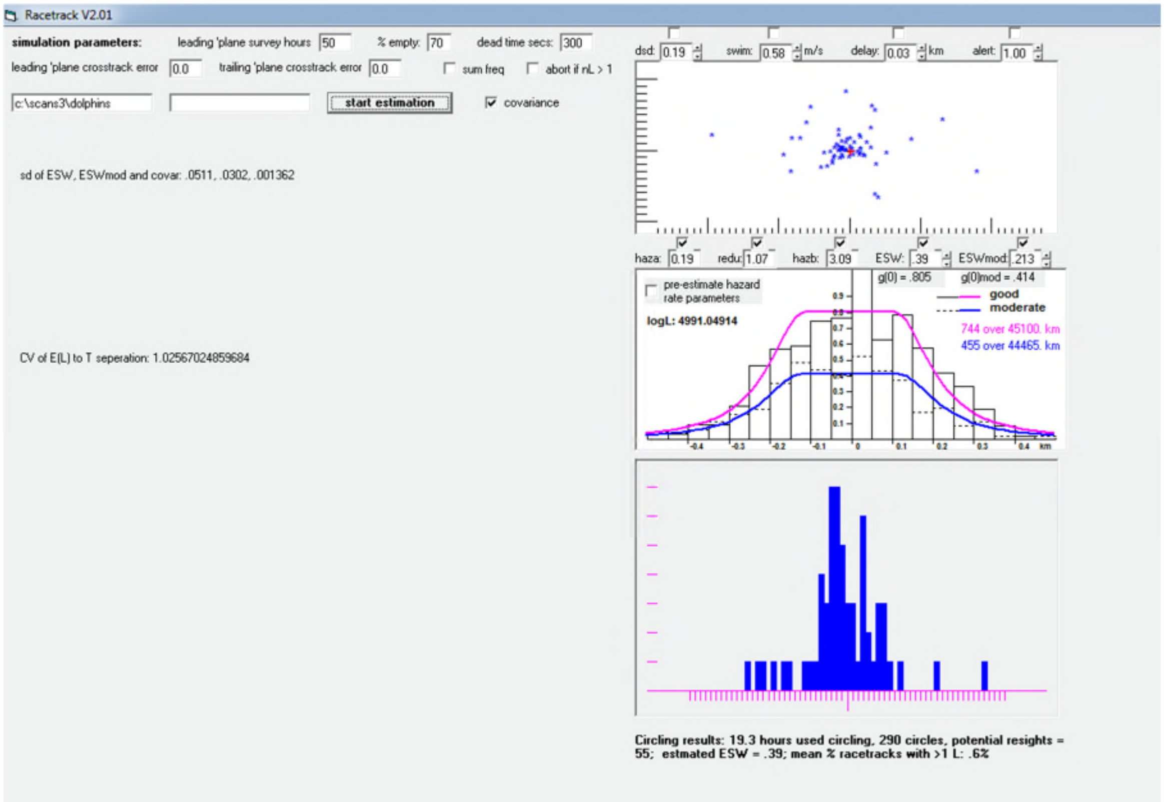
It was not possible to collect enough racetrack data (and potential re-sightings) to estimate esw for individual dolphin species. Therefore, we combined racetrack data of the following dolphin species/groups: *Delphinus delphis*, *Stenella coeruleoalba*, *Delphinus* sp. or *Stenella* sp., *Lagenorhynchus albirostris*, *L. acutus*, *Tursiops truncatus* and "Unidentified 'beaked' dolphin (Delphinidae)" yielding a total of 55 potential re-sightings. In this exercise, we also assumed that the selected dolphin species spend a similar proportion of time at the surface and rates of displacement are similar within these species and rates are also similar to porpoises in their distribution of displacement during the leading/trailing interval.

Minke whale (bacu)

For the minke whale, a total of 8 potential re-sightings were recorded, which was too low to stratify and to estimate esw for good and moderate conditions. Therefore, a single esw was estimated, which is 0.154 km (CV=0.42), corresponding to a g(0) of 0.302 which seems reasonable for this cryptic species. Please note that in the figure below the result for 'good' conditions should be ignored. Due to a simplification of the analysis in the programme Racetrack, all sightings were assigned to have been recorded under moderate conditions in order to retrieve a single esw estimate.



Dolphins




For the combined dolphin species, the effective strip width was estimated to be at 0.39 km (CV=0.13) and 0.213 km (CV=0.14) under good and moderate conditions, corresponding to a g(0) of 0.805 and 0.414 respectively.

The higher g(0) for dolphins seems reasonable and could result from larger average pod size increasing the probability that at least one member of the pod is a the surface near the trackline as the plane passes.