METHODS

Preparation of the Data for Statistical Modelling

Three sources of data were relevant to the study: (1) duplicates of the log books maintained by individual shark contractors, (2) the ledgers maintained by officers of the Queensland Department of Primary Industries (QDPI ledgers), and (3) the electronic database maintained by the Queensland Department of Primary Industries (QDPI database). The contractors employed by the Queensland Shark Control Program are required to enter catch data into individual logbooks. These data were subsequently transferred to the QDPI ledgers. Electronic records that had been entered in to the QDPI database were checked using archived duplicates of contractor's logbooks. If anomalies were detected, these were checked with the individual contractor, if possible. For our study, the following data were included for each month at each beach where shark nets were deployed: year; month; number of nets (0–3); number of days fished (effort / month); number of days not fished; number of months of net fishing since the nets were last removed; total number of months net operated in area / beach; total number of dugongs caught. A total of 446 records were excluded from the analyses, reflecting inconsistencies between the sources of data consulted. Two contract areas were excluded from all our analyses: (1) Tannum Sands where nets were never deployed, and (2) Point Lookout where nets were deployed only at a single beach for only seven years. Thus our analysis is conservative, especially with respect to dugong mortality in the early years of the Queensland Shark Control Program, e.g. *Review of the operation and maintenance of shark meshing equipment in Queensland waters* (1992) reports a total of 837 dugongs caught between 1962 and 1992 whereas our analysis is based on a catch of 579 dugongs.

The full data set we studied comprised 14 636 monthly records over 38 years (1962–1999) at 47 beaches within eight of the 10 contract areas including five of the six areas in the Great Barrier Reef World Heritage Area. The monthly catch at the eight contract areas studied ranged from 0–5 dugongs with almost 97% zeros.

Number of dugongs caught	0	1	2	3	4	5
Number of cases	14 169	380	69	12	5	1
Percentage of cases	96.81	2.69	0.47	0.08	0.03	0.01

Statistical Analysis

Data were analysed using generalized linear models (GLMs). The effects of the number of nets, the number of days fished and the month of the year were assessed using analysis of deviance tests, based on a model including these effects together with a smooth term in year (natural spline with 4 d.f.), beach and the year by beach interaction. Thus, all effects were adjusted for all other terms in the model. Shark nets were removed from most beaches for repair in most years, typically for 1–2 months. Catch rates of dugongs were compared for pre- and post-removal periods of one and three months using GLMs, and adjusting for beach and year as in the case of nets, days fished and month effects.

As detailed below, the effects of the number of nets, the number of days fished, months, and nets removal were statistically non-significant, and thus, to simplify further analyses, dugong catches were summed to give annual totals for each beach when at least one net was deployed. For years with less than 12 months of effort, totals were rescaled according to the number of months for which nets were used.

The 47 beaches considered here were selected by the Queensland Shark Control Program based on the extent and pattern of human use. Hence, for catch rates of dugongs, it is reasonable to treat these beaches as representative of the relevant contract areas. On this basis, we used variation of temporal profiles at the different beaches as the source of variation against which to compare differences between contract areas, and to obtain estimates of precision of the area and overall profiles. The catch data were difficult to model because of: (1) the large percentage of months with zero catches, (2) the repeated measures on individual beaches, and (3) the unbalanced data resulting from the nets not being deployed at each beach at all possible sampling times. To simplify the problem, we took the following steps to create a reduced data set which was more balanced and therefore more robust to statistical analysis than the full data set:

1. Data from beaches with total dugong captures of < 2 were removed since they provided minimal trend information.
2. Date from beaches with less than eight years of observations were removed since, compared to the overall period of 38 years, they provided little trend information, and they also greatly increased the imbalance of the data.
3. One contract area (Rainbow Beach) where nets were deployed at only one beach was also removed since the precision of the area profile could not be estimated because of the lack of replication.
4. Data were aggregated across months to give a single total for each combination of year and beach, and adjusted according to the number of months of observations; the non-significant effect of months justified this aggregation.

This reduced data set included six of the eight contract areas (four in the Great Barrier Reef World Heritage Area), and 31 of the 47 beaches in the full data set. The number of cases was reduced from 14 636 to 942 (largely because of aggregating the data from monthly to annual totals), and the total dugongs caught from 579 to 523. The sampling times of all beaches and the reduced data set are shown in figure 2.

Given the difficulties described above, we used resampling methods to estimate profiles for each contract area and overall. Since the data were counts, we used GLMs with a log link and Poisson error (log-linear models) for modelling the profiles from the resampled data. Confidence intervals for contract area and overall profiles were not based on GLM theory, because we consider the beaches as random effects, and instead we used the distributions of estimated profiles under resampling.

To estimate the mean profiles for each contract area and overall, we proceeded as follows:

1. GLMs with Poisson error and log link function (a log-linear model) and year as a numeric variable were used to model the profiles of each beach across years. Linear, quadratic and smooth profiles in year (natural spline with 4 d.f.) were compared, and the quadratic model was chosen based on deviance tests and residual plots. Temporal correlation along each beach profile was assessed by including an autoregressive term in year in the GLMs. In all cases these were non-significant.
2. We then estimated the profile and pointwise confidence intervals for each area. To do this, we took 500 bootstrap samples with replacement, using beach as the sampling unit. Thus each beach was either all-in or all-out of each sample, and if in, it could occur multiple times in a bootstrap sample. For each sample, we fitted the quadratic model (see 1 above), and predicted the mean profile for years 1962 to 1999. From the 500 sets of predictions, the 50%ile, 2.5%ile and 97.5%ile were calculated to estimate the mean profile for the contract area and its 95% confidence intervals at each year.
3. To estimate the overall profile, we used beach as the sampling unit for the reduced data

as in 2, but also stratified by contract area, so that each bootstrap sample included the same number of beaches occurring in each contract area.

4. We then estimated the rate of capture of dugongs for each year by fitting a cross-validated smoothing spline through the estimated overall profile and calculating the gradient at each year.
5. The overall mean profile, and the rate of capture of dugongs at each year, were also estimated from the full data set (47 beaches) as in 3 above.

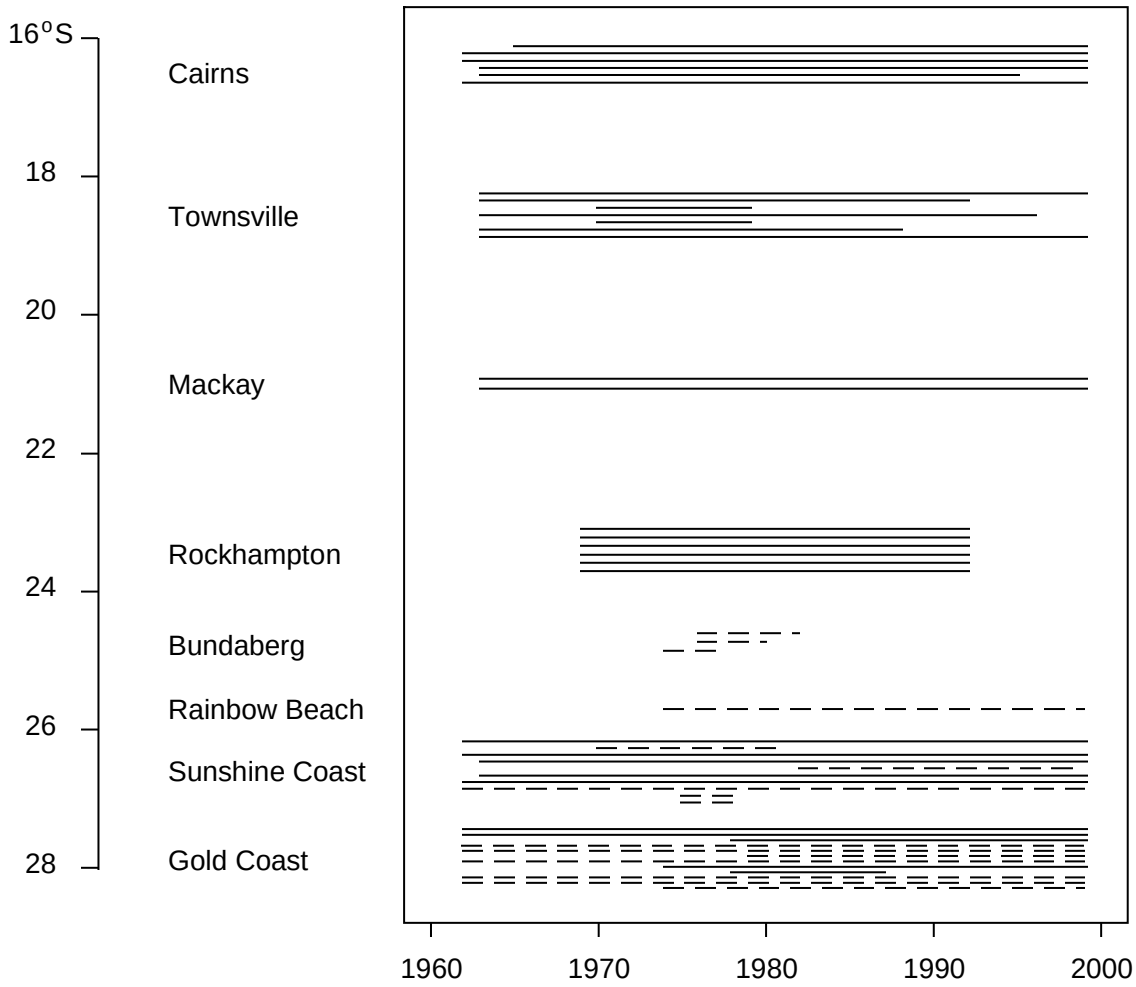

Figure 2. Sampling times for the 47 beaches within the eight contract areas used in the analyses. Beaches with less than eight years of sampling, or having less than two dugongs caught, and Rainbow Beach (a single beach in an area) were excluded from the full data set for some analyses and are indicated by dashed lines. The reduced data set was based on the beaches represented by solid lines.