A SURVEY DESIGN FOR INTEGRATED MONITORING OF SALMONIDS

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ABSTRACT

The Oregon Department of Fish and Wildlife conducts three large-scale projects to monitor coastal salmonids. The Coastal Salmonid Inventory Project conducts spawning surveys for returning adults, the Early Life History Project monitors juvenile salmonids, and the Aquatic Inventory Project monitors stream habitat. In 1998, an integrated monitoring design was initiated to facilitate the integration of data among these projects. A rotating panel design utilizing the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) site selection process was deemed to be the best approach to meet the needs of the studies. EMAP utilizes a Geographic Information System (GIS) to draw a spatially balanced sample of a population. The program provides forced overlap between projects where their sampling domains overlap, and facilitates sampling intensification. The rotating panel design balances the utility of trend detection through repeated sampling at the same sites over time, with the advantages of extensive sampling of the target populations. Arc Info was used to create coverages of the population of streams to be sampled for each project. EMAP selects a spatially balanced sample from a coverage, forces overlap of sites for each project where their sampling extents coincide, associates each point with a stream reach, and measures the distance upstream from the reach origin. This plan was successfully implemented during the 1998 field season.

Key words: GIS, long-term monitoring, status and trends, salmon, survey design

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INTRODUCTION

The advent of methods to geographically represent and analyze complex biological data promises to revolutionize population biology. In this paper, we present an integrated survey design that utilizes geographic information systems (GIS) to draw spatially balanced, overlapping survey sites for three interrelated projects. The implementation of this survey design is the latest chapter in the evolution of efforts to monitor salmon and aquatic habitat in the state of Oregon. The methods employed monitor salmon in Oregon have been continually improved and standardized since the 1950's. As wild salmon stocks become increasingly compromised, there is a corresponding need for increasingly accurate and precise estimates of status and trends of impacted populations.

The Environmental Monitoring and Assessment Program (EMAP) was put forward by the United States Environmental Protection Agency (US EPA) to address the need for consistent sampling of environmental conditions over large scales (Overton et al., 1990, Messer et al., 1991). It is designed to emphasize regional populations, not individual ecosystems (Kutz and Linthurst, 1990; Messer et al., 1991).

SAMPLING USING EMAP

EMAP is one of many site selection techniques that provides probability-based samples that allow unbiased estimates of status and trends within target populations. What sets EMAP apart from most other approaches is that it preserves spatial patterns across the landscape (Overton et al., 1991; Stevens, 1994; White et al., 1992). EMAP achieves geographic coverage of ecological resources through the use of a grid format (White et al., 1992). A grid-based sample can be used to sample any spatially dispersed population. It ensures that the sample is evenly spread over the landscape, allows detection of local disturbances, and ensures that spatially restricted sub-populations are sampled. This design addresses the need to sample at varying spatial extents. A lower density grid would be a subset of all higher density grids, and all sub-grids are interpenetrating. Consequently, the design is very flexible. EMAP's ability to isolate and recombine portions of the target population facilitates sub-population analyses. Selecting sites using a geographic grid also has the advantage that it returns an equiprobable sample. The variance of a completely random sample is larger than that of an equiprobable, spatially balanced sample because completely random designs are clustered by nature, and occasionally provide poor spatial coverage (Overton and McDonald, 1998).

The mechanics of how a sample is drawn under the EMAP protocol are described in detail by Larsen et al., 1991 & 1994; Larsen and Christie, 1993; and Overton et al., 1991. The EMAP site selection process utilizes a GIS to lay a grid over 1:100,000-scale digital line graphs of streams. Stream segments within a grid cell are clipped and uniquely identified along with their start and end points. The stream segments from nearby grid cells are then linked end to end to form one continuous line. A point is randomly placed on the line, and additional points are then placed at regular intervals as we move up the line (Figure 1). These points can then be re-projected on to the routed stream coverage (Figure 2).

This provides a spatially balanced random sample. By decreasing the clustering that is inherent to simple random sampling, we can potentially decrease the variance of our status estimators.

THE INTEGRATED PROJECTS

Three assessment categories are integrated in this design to represent integral elements for the success of salmon stocks, namely: the abundance and quality of in-stream habitat suitable for salmon spawning and rearing, the abundance of returning spawning adults, and the freshwater survival (i.e. abundance) of juvenile salmon.

Habitat

In 1989, the Oregon Department of Fish and Wildlife Restoration and Enhancement Program initiated the development of an aquatic inventory project. The research findings and experience of many individuals and agencies were melded together to design a methodology which incorporated the best available scientific knowledge on stream habitat assessment (Bisson et al., 1982; Everest et al., 1987; Grant, 1988; Hankin and Reeves, 1988). This project collects data on stream morphology and substrate, woody debris, riparian vegetation, and land use (Jones et al., this issue). Prior to 1998, habitat surveys were designed and implemented as a complete inventory of specific streams, not as a representative sample to be extrapolated to larger areas. The survey design described here provides a randomized sample of survey sites, thus paving the way for estimates pertaining to the total population of stream habitats.

Spawning

Visual counts of spawning salmon have been used as an index of naturally produced salmon stocks in Oregon since 1948 (Jacobs and Cooney, 1997). Originally, inter-annual comparisons of counts in a standard set of stream segments were used to make conclusions about annual trends. In 1971, the standard index was substantially modified to eliminate many surveys that were believed to be unsuitable. The remaining surveys were limited to areas thought to contain productive spawning habitat (Skeesick, 1972). Spawning escapement indices based on the standard index surveys were developed in 1975 (Cummings, 1976). Beginning in the early 1980's, the spawning survey program was gradually expanded. The Oregon Department of Fish and Wildlife's Coho Salmon Plan, established in 1982, initiated more intensive fishery management, and necessitated more accurate annual estimates of the total spawning escapement (Jacobs and Cooney, 1997). Beider and Nickelson (1984) and Ganio et al. (1986) reviewed the methods used to estimate spawning escapement. The recommendations of these reviews led to the implementation of a stratified random sampling design for spawning surveys in 1990. Randomly selected survey segments have been conducted in conjunction with the standard index since that time. Coho density estimates derived from randomly selected surveys have been found to be significantly lower than those derived from standard surveys (Jacobs and Cooney, 1997). It is believed that random surveys provide a more accurate estimate of stock abundance. The design described here provides us with the opportunity to further improve the power of our estimates because the sample is spatially balanced. It also facilitates the integration of separate projects by forcing overlap between different sets of random samples.

Rearing

Historically, estimates of the abundance of juvenile coho salmon have been based solely on the catch of out-migrating smolts at several traps placed in coastal Oregon streams. One drawback of this approach is that trap sites are generally not selected randomly due to the many constraints that limit possible trapping sites. In addition, trap counts do not provide the data necessary to provide estimates of egg to fry or egg to parr survival rates, nor is it possible to detect differential survival from different sites or habitat types.

Juvenile surveys, initiated in 1998, provide this important link. This project estimates the abundance of juvenile salmonids by snorkeling pools within stream reaches. Because these sites were randomly chosen to provide a representative sample, they can be used to construct juvenile population estimates. Additionally, the forced overlap between juvenile monitoring sites and the other monitoring projects will allow investigation of associations between juvenile survival and habitat or spawner abundance.

ELEMENTS OF THE DESIGN

Target Populations and Sampling Intensity

The first challenge we faced in creating an integrated sampling plan was the fact that each of the three projects samples a different subset of coastal streams (Figure 3). The habitat project samples the largest area, including all streams except large 4th order streams. The spawning project samples the most restricted area - surveying only areas with habitat suitable to coho spawning. The rearing project samples both areas where coho spawning occurs, and all habitats downstream, excluding 4th order streams. To further complicate the issue, the spawning project, which has the most restricted sampling extent, also samples at the highest intensity - with the goal of establishing 120 sites per Gene Conservation Area (GCA). The other two projects, on the other hand, sample 50 sites per GCA.

The interpenetrating grid format inherent to the EMAP selection protocol resolved this difficulty. Initially, the largest population of streams was sampled at the highest intensity; i.e. the sampling universe for the habitat project was sampled at the intensity necessary for the spawning project. Sub-grids were then used to sub-sample survey sites at the intensity needed for the rearing and habitat projects. Finally, ArcInfo coverages of the distribution of spawning and rearing habitats were used to isolate appropriate sites for those two projects. A similar process can be used to intensify the sample. Because all of the sites are drawn from the same base grid, there is forced overlap of sites between projects where their sampling domains overlap. These shared sites facilitate comparisons among different data sets.

Status vs. Trends and Rotating Panel Designs

The most important question that all three projects address is that of the status of salmon or habitat. We need to be able to make accurate and precise estimates of populations. However, there is also a need to describe trends over several time-scales - from year to year variation, to interdecadal oscillations. Prioritizing these questions puts some restrictions on the sampling design. To optimize status estimates, we want to visit as many different sites as possible. On the other hand, repeating sites year-to-year will give us better power of trend detection. A rotating panel design is a compromise that balances needs for status and trend detection. In addition, once the initial investment to set up the site has been made, repeating sites reduces the effort required for sampling.

A sampling design that exclusively emphasizes status detection would sample a unique group of sites every year in order to visit as much of the available habitat in the least amount of time possible. To emphasize trend detection exclusively, the same group of sites would be visited every year. A rotating panel design incorporates both of these approaches. See Rao and Graham, 1964; Binder and Hidiroglou, 1988; Duncan and Kalton, 1987; Kish, 1987; and Skalski, 1990 for further discussion of survey designs over time. An example of a simplified rotating panel design is outlined in Figure 4a. One group of sites is visited in the first year, another group of sites is visited in the second year, and a third group of sites is visited in the third year. In the fourth year, the first group of sites is sampled again. Under this regime, more of the habitat is sampled than would be possible if the same sites were repeated every year, but sites are still repeated to enhance trend detection, albeit over a longer time-scale. A slightly more complicated panel design is illustrated in Figure 4b. Some overlap has been introduced between the three sets of sample sites, and a group of sites has been added which is repeated every year. These modifications will bolster detection of inter-annual trends. Most rotating panel designs utilize a three to five year rotation. We adopted a three-year rotation to coincide with the three-year life cycle for coho salmon.

The panel design that was adopted for this study is outlined in Figure 4c. Don Stevens, Tony Olsen, Phil Larsen and Tom Kincaid of the U.S. Environmental Protection Agency, Corvallis, Oregon, created this design. The first panel, labeled S_0, consists of a group of sites that will be sampled every year. The next three panels (S_{10}, S_{20}, and S_{30}) contain sites that will be re-sampled at three-year intervals. The following nine panels will be sampled every nine years, and the final panel contains sites that are unique every year. In any given year, 25% of the sites drawn will be annual samples, 25% will be sampled on a three-year interval, 25% will be sampled on a nine-year interval, and 25% will be unique to that year. In year two, 25% of the sites will be the same as those sampled in year one. In year four, the sites in panel S_{10} will repeat, giving 50% site overlap with year one. In year 10, both panel S_{10} and panel S_{11} will repeat, giving 75% overlap with year 1. When three nine-year rotations have been completed, we will have sampled the entire target population of streams.

CONCLUDING REMARKS

This survey design was successfully implemented during the 1998 field season. The draw accomplished the defined goals. Prospective survey sites were evenly spread across three different spatial extents and densities, sites were evenly distributed among the four rotating panels, and 211 possible shared sites were drawn for the first year. Various impediments can prevent sampling of selected survey sites. For example, landowners may refuse to grant access to streams that run through their property or selected sites may not contain suitable spawning or rearing habitat. These possibilities were taken into account before survey sites were drawn, and over-sample rates were tailored to prior experience in each GCA. The spawning project established a target of 540 sites to be sampled in 1998. At the end of the field season, access had been obtained to 593 sites and 549 were surveyed, well within the target window. Dropped survey sites did not disrupt the panel structure, however access difficulties did disrupt the spatial coverage to some extent. Investigations are now under way to examine what impact this fact will have on the confidence of population estimates.

GIS is a powerful tool for survey design and site selection. This spatial database facilitates the construction of a spatially balanced survey. The EMAP site selection technique can accommodate different sampling extents and densities, and can force overlap between different subsets while maintaining spatial dispersion. The rotating panel design adopted for this integrated study balances needs for both trend detection and status estimates. The statistical advantages of an equiprobable sample and the ability to integrate sampling for related projects with different sampling needs are a boon to monitoring efforts.

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Captions:

Figure 1. EMAP Selection Process. The EMAP site selection process utilizes a GIS to lay a hexagonal grid over a stream coverage. Stream segments within a grid cell are clipped and linked end to end to form one continuous line. A point is randomly placed on the line, and additional points are then placed at regular intervals as we move up the line.

Figure 2. Survey Site Selection for the Mid-South Coast GCA, Oregon. EMAP selects a spatially-balanced random sample, and there is considerable degree of overlap among the three sets of survey sites.

Figure 3. Target Populations. Each project samples a different subset of coastal streams. The habitat project samples the largest area, including all streams except large 4th order streams. The spawning project samples the most restricted area - surveying only areas with habitat suitable to coho spawning. The rearing project samples both areas where coho spawning occurs, and all habitats downstream, excluding 4th order streams. The spawning project, which has the most restricted sampling extent, also samples at the highest intensity.

Figure 4. Rotating Panel Designs. a) A simplified rotating panel design. One group of sites is visited in the first year, another group of sites is visited in the second year, and a third group of sites is visited in the third year. In the fourth year, the first group of sites is sampled again. b) A slightly more complicated panel design. Some overlap has been introduced between the three sets of sample sites, and a group of sites has been added which is repeated every year to bolster detection of inter-annual trends. c) The panel design that was adopted for this study. The first panel (S_0) will be sampled every year. The next three panels (S_{10}, S_{20}, and S_{30}) contain sites that will be re-sampled at three-year intervals. The following nine panels will be sampled every nine years, and the final panel contains sites that are unique every year.

Figure 1

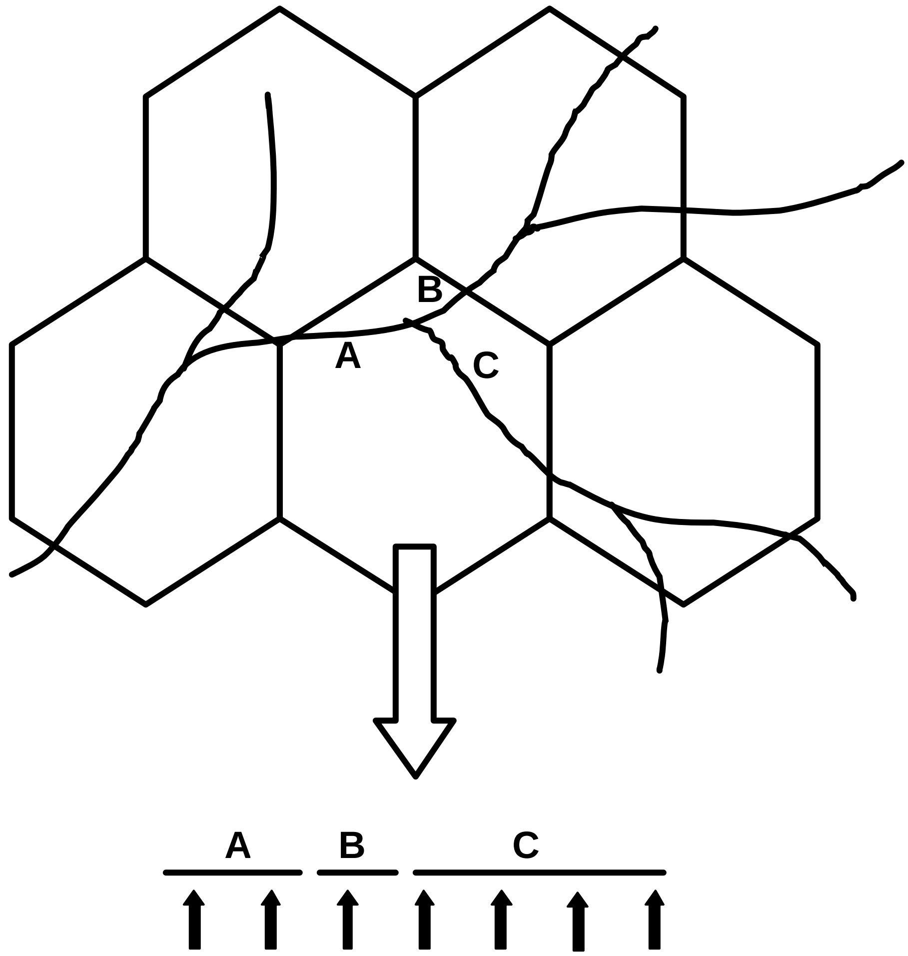


Figure 2

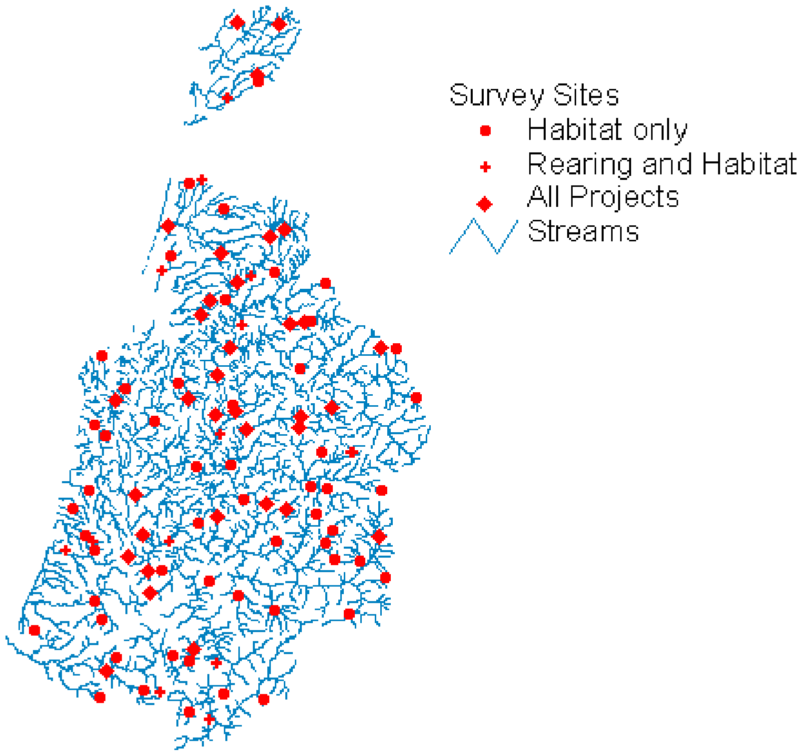


Figure 3

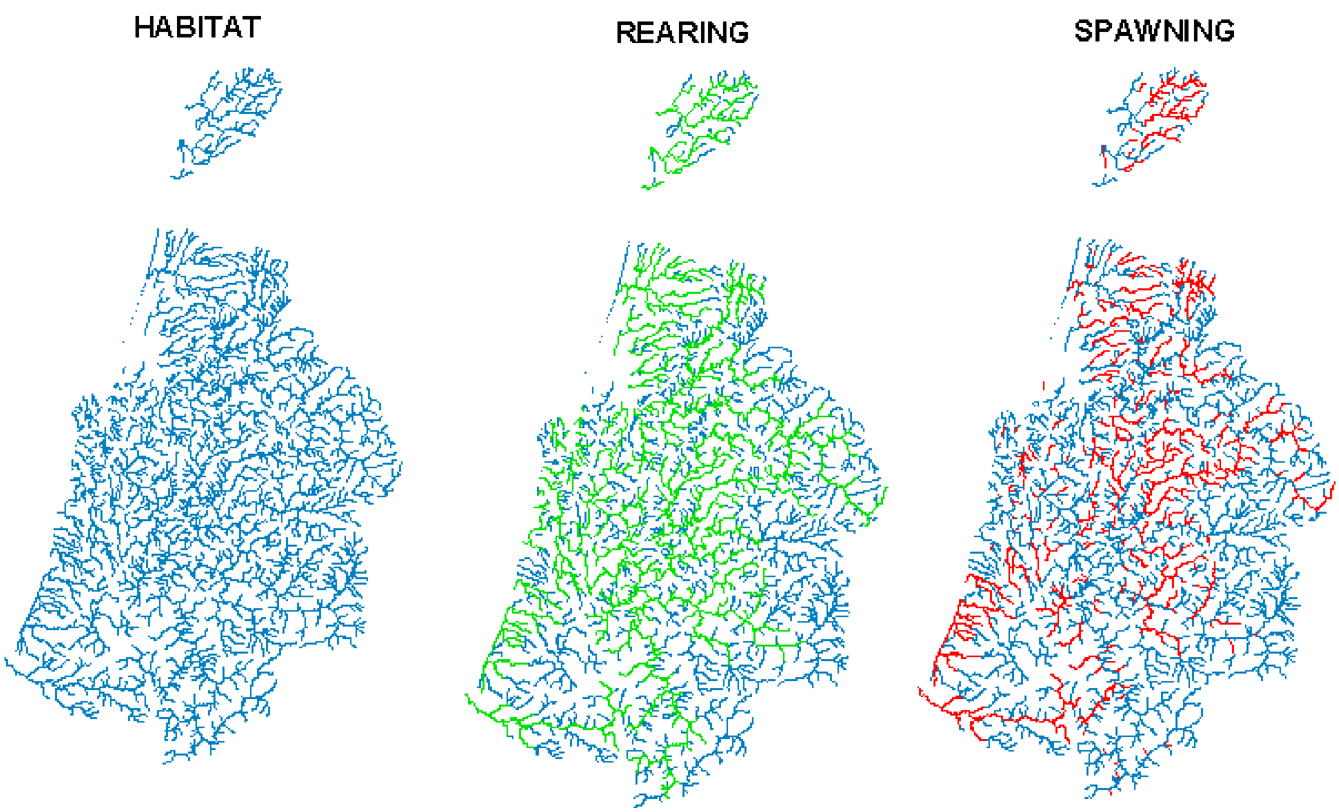
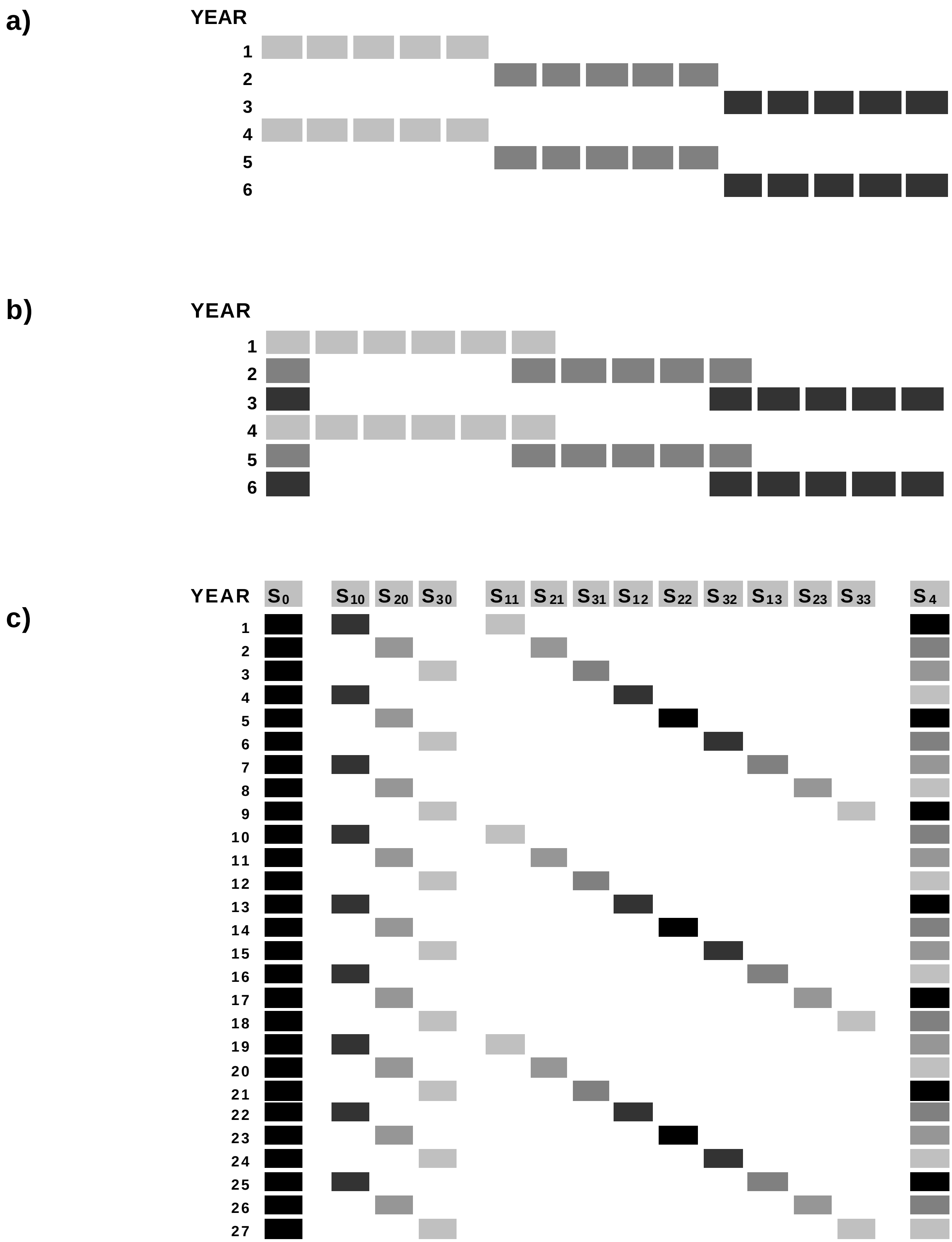


Figure 4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