Migrations suggested by the recapture of disk-tagged striped bass during their first year at large, 1969-2011.

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Introduction

Striped bass movements within the San Francisco Estuary (SFE) and the Sacramento-San Joaquin watershed are of interest to researchers, managers, and policy makers as those movements pertain to predator-prey relations (Loboschefsky et al. 2011) as well the as-yet-unexplained 'disconnect' between the relatively large number of adult striped bass and resulting relatively small number of young striped bass during the Pelagic Organism Decline (POD; Baxter et al. 2008; 2010). Here we illustrate some aspects of striped bass movements by investigating patterns in the recapture of striped bass tagged by the California Department of Fish and Wildlife (CDFW) striped bass population study.

The CDFW has released thousands of disk-tagged striped bass nearly every year since 1969. Up to 10% of the tags released each year offer a monetary reward to evaluate the potential for bias in the behavior of anglers who recapture tagged fish. Information from the return of tags provides estimates of various population metrics (e.g., harvest rate and survival rate) and — assuming the behavior of tagged fish and un-tagged fish is similar, and that angler behavior is not confounding — aspects of striped bass migrations.

Our intention here is to focus on potential changes in the timing and/or location of spawning migrations as those might pertain to the disconnect between the number of adult striped bass and resulting abundance of young striped bass. Were this investigation to discover changes of that sort, we would expect to see evidence of uncommon patterns in the timing and/or location of tag recoveries — especially since the mid-1990s, which is when the abundance of adult striped bass increased from a record low to a record high at the start of the POD.

Data and Analytical Methods

We used data collected from 1969-2011. Because no striped bass were tagged in 1995, 1997, 1999, 2001, and 2006, those years are not included in this investigation.

Given our focus, the large amount of tagging data, and the many variables that could be considered (e.g., season, location, sex, size, and age), we restricted this investigation to size at tagging as well as recapture location, month, and season.

To reduce bias — for example, annual mortality which varied but commonly approached 50% — and standardize the metrics, we used only data on non-reward tags returned by anglers who captured fish within 365 days from the tagging date. Because tagging occurred in the spring and/or early summer, the 365-day period (called 'year' hereafter) included parts of two calendar years (e.g., April 1, 2010 to March 31, 2011). We calculated the proportion (p; Equation 1; expressed as a percent) of tag returns (by year) for each length category for each of the three recapture strata (Table 1). Tag returns for which release or recapture information was not provided were included in the proportion calculation but not in any analyses.

$$p = \left[\frac{x_{l,y}}{x_y} \right] \times 100 \qquad \text{Equation 1}$$

where x = number of tag returns
l = length category
y = release (tagging) year

Strata for release and recapture variables are described in Table 1. Recapture location (as provided in narrative from anglers) was assigned to one of seven large geographical areas (see Table 2 for further description of recapture location). To the month of recapture, a -Y0 or -Y1 was added to denote year of release (-Y0) or year after release (-Y1). Similarly, spring and summer seasons were denoted with a 1 or a 2 to distinguish between year of release and the year after release. Seasons were grouped according to month of recapture. Fish length in centimeters fork length (cm FL) at release varied from 31-123 and was grouped into four categories.

Time Series

We plotted the annual proportion of tag returns (returns) for each recapture stratum for each length category. For consideration when interpreting the tag-recovery information, we also plotted the proportion of tagged-fish released annually in each location for each length category.

Cluster Analysis

Having realized that describing potentially-subtle patterns in the timing and/or location of tag recoveries — let alone gaining agreement that those patterns exist — would be difficult using only the time series, we also explored the data using hierarchical clustering and non-metric multidimensional scaling (NMDS).

We configured the data as a matrix with rows as (sampling/tagging) years and columns as the concatenation of <recapture variable>_<length category>. Though not depicted here, we used the Bray-Curtis method to calculate the dissimilarity matrix (years x years) and we observed natural groupings of years by plotting dendrograms (of the dissimilarity matrix) using average linkage (Johnson and Wichern 1988). We grouped (N = 5-7) the years based on the branches (configuration and height) of the dendrogram and the desire not to create too few or too many groups.

We used R statistical software (version 2.15.2; 2012-10-26) with the vegan package to perform NMDS on the dissimilarity matrix (R Core Team 2012, Oksanen et al. 2012), and then made two NMDS plots for each of the three recapture variables. The first plot represents the years (rows in the dissimilarity matrix) and the second plot represents the <recapture stratum>+<length category> combination.

Results

Tag Releases

Most fish were tagged from the Sacramento River and the San Joaquin River (Figure 1; see Table 3 for further location description). A particularly large fraction of fish tagged in recent years were *Small*. The number of larger fish tagged declined trendwise and the decline was particularly apparent for *Very Large* fish.

Tag Returns

Recapture Location

We see no evidence of uncommon patterns in the location of tag recoveries but thought the following items were noteworthy:

- Returns from the ocean in 1986 were exceptionally high (Figure 2), which suggests a bigger and/or longer migration there than usual and may explain an anomalously low SFE CPFV CPUE value (DuBois and Gingras 2013).
- Returns from the San Joaquin River (SJR) were consistently below two percent, even when substantial numbers of fish were tagged there (Figure 2).
- Returns from the ocean and western San Francisco Estuary gradually decreased while returns from the delta gradually increased, and this shift was least apparent for V*ery Large* fish (Figure 2).
- Early years of the mark-recapture study were clustered (Figure 3).
- The late 1980s and early 1990s were fairly tightly clustered, particularly years 1989, 1990, and 1991 (Figure 3).
- Returns from San Francisco Bay and San Pablo Bay of *Large* and *Very Large* fish were fairly tightly clustered (Figure 4).

Recapture Month

We see no evidence of uncommon patterns in the timing and/or location of tag recoveries but thought the following items were noteworthy:

- There were returns each year during the following tagging season (i.e., sometime between March [03-Y1] and May [05-Y1]). In general, these yearly proportions were lower for *Large* fish and *Very Large* fish compared to smaller fish (Figure 5).
- Early years of the mark-recapture study were clustered (Figure 6)
- Returns from *Very Large* fish recaptured in most months (except for 12-Y0 and 06-Y1) were clustered. Although there were some exceptions, a similar group emerged for returns from *Large* fish (Figure 7).
- Returns from *Small* fish and *Modest* fish were similar, especially for months 01-Y1, 02-Y1, and 03-Y1 (Figure 7).

Recapture Season

We see no evidence of uncommon patterns in the timing and/or location of tag recoveries but thought the following items were noteworthy:

- Returns were consistently very low in the second summer (Figure 8).
- Early years of the mark-recapture study were clustered (Figure 9).
- Returns were similar for *Large* and *Very Large* fish from spring, summer, and fall (Figure 10).

Discussion

We did not find any sign of substantial changes in the timing or location of spawning migrations. Thus, the POD-era disconnect between the production of young striped bass and the numbers of adult striped bass remains most-likely explainable by some combination of demographics (e.g., the change in apparent adult sex ratio (Baxter et al. 2010)), the changed behavior of young striped bass (Sommer et al. 2011), and perhaps changes in the survival of eggs and/or larvae.

This work clearly depicts a decrease in returns from the ocean and western San Francisco Estuary with a corresponding increase from the Delta. Although variations in fish demographics, fish movement, fishing effort, and catchability may each account for some of the change, we are certain the first two do and there is no comprehensive information on the latter two.

Cluster analysis helped organize the information somewhat, though not as much as we had hoped. 'The good old days' when large fish were abundant and the ocean fishery was substantial is obvious, but the subsequent collapse of striped bass (Stevens et al. 1985), the brief rebound, and the POD years are subtle at best. We suspect signs of the rebound are muted in large part because — as a cost-saving measure — the striped bass population study tagged only in alternate years during that period and as a result data during that period are sparse. Hindsight is 20:20!

The influence of Delta outflow, availability of striped bass prey, and water quality on the recapture of tagged fish could be investigated using this tagging data. We suspect that those sorts of analyses would not be especially helpful for answering current research priorities though, largely because recapture locations have been aggregated into relatively large areas and because — with one eye to cost-savings and the other eye to incidental take of listed fishes during tagging — the striped bass population study has for roughly 20 years been unable deploy the fishing effort necessary to tag many of the relatively rare *Large* fish and *Very Large* fish.

References

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Table 1 Strata for release and recapture variables

Table 2 Recapture location codes and description

Table 3 Release location codes and description

Figure 1 Proportion (as percent of total) of non-reward tags released (1969-2011) for each release location by length category

Figure 2 Proportion (as percent of annual total) of annual (1969-2011) non-reward tag returns for each recapture location by length category

Figure 3 NMDS plot showing release years (YY, in circle) for recapture location and length categories

Figure 4 NMDS plot showing recapture locations (in white text on symbol) and length categories (symbols)

Figure 5 Proportion (as percent of annual total) of annual (1969-2011) non-reward tag returns for each recapture month by length category

Figure 6 NMDS plot showing release years (YY, in circle) for recapture month and length categories; note red dot in subplot (year 2010, group 5) removed from main plot for easier viewing

Figure 7 NMDS plot showing recapture months (in white text on symbol; year in color) and length categories (symbols)

Figure 8 Proportion (as percent of annual total) of annual (1969-2011) non-reward tag returns for each recapture season by length category

Figure 9 NMDS plot showing release years (YY, in circle) for recapture season and length categories

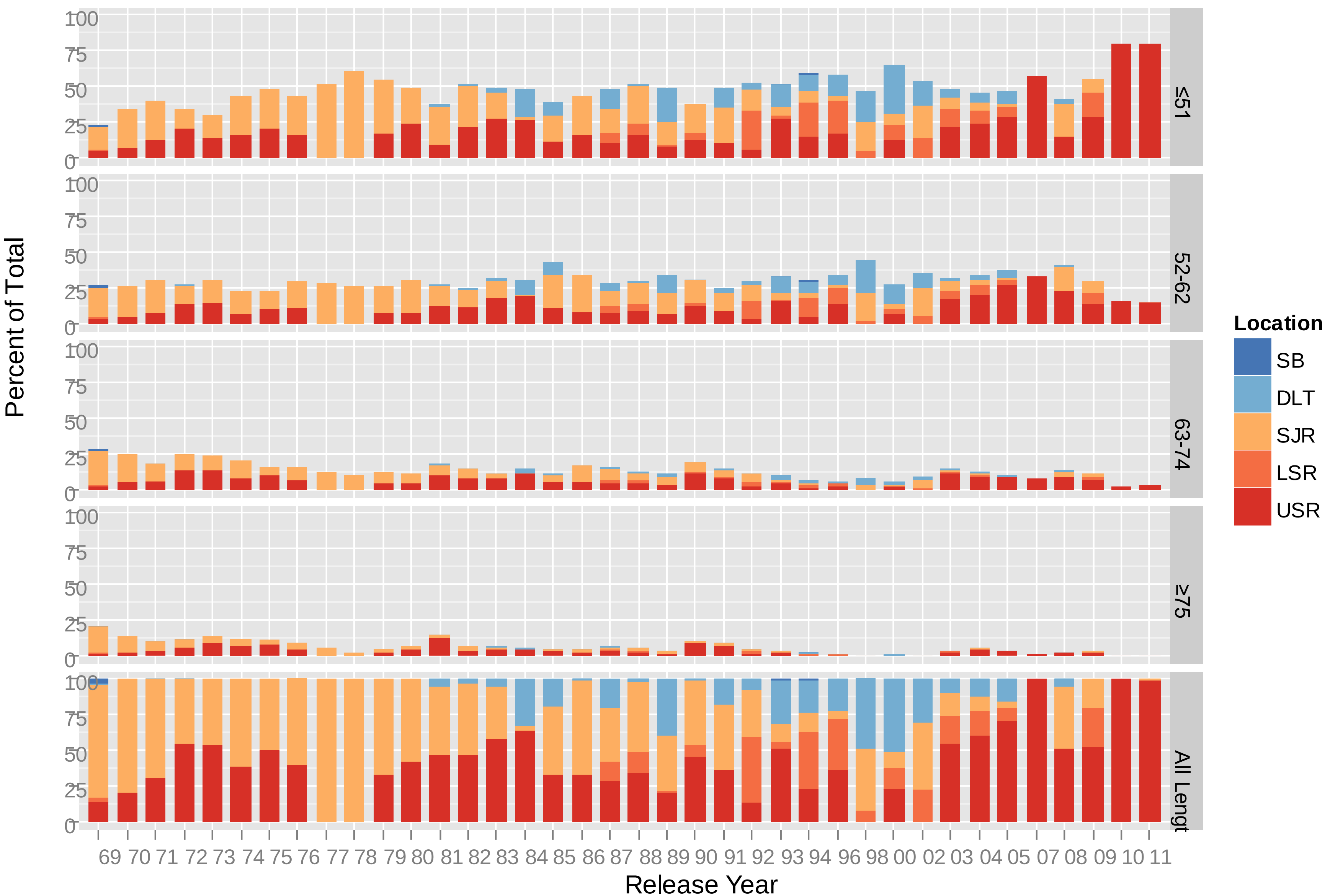
Figure 10 NMDS plot showing recapture seasons (in white text on symbol) and length categories (symbols)

Release Strata	Recapture Strata (1,2,3)				
Length Category (cm FL)	Location (1)	Month (2)	Season (3)	Season Abbreviation	Year
≤ 51 (small)	USR	Mar,Apr,May	Spring	SP1	-Y0
52-62 (modest)	SJR	Jun,Jul,Aug	Summer	SU1	-Y0
63-74 (large)	DLT	Sep,Oct,Nov	Fall	FAL	-Y0
≥ 75 (very large)	SB	Dec,Jan,Feb	Winter	WIN	-Y0, -Y1
	SPB	Mar,Apr,May	Spring	SP2	-Y1
	SFB	Jun	Summer	SU2	-Y1
	PAC				

Code	Name
USR	Upper Sacramento River
SJR	San Joaquin River
DLT	Delta
SB	Suisun Bay
SPB	San Pablo Bay
SFB	San Francisco Bay
PAC	Pacific Ocean
UNK	Unknown

Description
Sacramento River - Courtland to the mouth of the Feather River, including the American River to Nimbus Dam; Sacramento River and tributaries - above the mouth of the Feather River; Feather River and tributaries, Rio Oso, and the Yuba River
San Joaquin River - above Mossdale
Lower San Joaquin Delta - Broad Slough, Sherman Lake, San Joaquin River to Mokelumne River; Upper San Joaquin Delta - area bounded by San Joaquin River from Mokelumne River to Mossdale, Old River, and Salmon Slough; Sacramento River - Sherman Island to Courtland; Mokelumne River, Georgiana Slough, and sloughs north of the San Joaquin River and east of the Mokelumne River
Sacramento River - Sherman Island to SP Railroad Bridge (Martinez) - includes Suisun and Honker bays; Montezuma and Suisun Sloughs
Carquinez Strait - SP Railroad Bridge (Martinez) to Carquinez Bridge; San Pablo Bay - Davis Point to Points San Pablo and San Pedro, east to Carquinez Bridge; Napa River and sloughs north of San Pablo Bay, west to Sonoma Creek; Novato Creek, Petaluma Creek, and tributaries
North San Francisco Bay - bounded on the west by GG Bridge and on the south by Bay Bridge; South San Francisco Bay - south of Bay Bridge; San Francisco Bay - unknown north or south
Pacific Ocean - anything west of the Golden Gate Bridge
Unknown

Code	Name	Description
USR	Upper Sacramento River	Sacramento River - Clarksburg; Fremont Weir (Verona); Sacramento River - Colusa; Freeport; Knights Landing
LSR	Lower Sacramento River	Towers (Lower Sacramento River - Sherman Island); Ida's Island (Sacramento River, below Isleton); Steamboat Slough (Sacramento River system)
SJR	San Joaquin River	Schad Landing (Mouth of False River - San Joaquin River); San Joaquin River at Prisoners Point; Santa Clara Shoals (San Joaquin River)
DLT	Delta	Broad Slough; Mud Island (Collinsville - Sacramento River)
SB	Suisun Bay	Grizzly Bay - Pelican Point; Sacramento River at Chipps Island; Honker Bay



Percent of Total
Release Year
Location
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DLT
SJR
LSR
USR
≤51
52-62
63-74
≥75
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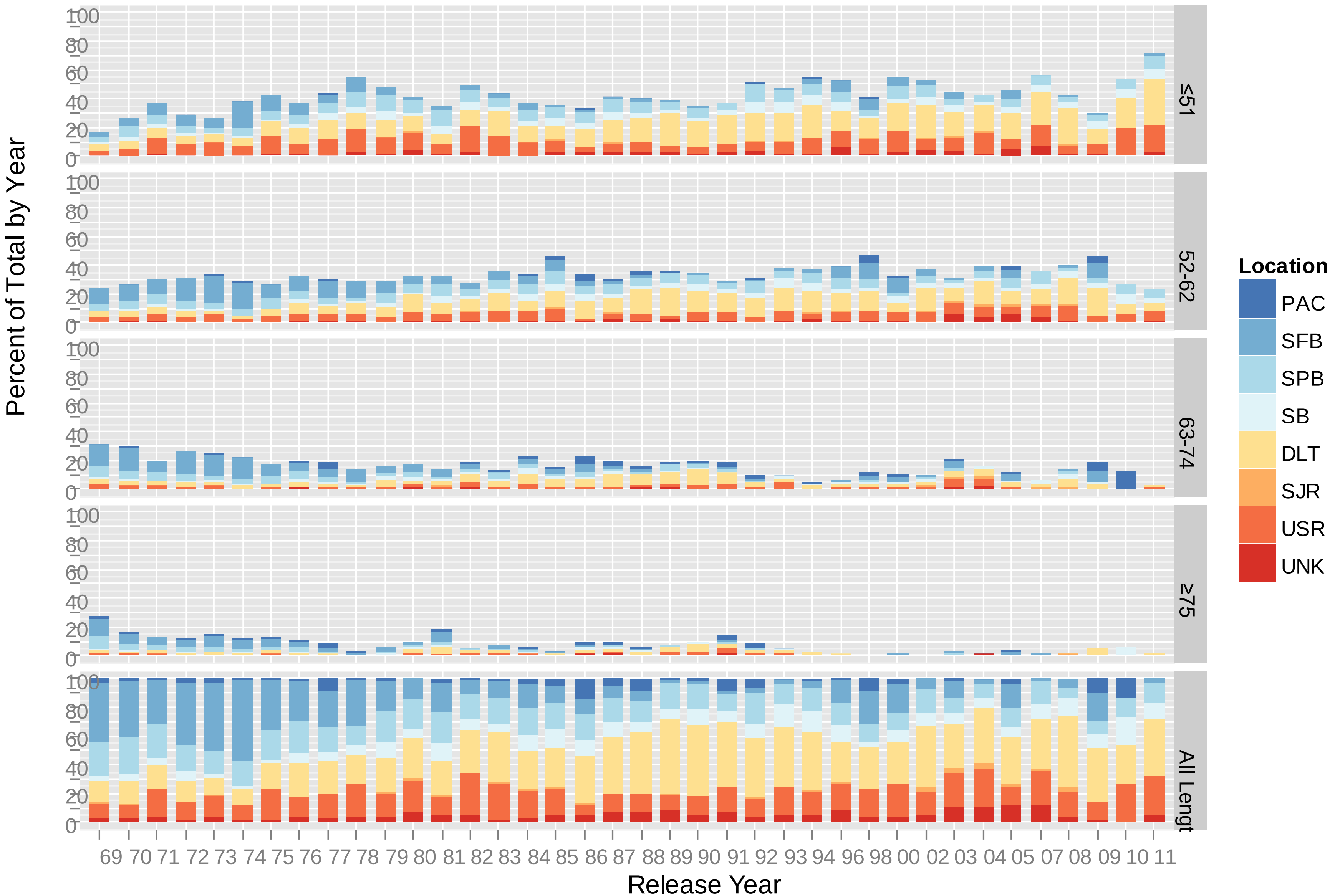

Percent of Total by Year
Release Year
≤51
52-62
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Location
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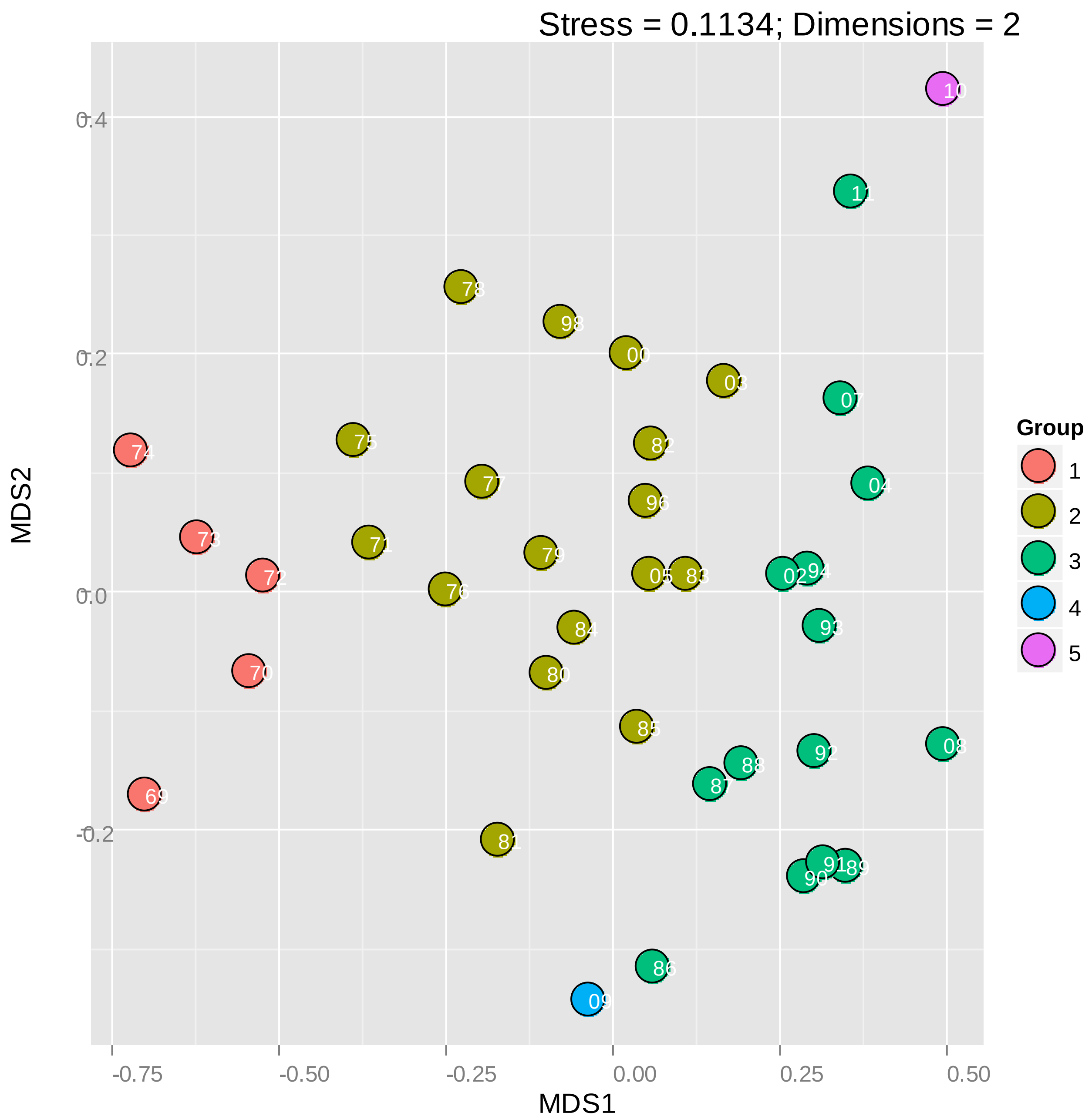

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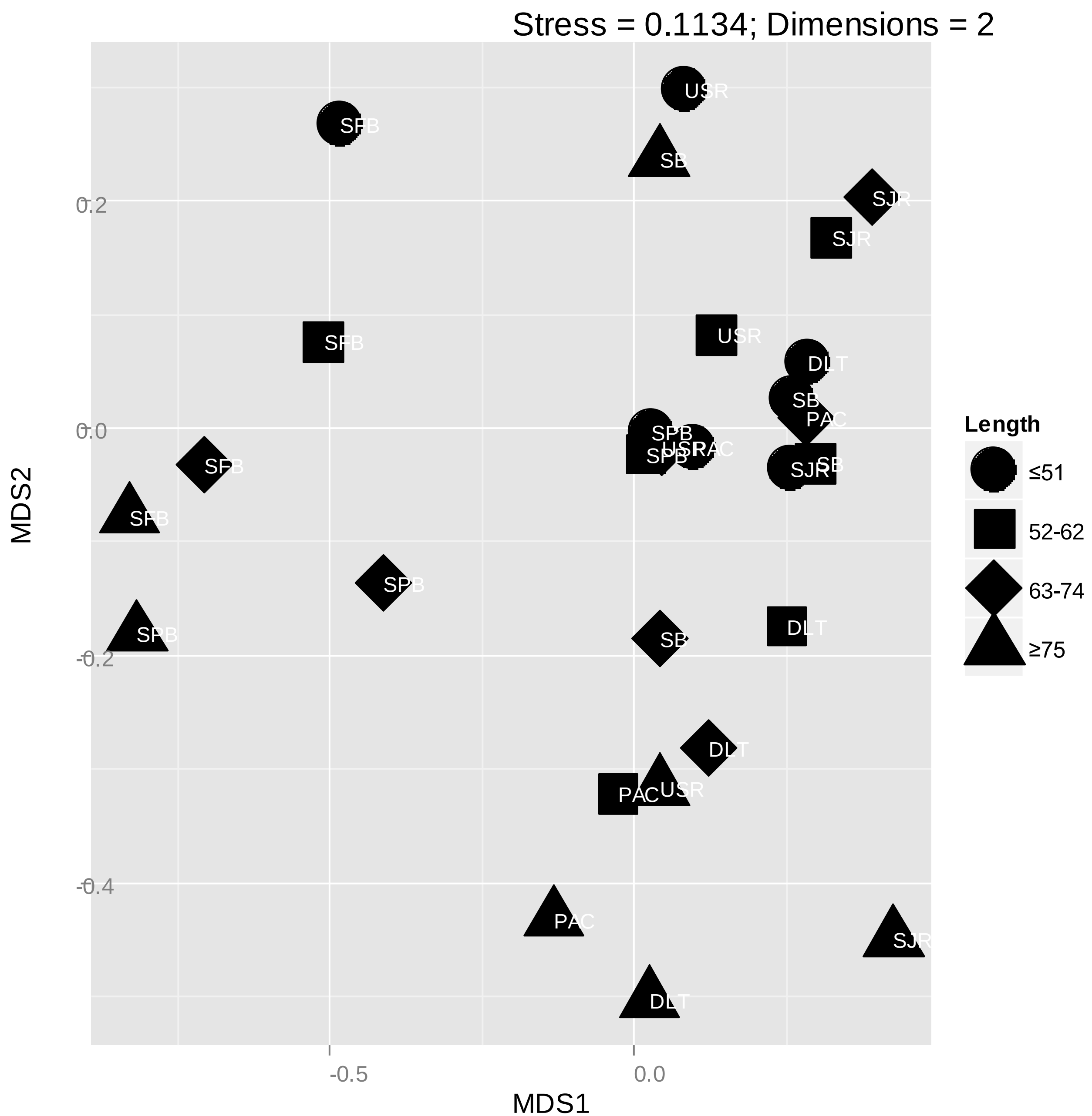

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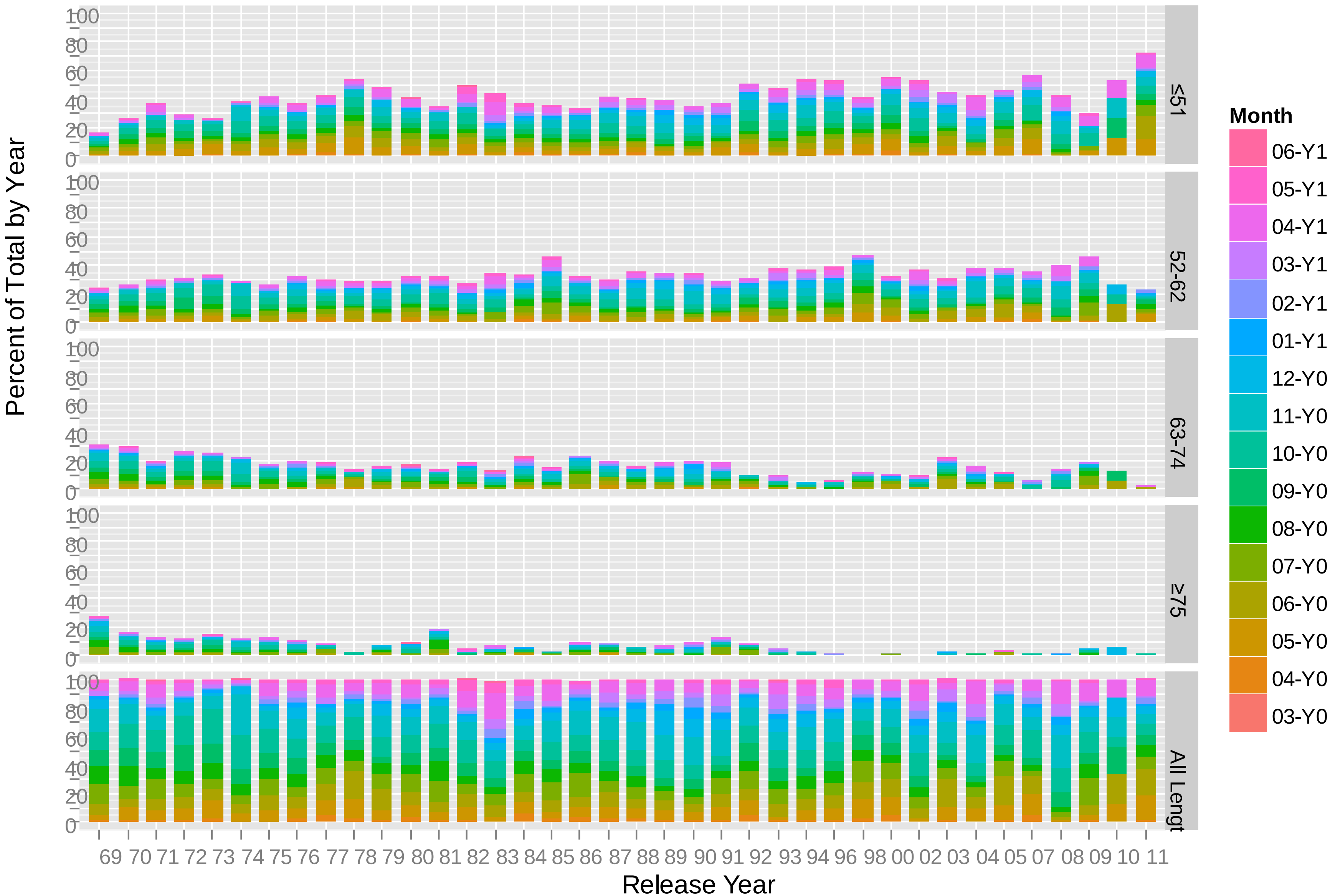

Percent of Total by Year
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09-Y0
08-Y0
07-Y0
06-Y0
05-Y0
04-Y0
03-Y0
≤51
52-62
63-74
≥75
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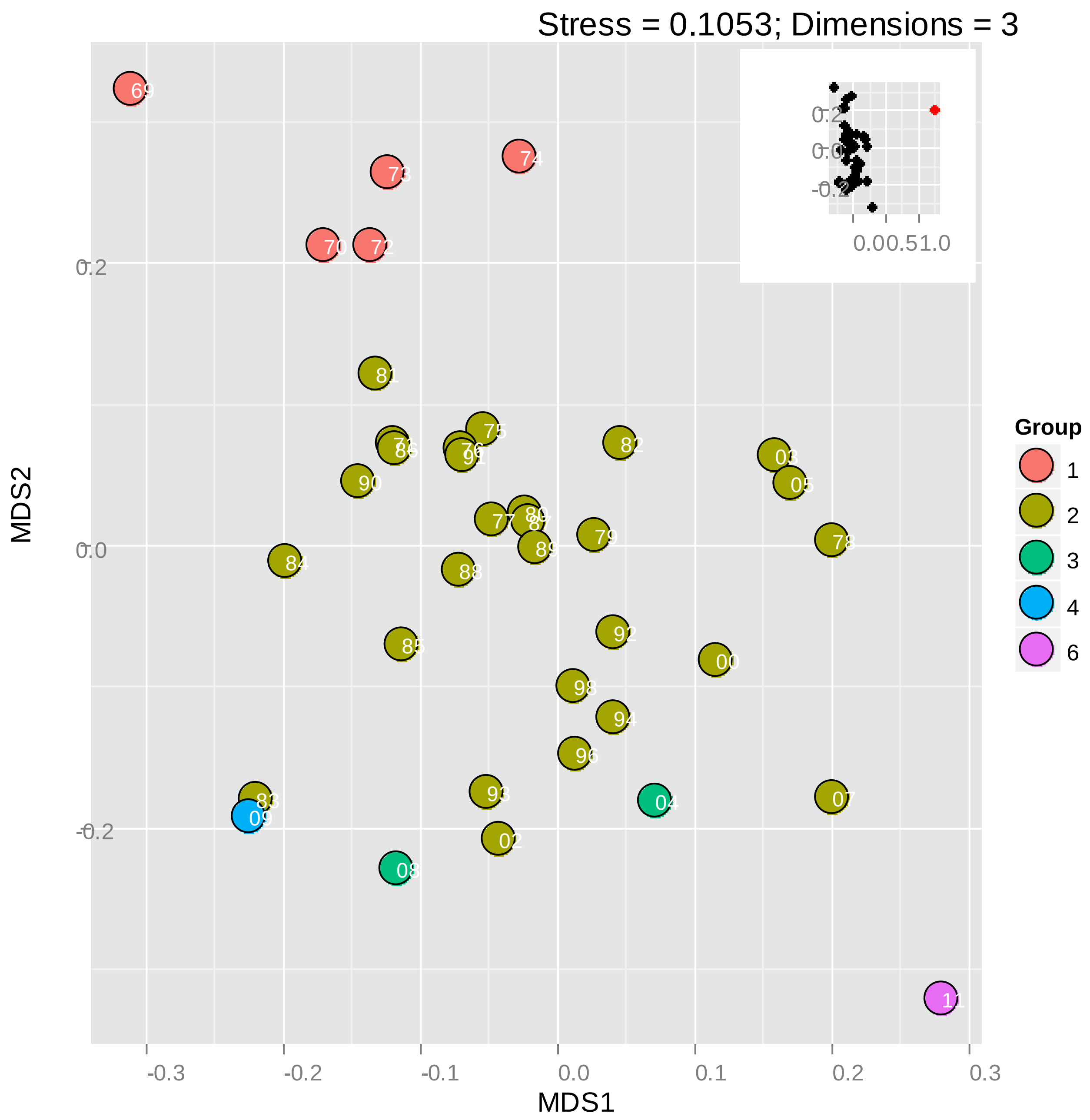
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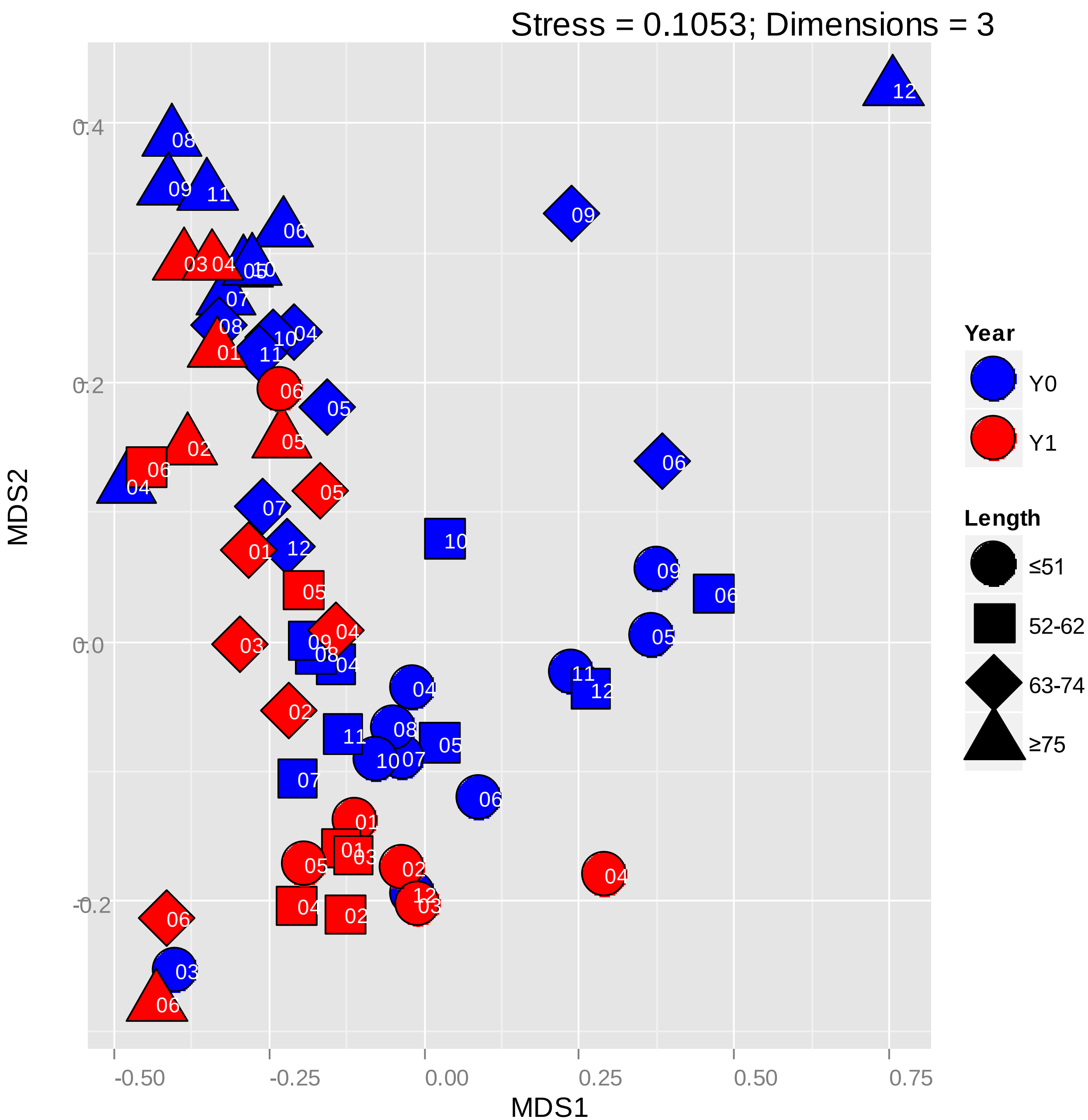
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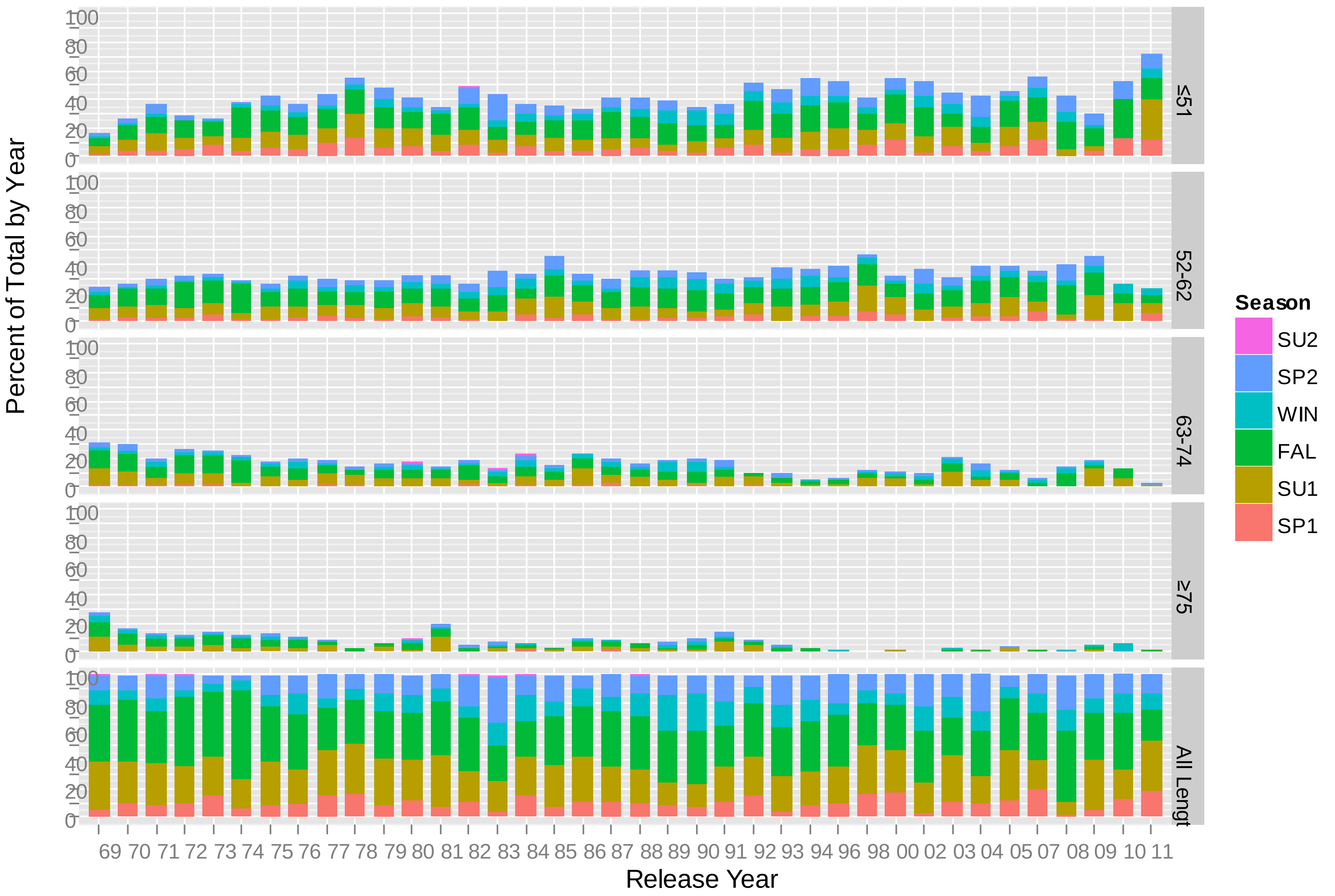

Percent of Total by Year
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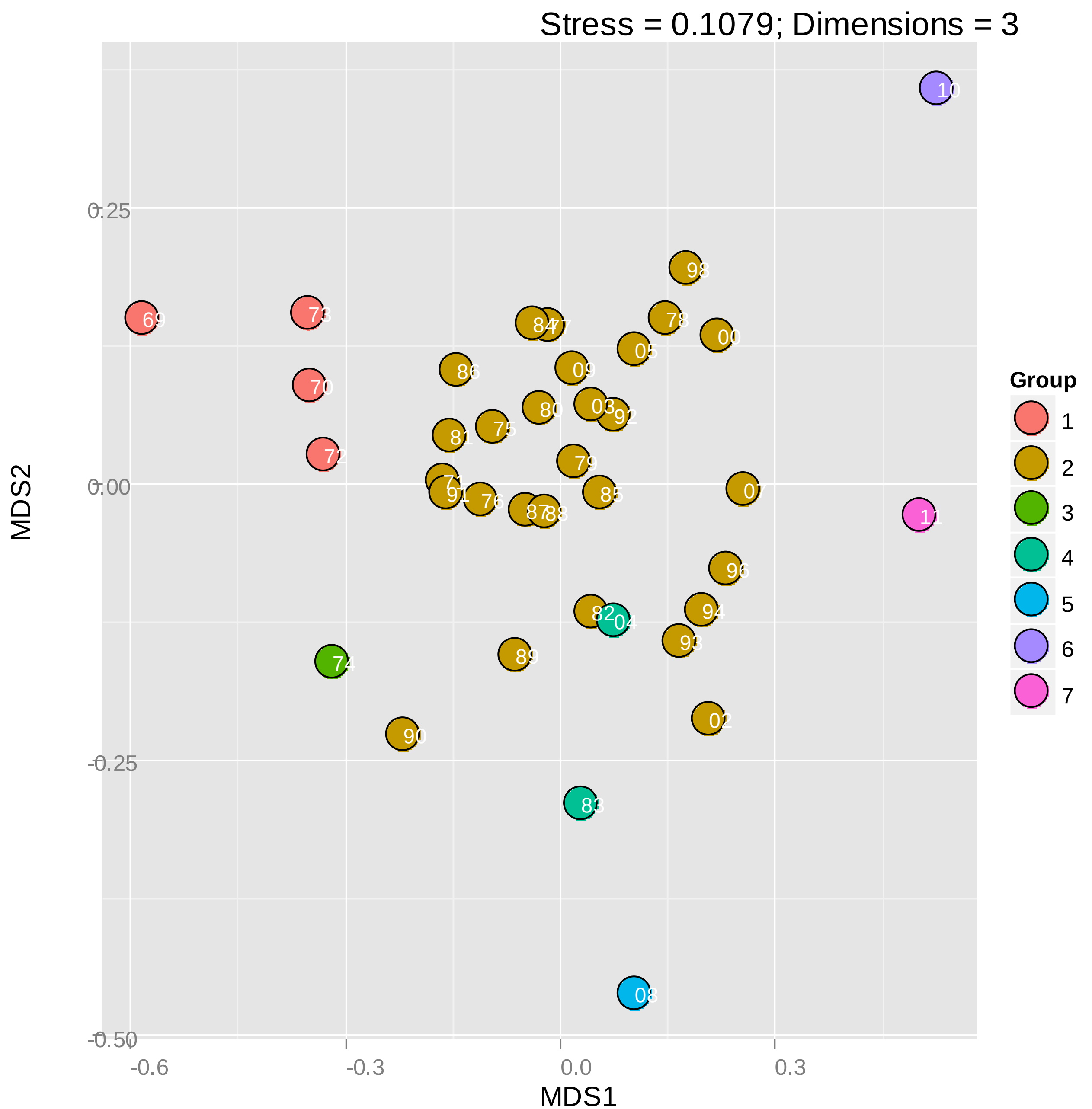

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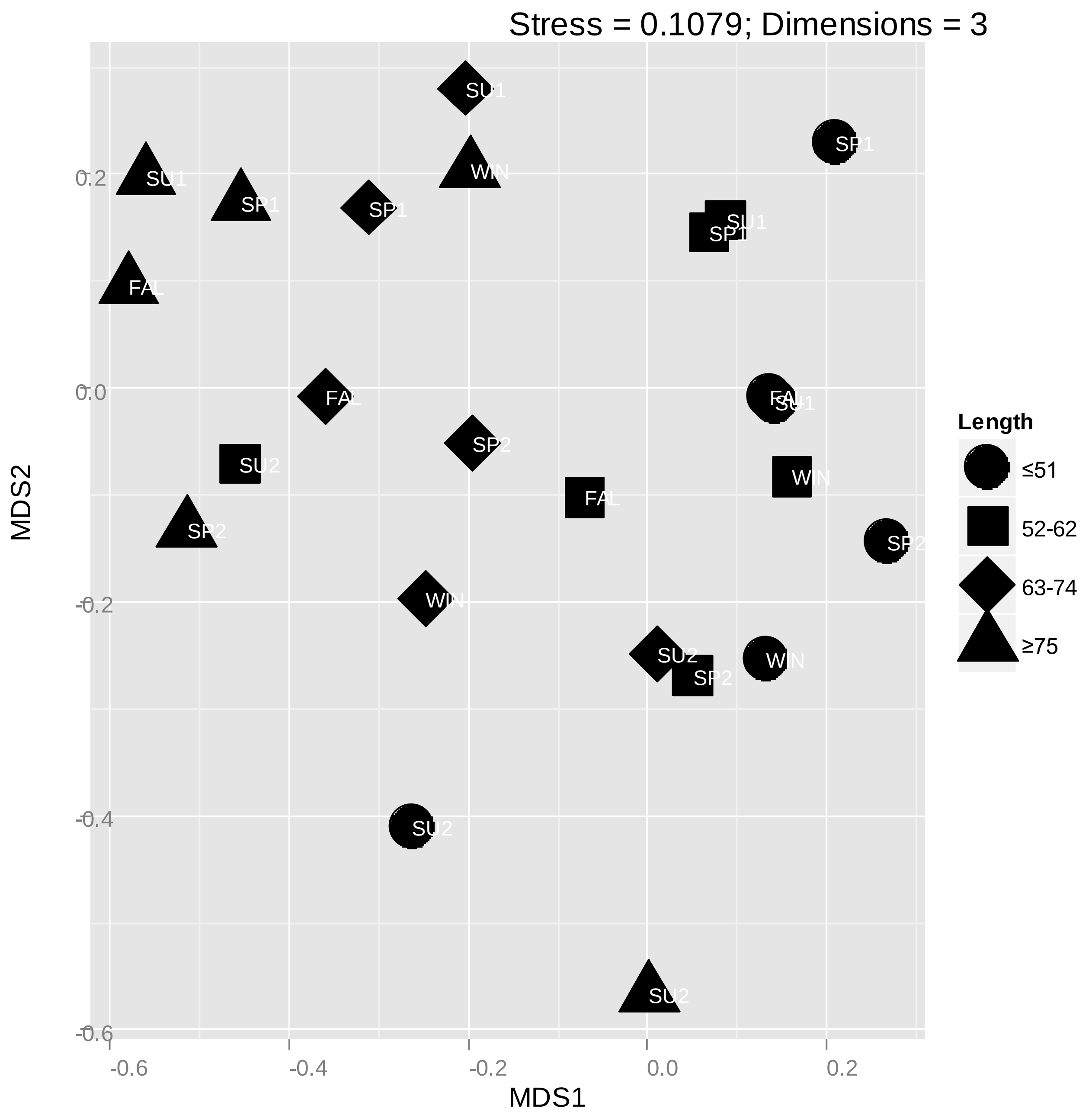

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SP2
WIN
SU2
SU2
Length
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63-74
≥75