Additional File 1: Detailed description of plots used to assess Pacific halibut bycatch survival in Bering Sea trawl fisheries

This supplementary file provides additional details on diagnostic plots used to infer survival or mortality based on accelerometer PSAT data. Our strategy for inferring bycatch survival or mortality of Pacific halibut was to characterize patterns in PSAT metrics for healthy fish, carcass tags, and weighted tags in the study area for eventual comparison with PSAT data from trawl-caught Pacific halibut. We developed diagnostic plots for PSAT data that included typical values for the 10 healthy fish caught on longlines in the study area and compared patterns from the carcass tags and weighted tags to patterns from healthy fish. Here we describe each type of plot and provide a detailed description of characteristics of "knockdowns" (KDs, count of abrupt changes in tilt) and "%tilt" (proportion of time spent active) for each control treatment.

1) Time series of knockdown and tilt data

For a live fish, the time series of all KD and %tilt values has a spiky appearance that reflects increases and decreases in the magnitude of activity over the course of each 24-hour period in the 60-day archival tag record (Figure 1). Halibut are almost always stationary at some point in a 24-hour period based on observations from accelerometer data provided by laboratory studies, free-ranging fish in Glacier Bay, Alaska (J. Nielsen, unpublished data) and free-ranging fish in Port Frederick, Alaska (Objectives 2 and 3 of this study). Although the magnitude of knockdown and tilt measurements varies from fish to fish (due to either calibration differences or fish swimming speeds), the "spiky" patterns are similar for all healthy fish. The maximum value for the KD metric per 2-hour bin is 127 and the maximum value of %tilt is 100.

To represent the range in magnitude of the daily "spikes" observed for healthy fish in the study area in the diagnostic plots, we added a polygon to the time series plots. Because most bycatch mortality is thought to occur in the first several weeks, we used data from only the first 20 days to calculate the range in average daily maximum for each of the 10 fish to provide a conservative estimate of activity during a potential recovery period. This polygon was added to individual plots of PSAT data from weighted tags and carcass tags. Only one weighted tag had KD values in the range observed for live fish, however weighted tags at Stations 1, 3, and 5 had spikes associated with tidal currents in the range of %tilt observed for healthy fish (Figure 2). Plots for carcasses had erratic patterns; tidal patterns were evident in the %tilt metric for the carcass tag at Station 1, but other carcass tags had consistently high values of %tilt not accompanied by KDs (Figure 3).

2) Daily sums of knockdown and tilt measurements

The total number of knockdowns and tilt per day provides an indication of change in activity over multiple days. In addition to a pattern of increasing and decreasing activity levels within a given day, halibut can also gradually increase and decrease their activity levels over multiple days. Acceleration data from fish in the laboratory and in Glacier Bay studies indicates that activity tends to increase and decrease over approximately 10 day periods (J. Nielsen, unpublished data).

To represent the range in maximum daily totals of KD and %tilt observed for healthy fish in the plots, we added a polygon that represents the range in average daily maximum KD and %tilt values using only the first 20 days of data. These polygons were added to individual plots for weighted tags and carcass tags. An overall trend of increasing activity over time is apparent for the healthy fish, but increases and decreases in activity over multiple days are also evident (Figure 4). Therefore, tags that show increasing and decreasing activity over a period of days followed by several days of lower activity are consistent with the activity pattern of a live Pacific halibut.

3) Cumulative Distribution Functions

Cumulative Distribution Function (CDF) plots provide a way to visualize the distribution of knockdown and tilt values from healthy fish for comparison with carcass tags and weighted tags. CDFs for each healthy fish were obtained by calculating quantile values from 0 to 1 in increments of 0.01. The mean CDF and 95% C.I. were calculated from the values of all 10 control fish at each quantile (Figure 5). Polygons that represent the 95% C.I. (dark gray) and range (light gray) of CDFs for healthy fish were added to plots to allow comparisons of carcass and weighted tag data with patterns from healthy fish. For example, the distribution of KD values for all four carcass tags, shown in each plot by a thick dashed line, was much lower than for the healthy fish. However, %tilt values were similar to healthy fish for Station 1 and considerably higher than values observed for healthy fish at Stations 2 and 5 (Figure 6).

4) Heat maps (activity by time of day)

As observed in the time series and daily sum plots, halibut tend to have regular increases and decreases in activity. Heat maps provide another way visualize temporal patterns (e.g., diel, tidal, or semi-lunar) by time of day (Y axis) for each day in the archival data set (X axis). In these plots, values of KD and %tilt for each time bin are color coded, where dark colors represent low activity and light colors represent high activity. To standardize the color coding among data sets, values above the 95^{th} quantile for all healthy fish combined were coded in yellow (e.g., > 50 KD and > 30 %tilt). Dawn and dusk are indicated by horizontal lines (the lower line is dusk, the upper line is dawn) and everything between the two lines is night. Therefore, afternoon is represented in the lower portion of each heat map, night-time is the middle, and morning to mid-day is the top portion (00:00 UTC is equivalent to 16:00 local time).

Temporal patterns were clearly evident in the heat maps for both KD and %tilt in healthy fish (Figure 7). For some fish, tidal patterns were present in the %tilt metric but not KD in the first week (e.g., Fish #5), suggesting some %tilt observations during that time period may have been caused by tidal currents. In contrast, the only temporal pattern observed for the carcass-tagged fish was a tidal pattern in the %tilt metric at Station 1 (Figure 8).

5) Knockdown and tilt values recorded for the last 5 days

Plots of KD and %tilt for the last 5 days of each data set are helpful for determining when KD and %tilt values are consistent with live or dead fish. KD and %tilt metrics tend to increase and decrease in tandem when fish are active based on the hourly subset analysis of detailed data from Port Frederick fish (shown in Figure 6 of the main manuscript), though the relative magnitudes of each metric may differ depending on the type of activity (e.g. hopping vs. sustained swimming). Plots for healthy fish in the Bering Sea also indicate that KD and %tilt generally track each other for live fish (Figure 9). In contrast, plots for carcass tags reveal either %tilt measurements that are not accompanied by KDs or an absence of KD or %tilt activity (Figure 10). The tidal pattern in %tilt for the carcass tag deployed at Station 1 is also evident in this plot.

6) Knockdown vs. tilt

Plots of knockdown vs. tilt can help identify patterns that are characteristic of survival or mortality. When a Pacific halibut is active, increased values of both knockdown and tilt will be observed, though the ratio of knockdowns to tilt may change depending on the type of behavior (e.g., intermediate values of knockdowns and low values of tilt indicate the hopping activity mode, whereas very high values of both knockdown and tilt indicate the sustained swimming activity mode).

To represent a typical range of KD vs. tilt ratios for healthy fish, we discretized values of KD and %tilt in a matrix with increments of 1 (e.g., 100 columns x 127 rows) and calculated the sum of observations within each bin for all healthy fish combined. Then we plotted a contour that contained 95% of the observations. A polygon that represents a simplified version of the contour was added to each plot. The ratio of KD versus %tilt tends to increase and decrease on a daily basis, which reflects a general tendency

toward regular periods of inactivity for halibut. For healthy fish, this results in a pattern of ratio values that extend out of and return to the origin at regular intervals and a typical range of KD vs. %tilt (Figure 11). However, for tags deployed on carcasses, values of KD versus %tilt are often outside of this range (Figure 12).

Assessing survival using plots

A page with the 10 diagnosis plots is generated for each data set to be assessed. The page is then examined to determine whether the KD and %tilt values from the data set examined are typical of a healthy fish in the study area (Figure 13) or a carcass tag (Figure 14). KD and %tilt values from the data set are also compared to plots for weighted tags in the release area to confirm potential effects of tidal currents on the %tilt metric (Figure 15).

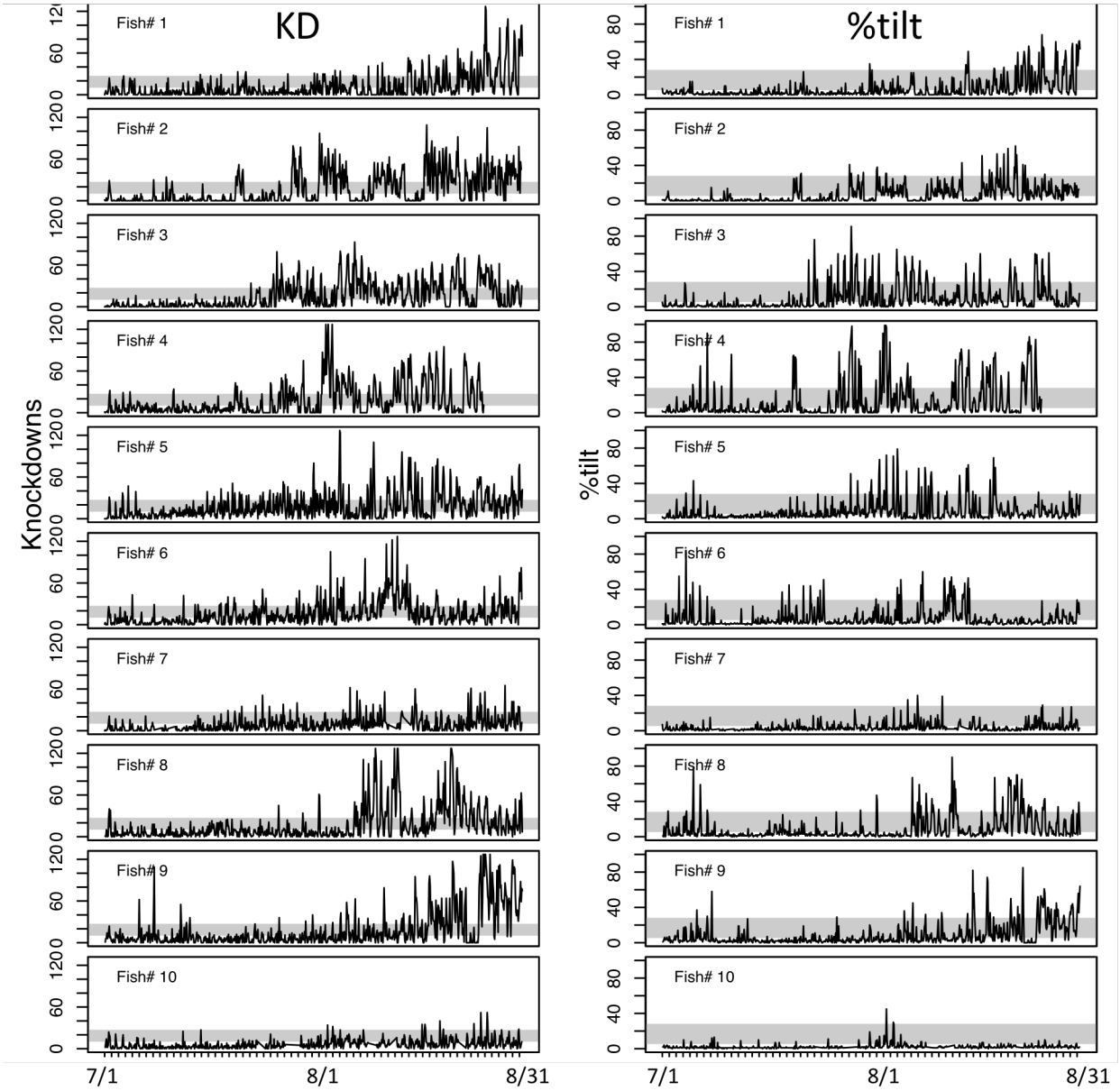

Figure 1. Time series of knockdowns (left column) and %tilt (right column) per 2-hour bin for the full 60-day archival tag records of the 10 healthy fish. Gray polygons represent the range in average daily maximum values for the first 20 days for healthy fish (e.g., a rough indication of the peak knockdown and tilt values that might be expected of a live fish during a recovery period).

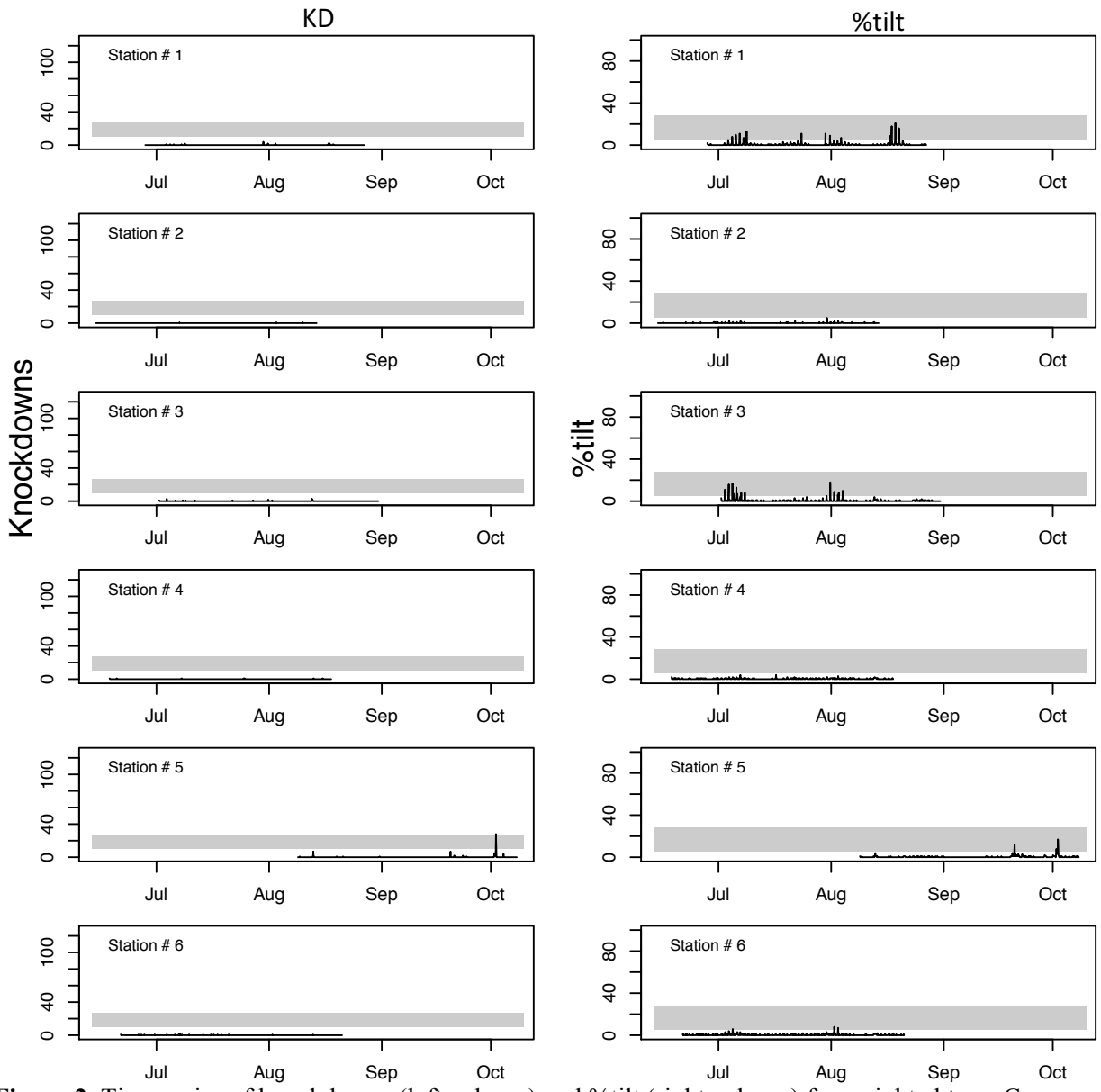

Figure 2. Time series of knockdowns (left column) and %tilt (right column) for weighted tags. Gray polygons represent the range in average daily maximum values observed for the first 20 days of the 10 healthy fish data sets (e.g., a rough indication of the peak knockdown and tilt values that might be expected of a live fish during low-level activity).

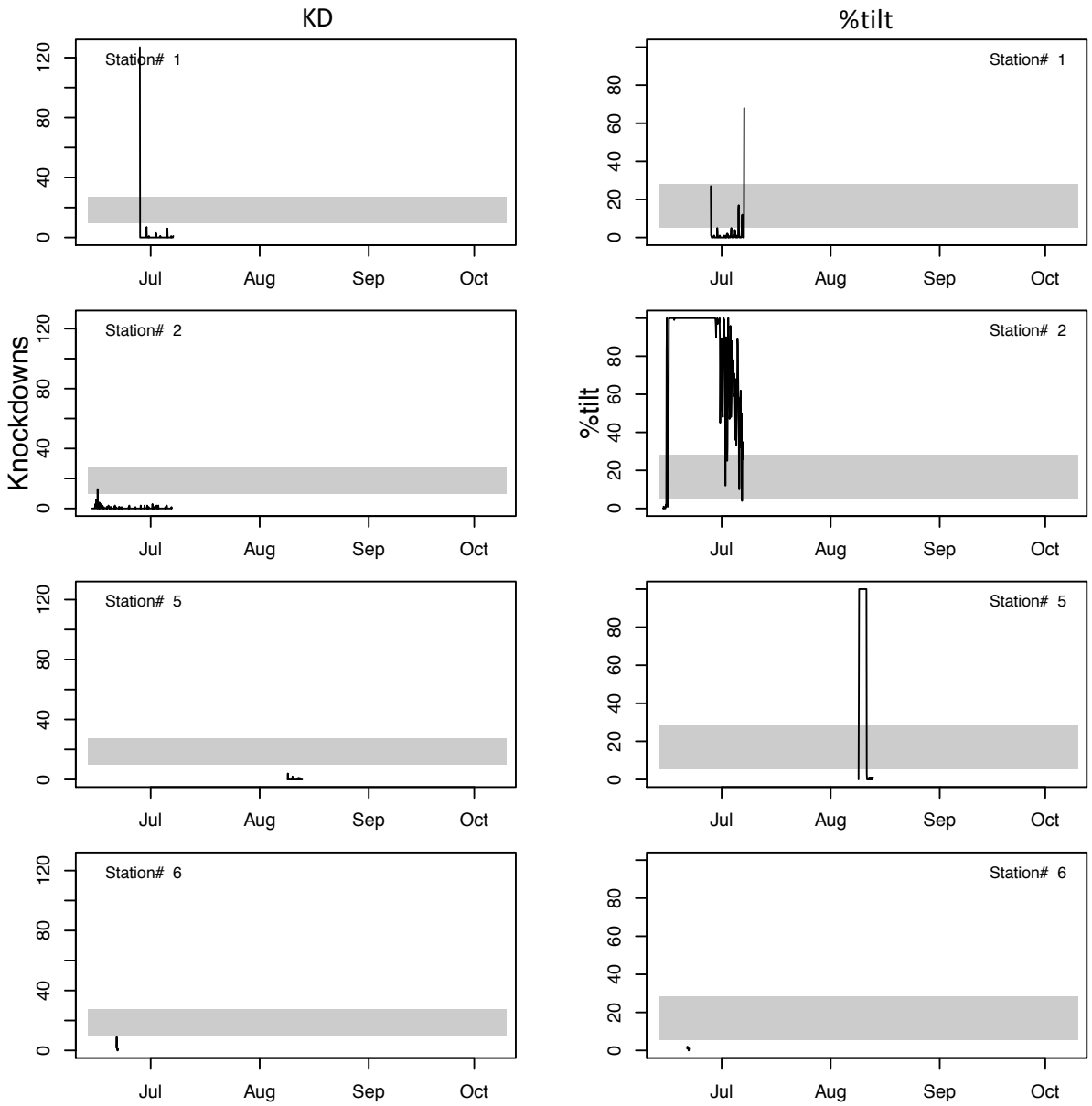

Figure 3. Time series of knockdowns (left column) and %tilt (right column) for carcass tags. Gray polygons represent the range in average daily maximum values observed for the first 20 days of the 10 healthy fish data sets (e.g., a rough indication of the peak knockdown and tilt values that might be expected of a live fish during low-level activity).

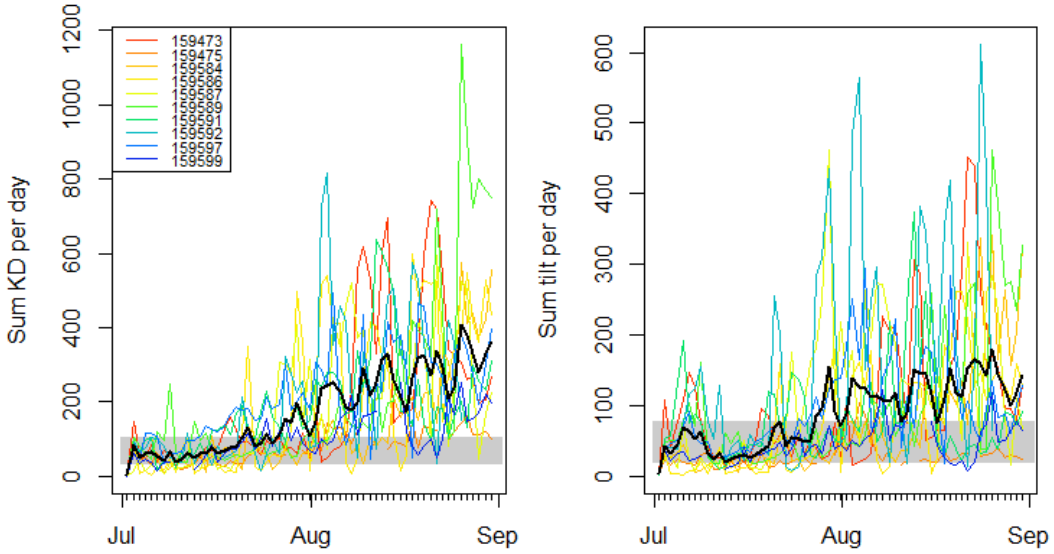

Figure 4. Daily sum of knockdown (left) and daily sum of %tilt (right) each day for 10 healthy fish (individual fish shown by different colors). The average maximum value for all 10 fish on each day is represented by the thick black line. The range in average daily maximum values among all healthy fish during the first 20 days is represented by the gray rectangle.

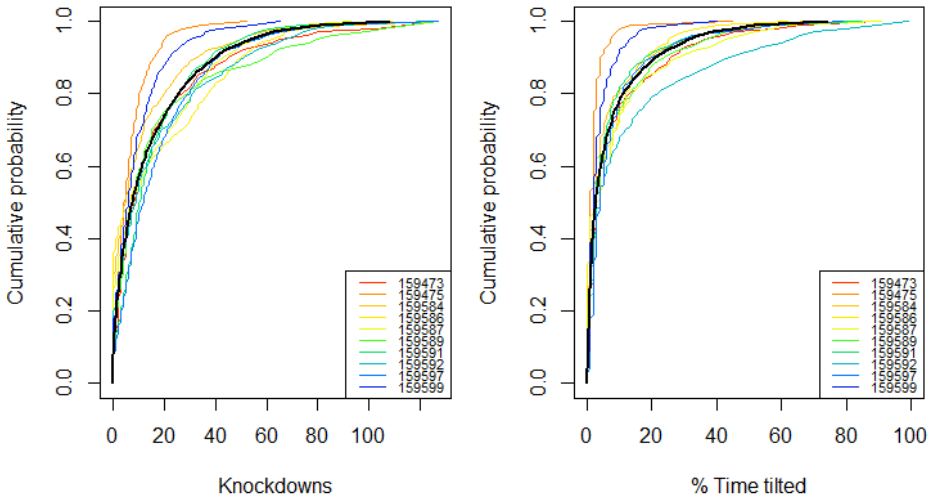

Figure 5. Cumulative distribution functions (CDFs) for knockdown (left) and %tilt (right) for 10 healthy fish. Individual fish are shown by different line colors. The mean CDF for all 10 fish is shown by a thick black line.

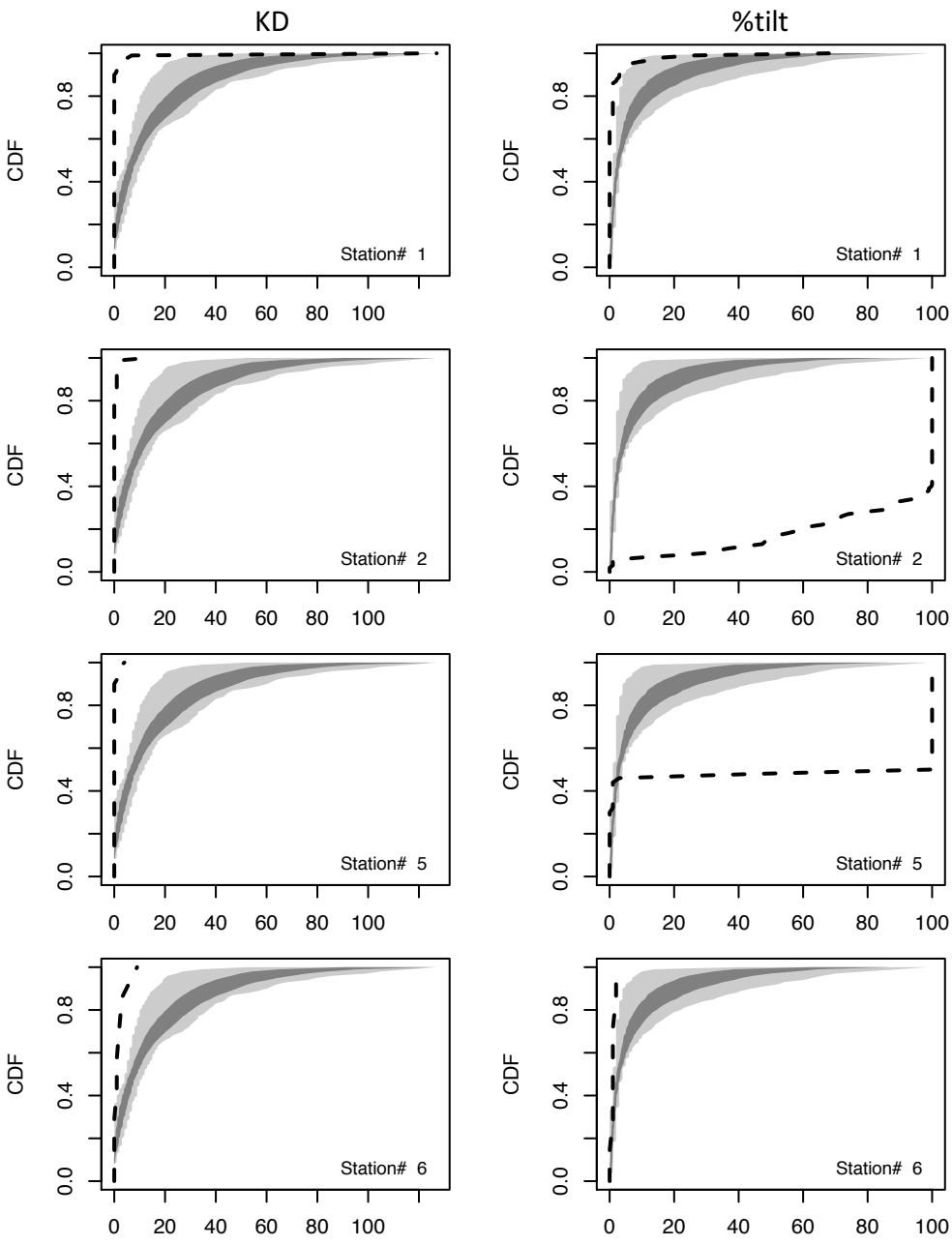

Figure 6. CDFs of knockdown (left) and %tilt (right) for four carcass tags (thick dashed lines). Dark gray polygons indicate 95% C.I. for mean of healthy fish CDFs, light gray polygons indicate range of CDFs for healthy fish.

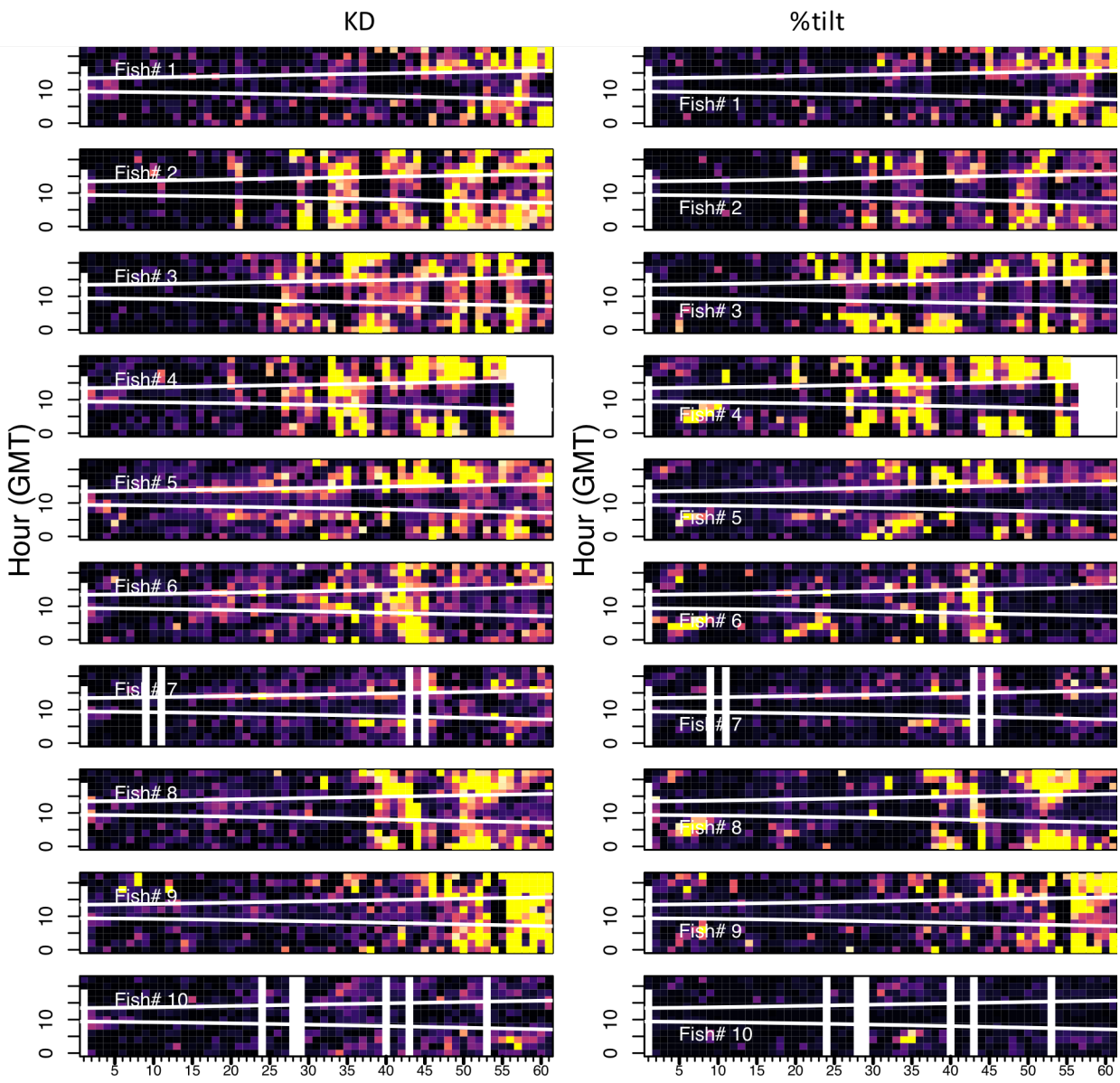

Figure 7. Heat maps of knockdown (KD, left) and %tilt (right) values for all 10 healthy fish by hour of day (Y axis) for each deployment day (X axis). Low activity values are shown in dark colors, high in light colors, and yellow cells indicate the highest values (knockdowns > 50 and %time tilted > 30 %). See Figure 8 for color coding legend for KD and %tilt values. White horizontal lines indicate time of dusk (lower line) and dawn (upper line). White vertical spaces indicate days when no PSAT data were available.

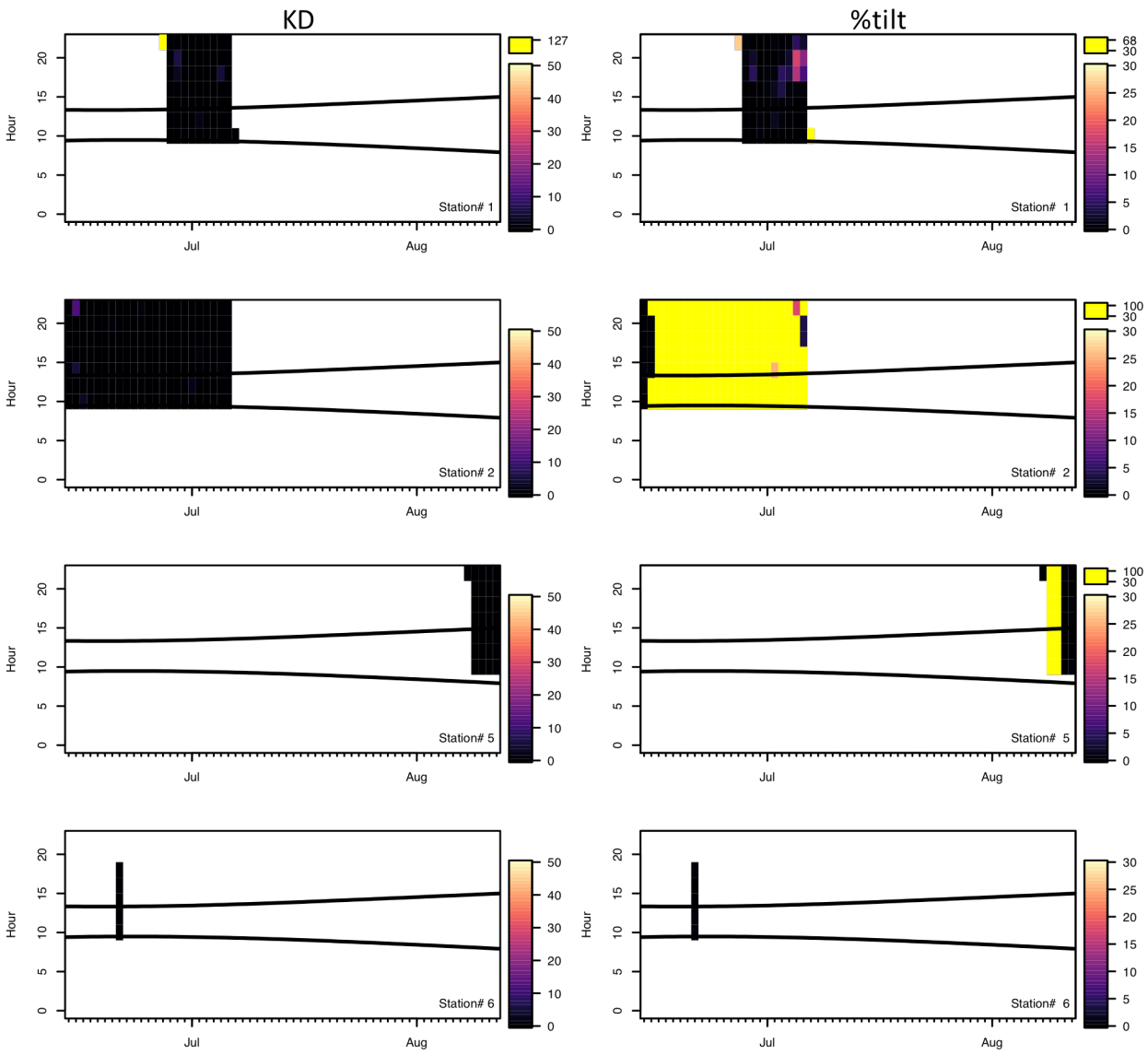

Figure 8. Heat maps for carcass tags. Low activity values are shown in dark colors and high activity by light colors. Yellow cells indicate the highest values (knockdowns > 50 and %time tilted > 30 %). Black lines indicate time of dusk (lower line) and dawn (upper line).

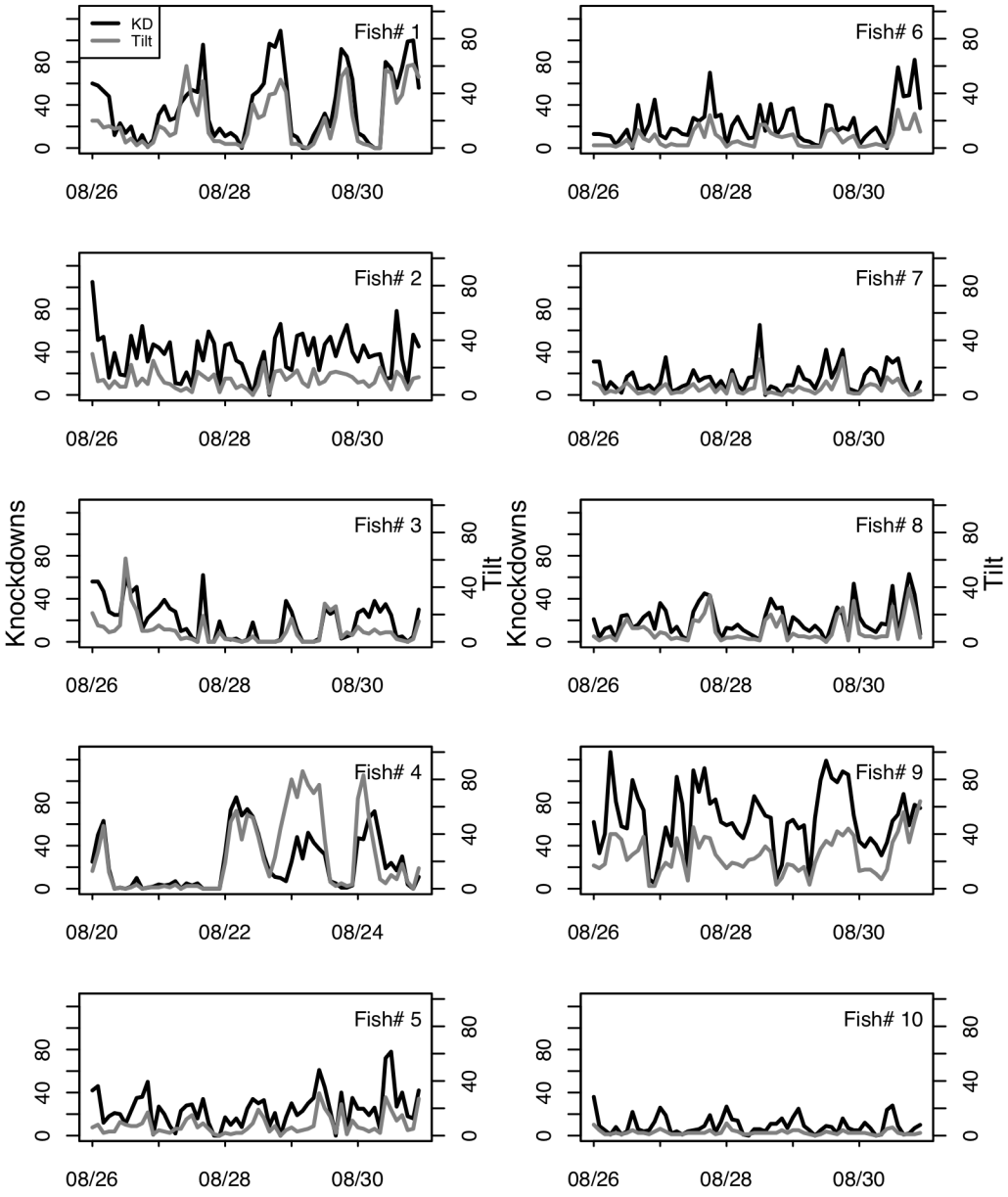

Figure 9. KD (black line) and %tilt (gray line) measurements during the last 5 days of the data set for all 10 healthy fish.

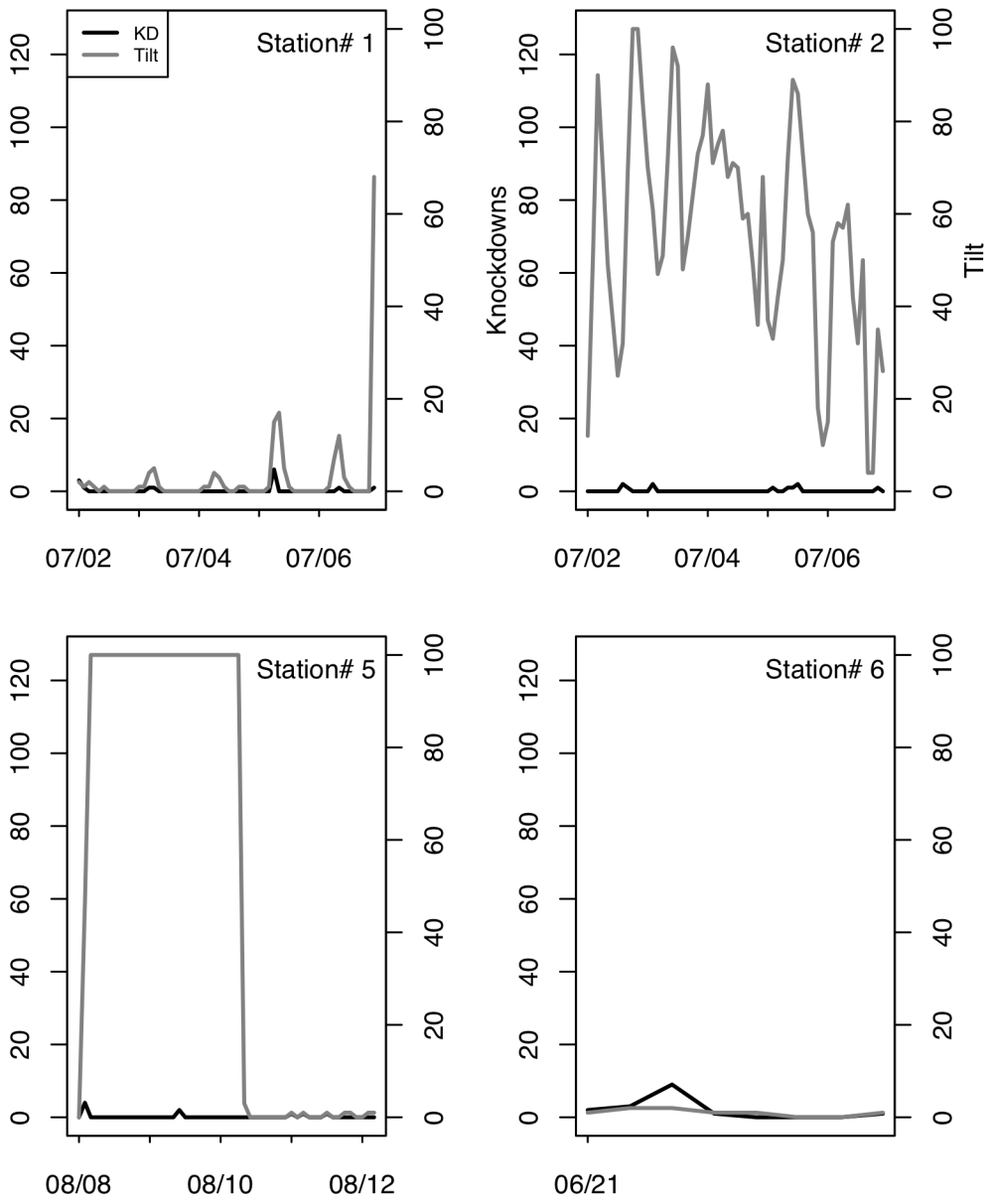

Figure 10. KD (black line) and %tilt (gray line) measurements during the last 5 days of the data set for carcass tags.

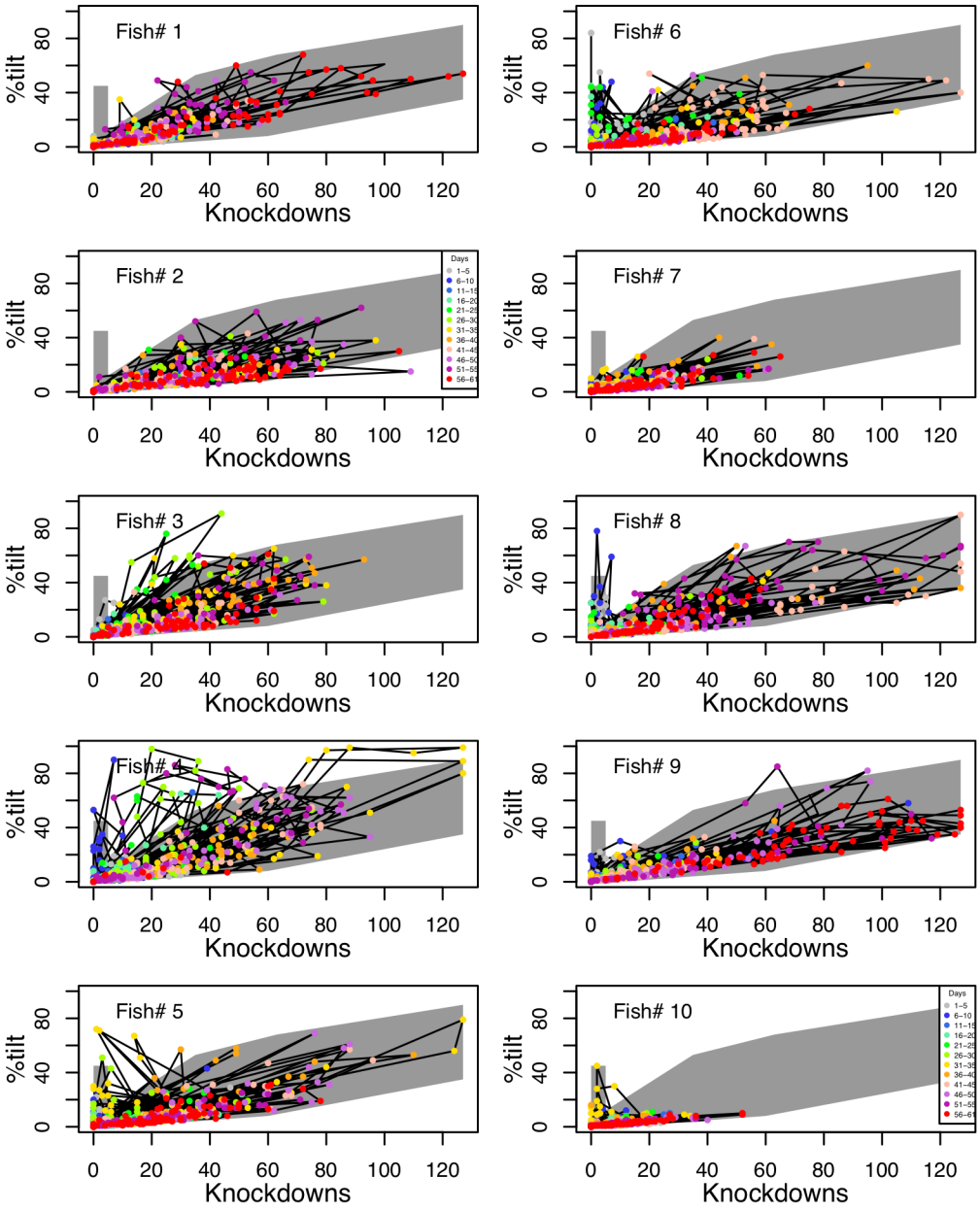

Figure 11. Knockdown versus %tilt values (2-hour bins) for healthy fish. Subsequent observations are linked by black lines, and observations are color coded by number of days following release. Gray polygons indicate 95% quantile area for all 10 healthy fish combined.

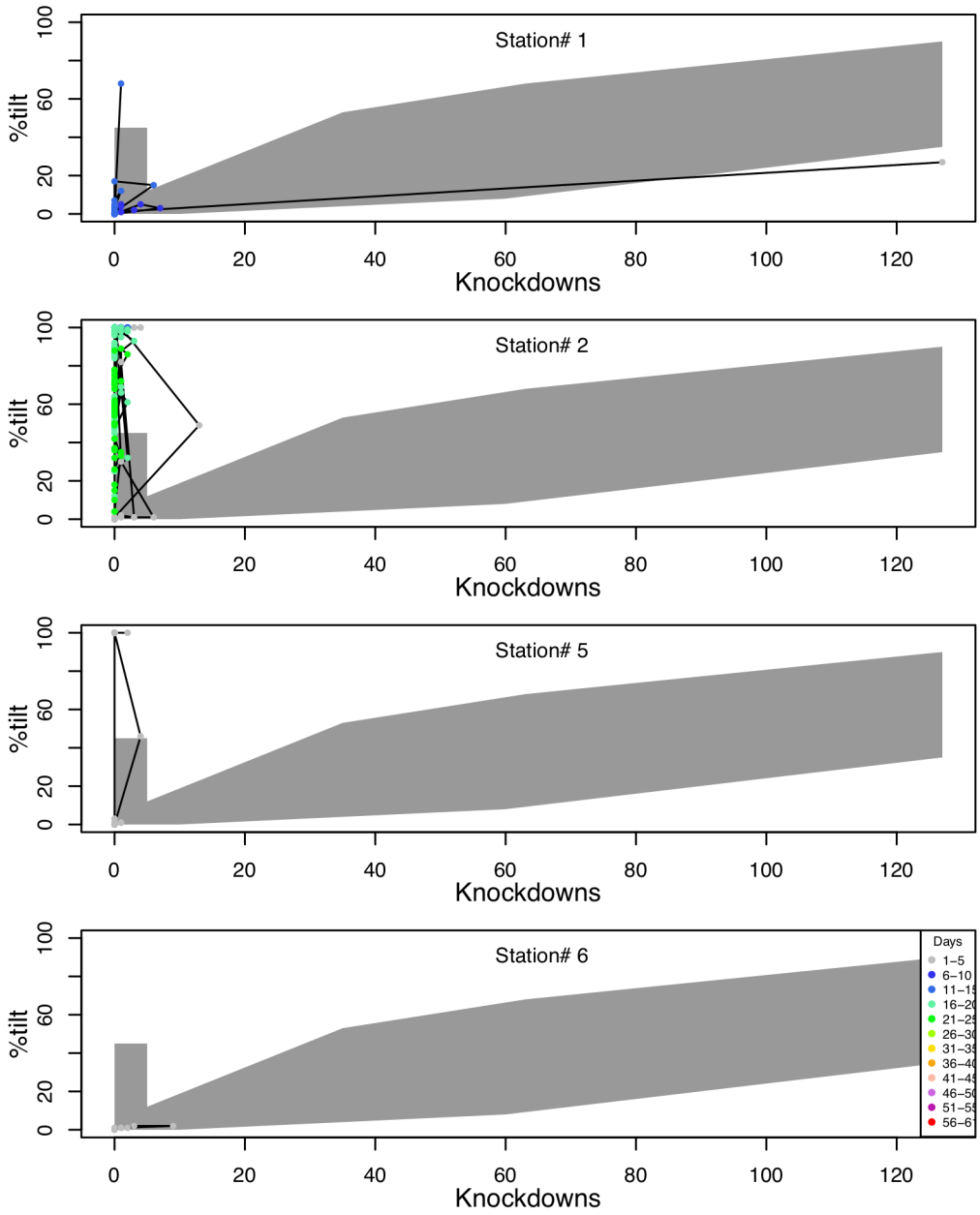

Figure 12. Knockdown vs. %tilt values (2-hour bins) for carcass tags. Subsequent observations are linked by black lines, and observations are color coded by number of days following release. Gray polygon indicates 95% quantile area for all 10 healthy fish combined.

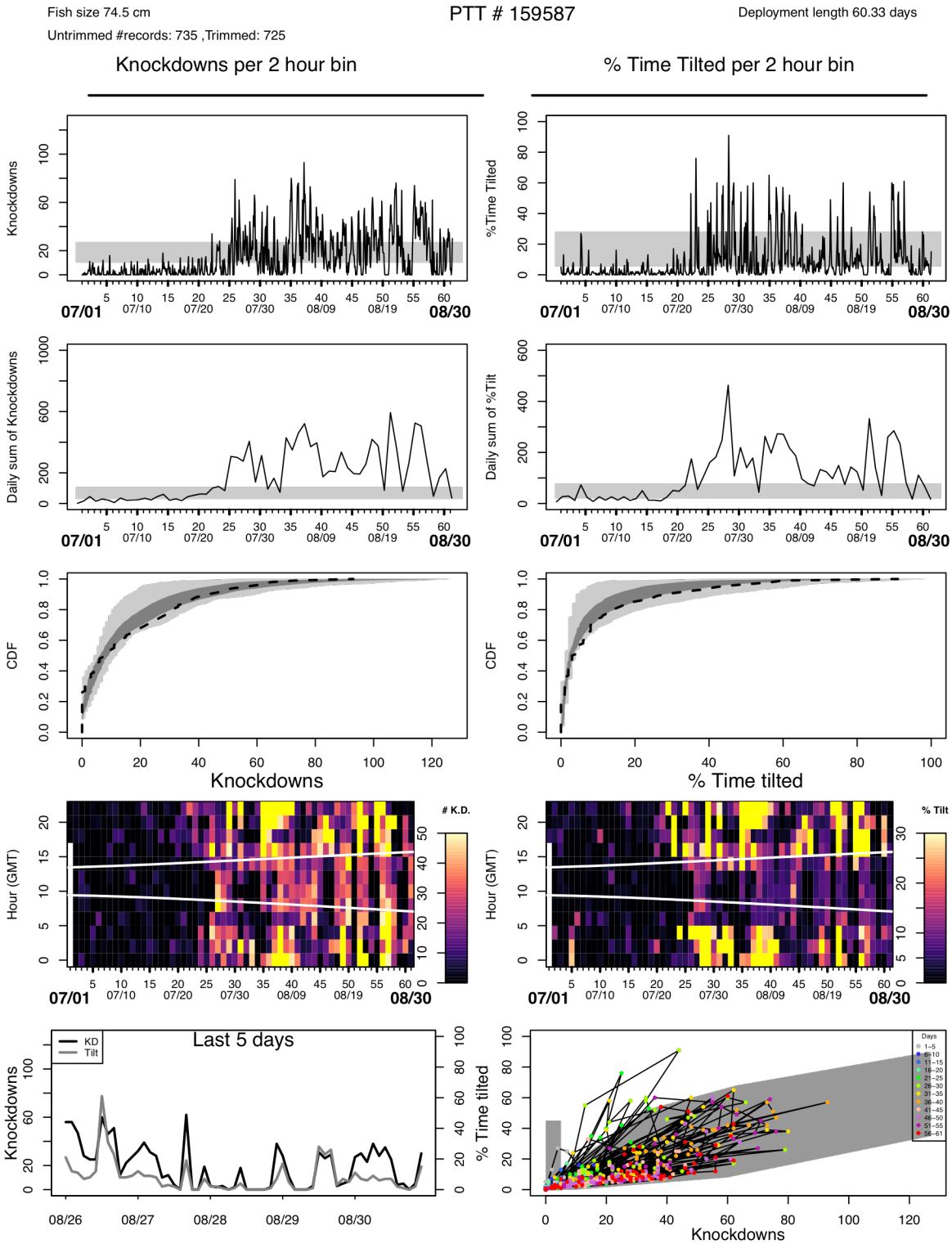

Figure 13. Example of diagnosis plots for a healthy fish. For time series of raw data, time series of daily sums, CDFs, and KD vs. %tilt plots, gray polygons indicate range of typical values observed for healthy fish.

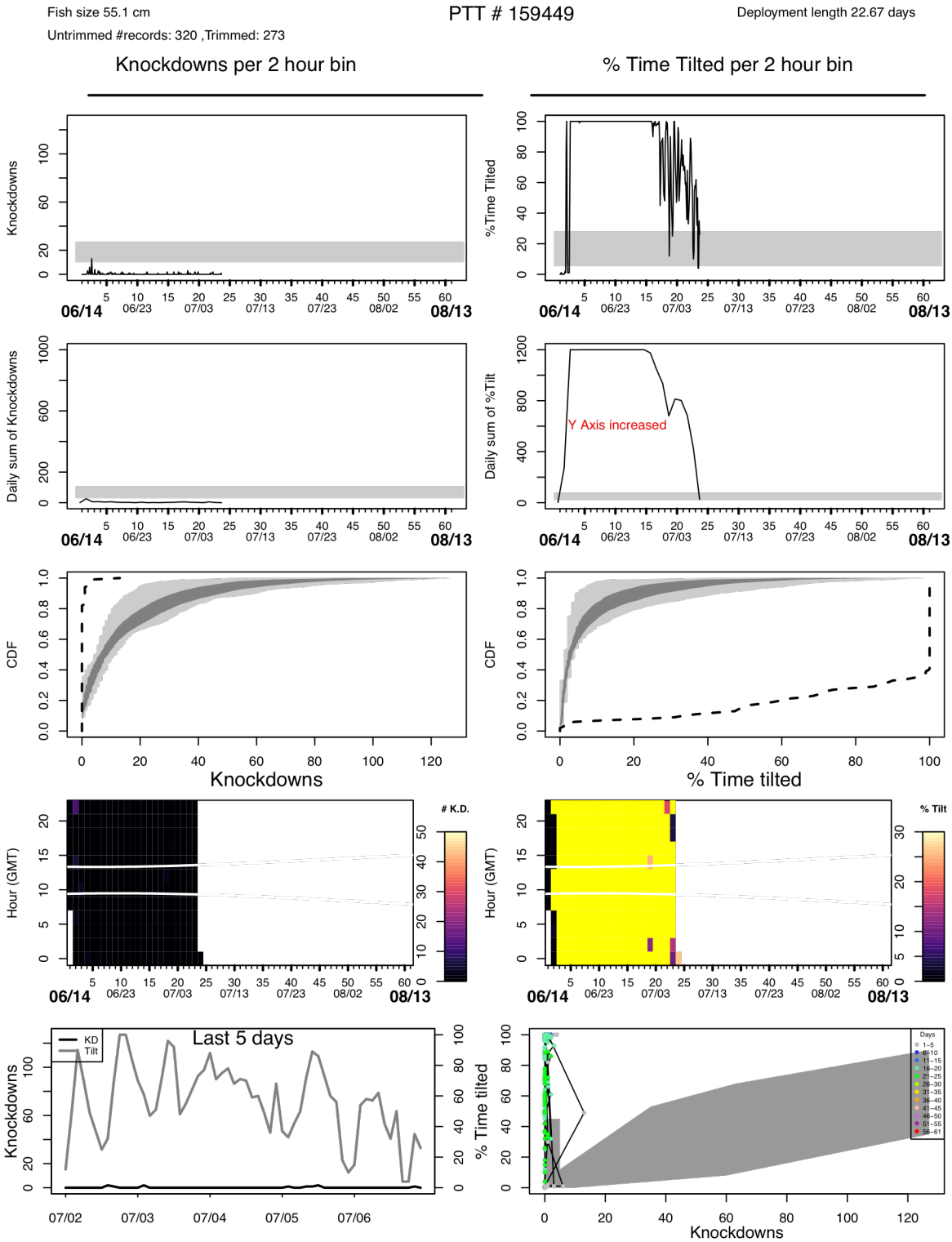

Figure 14. Example of diagnosis plots for the carcass tag deployed at Station 2. For time series of raw data, time series of daily sums, CDFs, and KD vs. tilt plots, gray polygons indicate range of typical values observed for healthy fish.

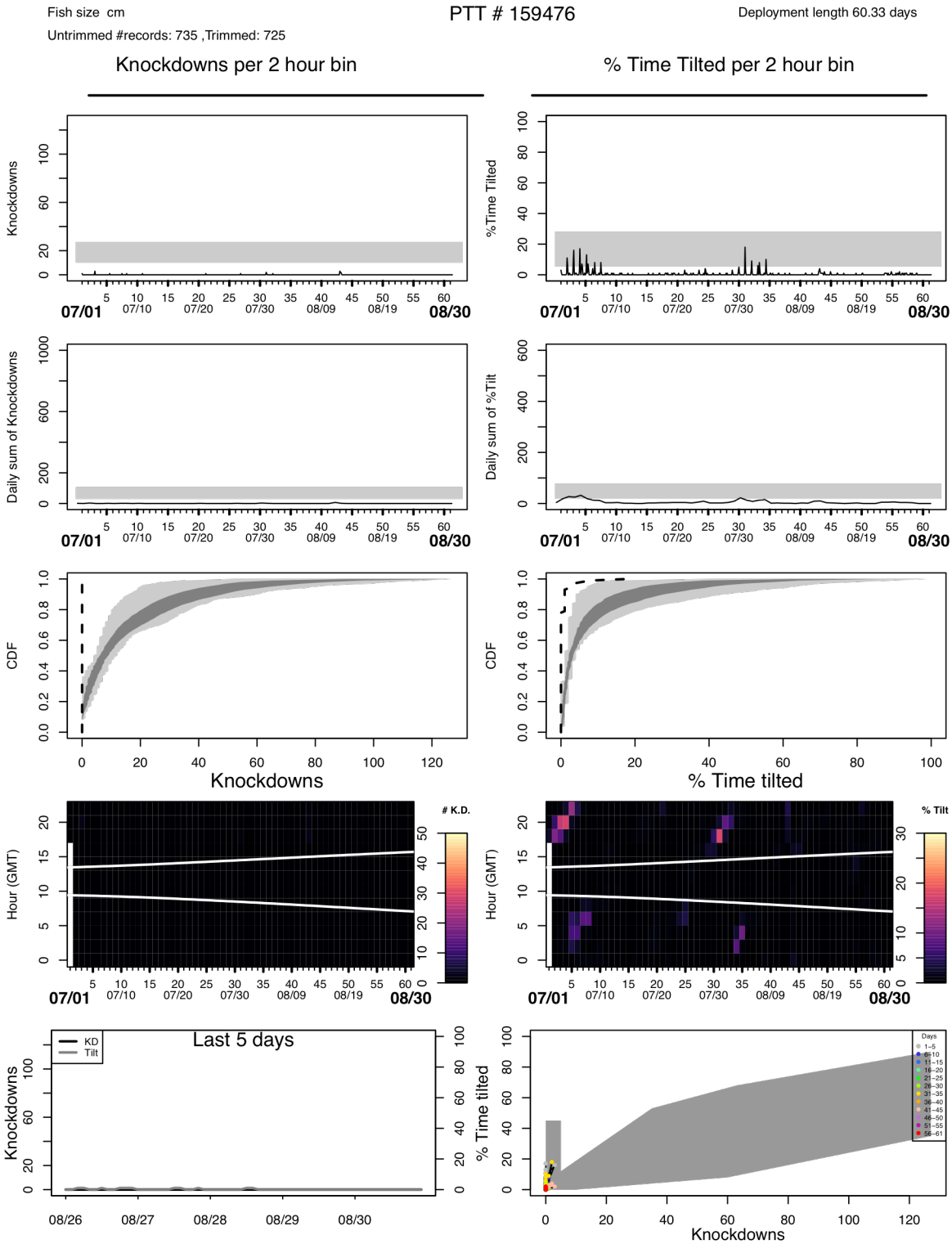

Figure 15. Example of diagnosis plots for the weighted tag deployed at Station 3 (where tags on healthy fish were also deployed). For time series of raw data, time series of daily sums, CDFs, and KD vs. tilt plots, gray polygons indicate range of typical values observed for healthy fish.