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Modesto Irrigation District
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February 8, 2016

Filed via Electronic Submittal (E-File)

Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street NE
Washington, DC 20426

Subject: Don Pedro Hydroelectric Project, FERC Project No. 2299
Submittal of Final Chinook Salmon Otolith Study Report (W&AR-11)

Dear Secretary Bose:

On March 16, 2015, Turlock Irrigation District and Modesto Irrigation District (collectively, the "Districts"), co-licensees of the Don Pedro Hydroelectric Project on the Tuolumne River, provided the draft Chinook Salmon Otolith Study Report (W&AR-11) to relicensing participants for a 30-day review and comment period. On April 14, 2015, comments were received from Dr. Rachel Johnson, who oversaw the Chinook Salmon Otolith Study laboratory analysis. On April 23, 2015, the U.S. Fish and Wildlife Service provided comments. The Districts have reviewed all comments. Responses to comments from Dr. Johnson and the U.S. Fish and Wildlife Service are provided in an errata sheet and Attachment B, respectively. In addition, revisions to the study report were made based on the comments.

The Districts herewith file with FERC the final Chinook Salmon Otolith Study Report. If you have any questions about this filing, please contact the undersigned at the addresses and telephone numbers listed below.

Sincerely,

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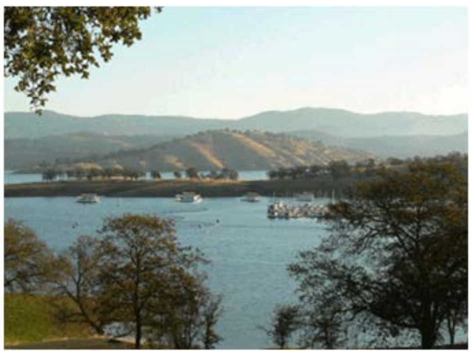
Attachment: Chinook Salmon Otolith Study Report (W&AR-11)

CHINOOK SALMON OTOLITH STUDY
STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299



Prepared for:
Turlock Irrigation District – Turlock, California
Modesto Irrigation District – Modesto, California

Prepared by:
Stillwater Sciences

February 2016

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This study has involved the cooperation and participation of the
California Department of Fish and Wildlife
and Dr. Rachel Johnson and Dr. Anna Sturrock
at the University of California Davis,
Department of Animal Science.

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Errata Sheet

The following changes were made to the draft study report in response to comments provided by Dr. Rachel Johnson (University of California, Davis), who oversaw the laboratory analysis conducted for W&AR-11.

Section 5.2, pages 5-11 to 5-12, various. Language to clarify that otolith data have been used to *estimate* juvenile outmigrant age, size, and growth rates, such that the reader does not misinterpret study results as actual juvenile outmigration size data rather than a reconstruction of the early life history of surviving adults.

Section 5.3.2, pages 5-20 to 5-33, including new figures 5.3-4 to 5.3-9. Inclusion of juvenile outmigrant monitoring data corresponding to water years (WYs) represented in the study, in order to better support statements about emigration patterns and variations in phenotypic contributions estimated from otolith data.

Section 6.3, page 6-3. Clarification of study findings regarding the low representation of early emigrating fry contributions to subsequent escapement.

Section 6.3, page 6-3. Reference to recent study results from the Stanislaus River, California, regarding phenotypic contributions to escapement during wet and dry water year types, as further context for the Tuolumne River results reported in this study.

Chinook Salmon Otolith Study
Study Report

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List of Acronyms

ac................................acres

ACEC.........................Area of Critical Environmental Concern

AF ....acre-feet

ACOE.........................U.S. Army Corps of Engineers

AFY............................acre-feet per year

ADA...........................Americans with Disabilities Act

ALJ.............................Administrative Law Judge

APE............................Area of Potential Effect

ARMR........................Archaeological Resource Management Report

BA..............................Biological Assessment

BAWSCA ....Bay Area Water Supply Conservation Agency

BDCP.........................Bay-Delta Conservation Plan

BEA............................Bureau of Economic Analysis

BLM...........................U.S. Department of the Interior, Bureau of Land Management

BLM-S ....Bureau of Land Management – Sensitive Species

BMI............................Benthic macroinvertebrates

BMP...........................Best Management Practices

BO..............................Biological Opinion

CAISO........................California Independent System Operators

CalEPPC ....California Exotic Pest Plant Council

CalSPA.......................California Sports Fisherman Association

CALVIN ....California Value Integrated Network

CAS............................California Academy of Sciences

CASFMRA ....California Chapter of the American Society of Farm Managers and Rural Appraisers

CCC............................Criterion Continuous Concentrations

CCIC..........................Central California Information Center

CCSF..........................City and County of San Francisco

CCVHJV....................California Central Valley Habitat Joint Venture

CD..............................Compact Disc

CDBW........................California Department of Boating and Waterways

CDEC........................California Data Exchange Center

CDFA........................California Department of Food and Agriculture

CDFG........................California Department of Fish and Game (as of January 2013, Department of Fish and Wildlife)

CDMG.......................California Division of Mines and Geology

CDOF........................California Department of Finance

CDP...........................Census Designated Place

CDPH........................California Department of Public Health

CDPR........................California Department of Parks and Recreation

CDSOD.....................California Division of Safety of Dams

CDWR.......................California Department of Water Resources

CE ....California Endangered Species

CEII...........................Critical Energy Infrastructure Information

CEQA........................California Environmental Quality Act

CESA ....California Endangered Species Act

CFR...........................Code of Federal Regulations

cfs..............................cubic feet per second

CGS...........................California Geological Survey

CMAP ....California Monitoring and Assessment Program

CMC..........................Criterion Maximum Concentrations

CNDDB.....................California Natural Diversity Database

CNPS.........................California Native Plant Society

CORP ....California Outdoor Recreation Plan

CPI ....Consumer Price Index

CPUE ....Catch Per Unit Effort

CRAM.......................California Rapid Assessment Method

CRLF.........................California Red-Legged Frog

CRRF ....California Rivers Restoration Fund

CSAS.........................Central Sierra Audubon Society

CSBP.........................California Stream Bioassessment Procedure

CT ....Census Tract

CT ....California Threatened Species

CTR...........................California Toxics Rule

CTS ....California Tiger Salamander
CUWA ....California Urban Water Agency
CV ....Contingent Valuation
CVP............................Central Valley Project
CVPIA........................Central Valley Project Improvement Act
CVRWQCB ....Central Valley Regional Water Quality Control Board
CWA ....Clean Water Act
CWD ....Chowchilla Water District
CWHR........................California Wildlife Habitat Relationship
CWT...........................hundredweight
Districts......................Turlock Irrigation District and Modesto Irrigation District
DLA ....Draft License Application
DPRA.........................Don Pedro Recreation Agency
DO..............................Dissolved Oxygen
DPS ....Distinct Population Segment
EA ....Environmental Assessment
EC ....Electrical Conductivity
EDD ....Employment Development Department
EFH............................Essential Fish Habitat
EIR ....Environmental Impact Report
EIS..............................Environmental Impact Statement
ENSO ....El Nino – Southern Oscillation
EO ....Executive Order
EPA............................U.S. Environmental Protection Agency
ERS ....Economic Research Service (USDA)
ESA............................Federal Endangered Species Act
ESRCD.......................East Stanislaus Resource Conservation District
ESU............................Evolutionary Significant Unit
ET...............................Evapotranspiration
EVC............................Existing Visual Condition
EWUA........................Effective Weighted Useable Area
FEMA ....Federal Emergency Management Agency
FERC..........................Federal Energy Regulatory Commission

FFS.............................Foothills Fault System
FL...............................Fork length
FMU...........................Fire Management Unit
FMV...........................Fair Market Value
FOT............................Friends of the Tuolumne
FPC............................Federal Power Commission
FPPA..........................Federal Plant Protection Act
FPC............................Federal Power Commission
ft.................................feet
ft/mi............................feet per mile
FWCA........................Fish and Wildlife Coordination Act
FYLF..........................Foothill Yellow-Legged Frog
g..................................grams
GAMS........................General Algebraic Modeling System
GIS.............................Geographic Information System
GLO...........................General Land Office
GPM...........................Gallons per Minute
GPS............................Global Positioning System
HCP............................Habitat Conservation Plan
HHWP........................Hetch Hetchy Water and Power
HORB........................Head of Old River Barrier
HPMP.........................Historic Properties Management Plan
ILP..............................Integrated Licensing Process
IMPLAN....................Impact analysis for planning
I-O..............................Input-Output
ISR.............................Initial Study Report
ITA.............................Indian Trust Assets
kV...............................kilovolt
LTAM........................Long-Term Acoustic Monitoring
LTR............................Lower Tuolumne River
m................................meters
M&I............................Municipal and Industrial
MCL...........................Maximum Contaminant Level

mg/kg ....milligrams/kilogram
mg/L..........................milligrams per liter
mgd ....million gallons per day
mi ....miles
mi^2 ....square miles
MID...........................Modesto Irrigation District
MOU ....Memorandum of Understanding
MRP ....Monitoring and Reporting Program
MRWTP.....................Modesto Regional Water Treatment Plant
MSCS.........................Multi-Species Conservation Strategy
msl.............................mean sea level
MVA ....Megavolt Ampere
MW ....megawatt
MWh ....megawatt hour
mya............................million years ago
NAE ....National Academy of Engineering
NAHC ....Native American Heritage Commission
NAICS........................North America Industrial Classification System
NAS............................National Academy of Sciences
NASS ....National Agricultural Statistics Service (USDA)
NAVD 88...................North American Vertical Datum of 1988
NAWQA ....National Water Quality Assessment
NCCP ....Natural Community Conservation Plan
NEPA ....National Environmental Policy Act
ng/g ....nanograms per gram
NGOs ....Non-Governmental Organizations
NHI ....Natural Heritage Institute
NHPA.........................National Historic Preservation Act
NISC ....National Invasive Species Council
NMFS.........................National Marine Fisheries Service
NMP...........................Nutrient Management Plan
NOAA ....National Oceanic and Atmospheric Administration
NOI ....Notice of Intent

NPS ............................U.S. Department of the Interior, National Park Service
NRCS ....National Resource Conservation Service
NRHP..........................National Register of Historic Places
NRI.............................Nationwide Rivers Inventory
NTU ....Nephelometric Turbidity Unit
NWI............................National Wetland Inventory
NWIS ....National Water Information System
NWR ....National Wildlife Refuge
NGVD 29 ....National Geodetic Vertical Datum of 1929
O&M ....operation and maintenance
OEHHA.......................Office of Environmental Health Hazard Assessment
OID ....Oakdale Irrigation District
ORV ....Outstanding Remarkable Value
PAD............................Pre-Application Document
PDO............................Pacific Decadal Oscillation
PEIR ....Program Environmental Impact Report
PGA............................Peak Ground Acceleration
PHG............................Public Health Goal
PM&E ....Protection, Mitigation and Enhancement
PMF............................Probable Maximum Flood
PMP............................Positive Mathematical Programming
POAOR ....Public Opinions and Attitudes in Outdoor Recreation
ppb..............................parts per billion
ppm ....parts per million
PSP ....Proposed Study Plan
QA ....Quality Assurance
QC ....Quality Control
RA ....Recreation Area
RBP ....Rapid Bioassessment Protocol
Reclamation ...............U.S. Department of the Interior, Bureau of Reclamation
RM ....River Mile
RMP ....Resource Management Plan
RP...............................Relicensing Participant

RR..............................Recreation Resources
RSP ....Revised Study Plan
RST ....Rotary Screw Trap
RWF...........................Resource-Specific Work Groups
RWG ....Resource Work Group
RWQCB.....................Regional Water Quality Control Board
SC...............................State candidate for listing under CESA
SCD............................State candidate for delisting under CESA
SCE ....State candidate for listing as endangered under CESA
SCT ....State candidate for listing as threatened under CESA
SD1 ....Scoping Document 1
SD2 ....Scoping Document 2
SE...............................State Endangered Species under the CESA
SFP.............................State Fully Protected Species under CESA
SFPUC ....San Francisco Public Utilities Commission
SHPO ....State Historic Preservation Office
SIC ....Standard Industry Classification
SJR.............................San Joaquin River
SJRA ....San Joaquin River Agreement
SJRGA ....San Joaquin River Group Authority
SJTA ....San Joaquin River Tributaries Authority
SPD ....Study Plan Determination
SRA............................State Recreation Area
SRMA ....Special Recreation Management Area or Sierra Resource Management Area (as per use)
SRMP.........................Sierra Resource Management Plan
SRP ....Special Run Pools
SSC ....State species of special concern
ST...............................California Threatened Species under the CESA
STORET ....Storage and Retrieval
SWAMP.....................Surface Water Ambient Monitoring Program
SWAP ....Statewide Agricultural Model
SWE...........................Snow-Water Equivalent

SWP ....State Water Project
SWRCB.......................State Water Resources Control Board
TAC.............................Technical Advisory Committee
TAF.............................thousand acre-feet
TC ....Travel Cost
TCP ....Traditional Cultural Properties
TDS ....Total Dissolved Solids
TID.............................Turlock Irrigation District
TIN............................. Triangular Irregular Network
TMDL.........................Total Maximum Daily Load
TOC............................Total Organic Carbon
TPH ....Total Petroleum hydrocarbon
TRT ....Tuolumne River Trust
TRTAC ....Tuolumne River Technical Advisory Committee
UC ....University of California
UCCE.........................University of California Cooperative Extension
USDA.........................U.S. Department of Agriculture
USDOC ......................U.S. Department of Commerce
USDOI .......................U.S. Department of the Interior
USFS ..........................U.S. Department of Agriculture, Forest Service
USFWS ......................U.S. Department of the Interior, Fish and Wildlife Service
USGS .........................U.S. Department of the Interior, Geological Survey
USR............................Updated Study Report
UTM...........................Universal Transverse Mercator
VAMP ....Vernalis Adaptive Management Plan
VELB ....Valley Elderberry Longhorn Beetle
VES ....Visual Encounter Surveys
VRM ....Visual Resource Management
W&AR ....Water & Aquatic Resources
WMP ....Waste Management Plan
WPT ....Western Pond Turtle
WSA...........................Wilderness Study Area
WSIP ....Water System Improvement Program

WTP ....Willingness to Pay

WWTP ....Wastewater Treatment Plant

WY.............................water year

μS/cm ....microSiemens per centimeter

1.0 INTRODUCTION

1.1 Background

Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir has a normal maximum water surface elevation of 830 ft above mean sea level (msl; NGVD 29). At elevation 830 ft, the reservoir stores over 2,000,000 acre-feet (AF) of water and has a surface area slightly less than 13,000 acres (ac). The watershed above Don Pedro Dam is approximately 1,533 square miles (mi^2). The Project is designated by the Federal Energy Regulatory Commission (FERC) as project no. 2299.

Both TID and MID are local public agencies authorized under the laws of the State of California to provide water supply for irrigation and municipal and industrial (M&I) uses and to provide retail electric service. The Don Pedro Project serves many purposes including providing water storage for the beneficial use of irrigation of over 200,000 ac of prime Central Valley farmland and for the use of M&I customers in the City of Modesto (population 210,000). Consistent with agreements between the Districts and City and County of San Francisco (CCSF), the Don Pedro Reservoir also includes a "water bank" of up to 570,000 AF of storage which CCSF uses to efficiently manage the water supply from its Hetch Hetchy water system while meeting the senior water rights of the Districts. The "water bank" within Don Pedro Reservoir provides significant benefits for CCSF's 2.6 million customers in the San Francisco Bay Area.

The Don Pedro Project also provides storage for flood management purposes in the Tuolumne and San Joaquin rivers in coordination with the U.S. Army Corps of Engineers (ACOE). Other important uses supported by the Don Pedro Project are recreation, protection of aquatic resources in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at a water surface elevation of 845 ft (31 FPC ¶ 510 [1964]). The Project Boundary encompasses approximately 18,370 ac with 74 percent of the lands owned jointly by the Districts and the remaining 26 percent (approximately 4,802 ac) owned by the United States and managed as a part of the U.S. Bureau of Land Management (BLM) Sierra Resource Management Area.

The primary Don Pedro Project facilities include the 580-foot-high Don Pedro Dam and Reservoir completed in 1971; a four-unit powerhouse situated at the base of the dam; related facilities including the Project spillway, outlet works, and switchyard; four dikes (Gasburg Creek Dike and Dikes A, B, and C); and three developed recreational facilities (Fleming Meadows, Blue Oaks, and Moccasin Point Recreation Areas). The location of the Don Pedro Project and its primary facilities is shown in Figure 1.1-1.

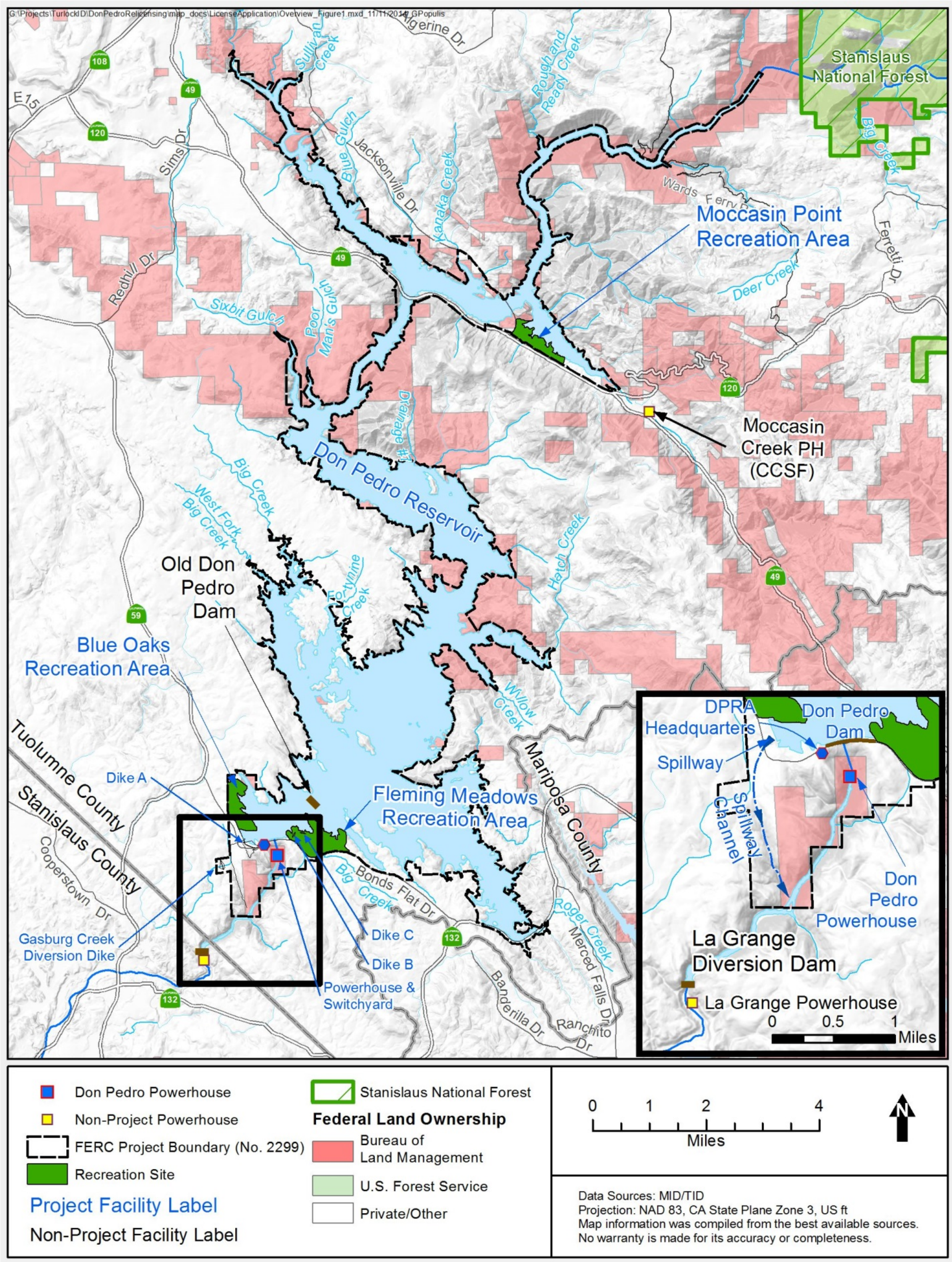

Figure 1.1-1. Don Pedro Project site location map.

1.2 Relicensing Process

The current FERC license for the Project expires on April 30, 2016, and the Districts applied for a new license on April 30, 2014. At that time, and consistent with study schedules approved by FERC through the Integrated Licensing Process (ILP) study plan determinations, five important studies involving the resources of the lower Tuolumne River were still in-progress. These studies are scheduled to be completed by April 2016. Once these studies are completed, the Districts will evaluate all data, reports, and models then available for the purpose of identifying appropriate protection, mitigation, and enhancement (PM&E) measures to address the direct, indirect, and cumulative effects of Project operations and maintenance. Upon completion of this evaluation, the Districts will prepare any needed amendments to the license application.

The Districts began the relicensing process by filing a Notice of Intent and Pre-Application Document (PAD) with FERC on February 10, 2011, in accordance with the regulations governing the ILP. The Districts' PAD included descriptions of the Project facilities, operations, license requirements, and Project lands as well as a summary of the extensive existing information available on Project area resources. The PAD also included ten draft study plans describing a subset of the Districts' proposed relicensing studies. The Districts then convened a series of Resource Work Group meetings, engaging agencies and other relicensing participants in a collaborative study plan development process culminating in the Districts' Proposed Study Plan (PSP) and Revised Study Plan (RSP) filings to FERC on July 25, 2011 and November 22, 2011, respectively.

On December 22, 2011, FERC issued its Study Plan Determination (SPD) for the Project, approving, or approving with modifications, 34 studies proposed in the RSP that addressed Cultural and Historical Resources, Recreational Resources, Terrestrial Resources, and Water and Aquatic Resources. In addition, as required by the SPD, the Districts filed three new study plans (W&AR-18, W&AR-19, and W&AR-20) on February 28, 2012 and one modified study plan (W&AR-12) on April 6, 2012. Prior to filing these plans with FERC, the Districts consulted with relicensing participants on drafts of the plans. FERC approved or approved with modifications these four studies on July 25, 2012.

Following the SPD, a total of seven studies (and associated study elements) that were either not adopted in the SPD, or were adopted with modifications, formed the basis of Study Dispute proceedings. In accordance with the ILP, FERC convened a Dispute Resolution Panel on April 17, 2012 and the Panel issued its findings on May 4, 2012. On May 24, 2012, the Director of FERC issued his Formal Study Dispute Determination, with additional clarifications related to the Formal Study Dispute Determination issued on August 17, 2012. The *Chinook Salmon Otolith Study* (W&AR-11) was not a subject of the dispute resolution process.

On January 17, 2013, the Districts issued the Initial Study Report (ISR) and held an ISR meeting on January 30 and 31, 2013. The Districts filed a summary of the ISR meeting with FERC on February 8, 2013. Comments on the meeting summary and requests for new studies and study modifications were filed by relicensing participants on or before March 11, 2013, and the Districts filed reply comments on April 9, 2013. FERC issued the Determination on Requests for

Study Modifications and New Studies on May 21, 2013. The determination did not involve the study plan for the *Chinook Salmon Otolith Study* (W&AR-11).

The Districts filed the Updated Study Report (USR) on January 6, 2014; held a USR meeting on January 16, 2014; and filed a summary of the meeting on January 27, 2014. Relicensing participant comments on the meeting summary and requests for new studies and study modifications were due by February 26, 2014. The Districts filed reply comments on March 28, 2014. FERC issued the Determination on Requests for Study Modifications on April 29, 2014.

This study report describes the objectives, methods, and results of the *Chinook Salmon Otolith Study* (W&AR-11) as implemented by the Districts in accordance with FERC's December 22, 2011 Order. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at http://www.donpedro-relicensing.com/.

1.3 Study Report

Results of laboratory analyses conducted for W&AR-11 are provided in Appendix A of this study report. The draft study report (including Appendix A) was provided to relicensing participants on March 16, 2015, for 30-day review. Comments on the draft report were provided on April 23, 2015 by the U.S. Fish and Wildlife Service (USFWS). Responses to draft study report comments are presented in Appendix B. Additional comments on the draft report were provided by Dr. Rachel Johnson (University of California, Davis), who oversaw the laboratory analysis, on April 14, 2015. Changes made to the draft report based on Dr. Johnson's comments are presented in the errata sheet included above.

2.0 CHINOOK SALMON OTOLITH STUDY GOALS AND OBJECTIVES

Otoliths (commonly referred to as "earstones") are calcium carbonate structures in the inner ear of fish that grow in proportion to the overall growth of the individual, such that daily or weekly growth increments can be measured to allow the age and fish size at various habitat transitions to be identified. Through analysis of otoliths, the goal of this study was to identify the geographic origin and early life history rearing and emigration patterns of Tuolumne River Chinook salmon during above- and below-normal water year (WY) types. Examination of otolith microstructure has been used to identify differing rearing environments of juvenile salmon (e.g., Neilson et al. 1985) as well as differences in rearing temperatures (Zhang et al. 1995; Volk et al. 1996). Additionally, using one of several methods of microchemical analysis, the concentrations of elements (e.g., strontium, barium, calcium) and proportions of stable strontium (Sr) isotopes in otoliths may be compared to those in the water in which the fish inhabits in order to provide a tracer of the location where the fish has been (e.g., freshwater, saltwater, natal stream) (Campana and Neilson 1985). Otolith microchemistry has been used to examine early life history rearing environments of salmonids to address questions of streams of natal origin (Ingram and Weber 1999; Campana and Thorrold 2001) as well as the timing of entry into estuarine and saline environments (Zimmerman 2005).

This study applies microstructural and microchemical analysis of otoliths to address questions regarding the success of various early life-history emigration patterns of fall-run Chinook salmon originating from the Tuolumne River. Early life history events in juvenile salmonid development, including incubation, emergence, and habitat transitioning, can be linked to otolith microstructural patterns due to the thermal, physical, and chemical regime under which these fish were reared. Identification of the natal streams of adults that spawn in the Tuolumne River may allow additional quantification of straying rates from other rivers and, hence, more accurate assessments of the population size of indigenous Tuolumne River salmon. The relative contribution of emigrant fry, parr and smolts to subsequent escapement may have implications for the magnitude and timing of flow in the Tuolumne River, as well as the timing of operations of barriers and export facilities in the southern Sacramento and San Joaquin River delta (Delta[1]).

In brief, the study objectives were to use otolith microstructural growth patterns and/or microchemistry in order to identify:

- whether returning adults originated from hatcheries or riverine environments other than the Tuolumne River; and,
- growth rates and sizes of 'wild' fish at exit from the Tuolumne River and from the freshwater Delta.

[1] The Delta received its first official boundary in 1959 with the passage of the Delta Protection Act (Section 12220 of the California Water Code), with the southern boundary in the San Joaquin River located at Vernalis (RM 69.3) and a western boundary at the confluence of the Sacramento and San Joaquin Rivers (RM 0) near Chipps Island.

3.0 STUDY AREA

The study area consists of locations of Chinook salmon carcass recoveries collected by California Department of Fish and Wildlife (CDFW) from the lower Tuolumne River, typically extending from approximately 0.5 miles downstream of the lower end of the La Grange powerhouse tailrace (RM 51.6) to the end of routine spawning surveys at approximately RM 21.2. The lower San Joaquin River from the Tuolumne River confluence (RM 84) to Vernalis (RM 69.3), Delta, San Francisco Bay Estuary[2], and the Pacific Ocean are also addressed in terms of their use by rearing and emigrant juvenile life stages of Chinook salmon.

[2] The greater San Francisco Bay estuary extends from the Golden Gate Bridge in San Francisco Bay eastwards across salt and brackish water habitats included in San Leandro, Richardson, San Rafael, and San Pablo bays, as well as the Carquinez Strait, Honker, and Suisun bays further to the east near the western edge of the Delta.

4.0 METHODOLOGY

4.1 Existing Data Compilation

This study relied upon the existing inventory of fall-run Chinook salmon otoliths sampled from unmarked carcasses collected by CDFW during annual spawner escapement surveys in the lower Tuolumne River, which are typically conducted from October to early-January. Otoliths were provided cooperatively by CDFW under a memorandum of understanding (MOU) with the Districts and the Department of Animal Science, University of California, Davis (UC Davis). In order to examine potential variations in early life-history emigration patterns, otoliths were selected to represent returning adults that had emigrated during five focus years (1998, 1999, 2000, 2003, and 2009), representing "above normal" or "wet" and "below normal" or "dry" WY types[3]. With a sampling goal of obtaining 100–200 otoliths from each outmigration year for laboratory analysis, these five years were also selected because they represented years with the greatest number of available samples from the existing CDFW inventory. The sampling goal was met for the above normal/wet WY types 1998, 1999, and 2000, but was not met for the below normal/dry WY types 2003 and 2009, which had comparatively fewer samples available (Table 4.2-1). As the otoliths were collected from unmarked fish, the samples did not include known hatchery-origin fish[4].

4.2 Laboratory Otolith Analysis

A summary of the otolith analytical methods is provided below, with additional details provided in Sturrock and Johnson (2014), which is appended to this study report as Appendix A.

4.2.1 Adult sampling and cohort reconstruction

Adult salmon from a given outmigration year typically return between 2 and 5 years later with the greatest proportion returning after 3 and 4 years respectively in historical Tuolumne River spawner surveys (TID/MID 2014a). Thus, for each outmigration year that was examined in this study, otolith samples were recovered from carcasses collected over several escapement years (Table 4.2-1). Experts at CDFW determined the ages of the adult samples by counting scale winter annuli from unmarked adult salmon carcasses in accordance with established and validated techniques (Guignard 2008). Information regarding the date of collection, location, fish length, sex, and estimated age-at-return were provided by CDFW for each otolith sample.

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3 CDWR Bulletin 120 estimates unimpaired runoff as TAF for the San Joaquin River and tributaries. The San Joaquin Basin 60-20-20 Index classifies water years (October 1 through September 30) into five basic types (C=Critical, D=Dry, BN=Below Normal, AN=Above Normal, W=Wet) which are further refined under Article 37 of the FERC (1996) license. For the purposes of this report, the broader CDWR Water Year types are used as a basis of discussion.

4 Although the Merced River Fish Facility (MRFF) does not participate in the Constant Fractional Marking Program implemented since 2007, the MRFF historically only marked a proportion of hatchery fish, and that proportion has varied over time.

Table 4.2-1. Otolith sampling inventory by juvenile cohort and outmigration WY type collected from unmarked adult salmon carcasses in the Tuolumne River between 1999 and 2012. Source: Sturrock and Johnson (2014).

Juveniles Represented			Adults Sampled			
Spawning year[1]	Outmigration year[2]	WY type during rearing & outmigration[3]	Escapement year[4]	Estimated age at return (yr)[5]	Number of individuals sampled	% of total sample
1997	1998	Wet	1999	2	0	0%
			2000	3	124	62%
			2001	4	76	38%
			Sum		**200**	**100%**
1998	1999	Above normal	2000	2	9	6%
			2001	3	64	44%
			2002	4	73	50%
			Sum		**146**	**100%**
1999	2000	Above normal	2001	2	31	28%
			2002	3	79	72%
			2003	4	0	0%
			Sum		**110**	**100%**
2002	2003	Below normal	2004	2	0	0%
			2005	3	87	91%
			2006	4	9	9%
			Sum		**96**	**100%**
2008	2009	Below normal	2010	2	14	30%
			2011	3	30	65%
			2012	4	2	4%
			Sum		**46**	**100%**
TOTAL					**598**	

1 Although CDFW uses the term “brood-year” to designate the year in which fry first emerge (typically December), here we simply indicate the year in which the majority of spawning occurred.
2 Outmigration-year designation is based on the timing of the first juveniles’ departure from the natal river.
3 CDWR Bulletin 120 estimates unimpaired runoff as TAF for the San Joaquin River and tributaries. The San Joaquin Basin 60-20-20 Index classifies WYs (October 1 through September 30) into five basic types (C=Critical, D=Dry, BN=Below Normal, AN=Above Normal, W=Wet), which are further refined under Article 37 of the FERC (1996) license. For the purposes of this report, the broader CDWR WY types are used as a basis of discussion.
4 Sampled during CDFW annual spawner escapement surveys.
5 Estimated from CDFW scale readings.

4.2.2 Strontium isotope analysis

Adult otoliths were prepared and analyzed for strontium isotopic ($^{87}Sr/^{86}Sr$) ratios using standard techniques described in Sturrock and Johnson (2014). In brief, the technique relies on detecting daily deposition of chemical elements from the surrounding environment in otolith growth rings, producing a distinct and reproducible “chemical fingerprint”. In the California Central Valley, strontium isotopes ($^{87}Sr/^{86}Sr$) are ideal markers because the water signature varies with watershed geology, therefore differing among many of the rivers and salmon outmigration paths (Ingram and Weber 1999; Barnett-Johnson et al. 2008).

Otoliths were rinsed and cleaned of adhering tissue, then mounted in resin and polished until each primordial core (i.e., center) was exposed. Each otolith was sampled at multiple spots along a 90° radial transect starting at the primordial core and ending just past the point of ocean entry (also called the "freshwater exit"), in order to ensure inclusion of the full freshwater outmigration period in the analysis (Figure 4.2-1). At each sample spot, $^{87}Sr/^{86}Sr$ ratios were determined by multi-collector laser ablation inductively coupled plasma mass spectrometry (MC-LA-ICPMS) (Barnett-Johnson et al. 2005). To improve the spatial resolution and accuracy of the ocean entry spot identification and outmigration fork length (see also Section 4.2.4), additional $^{87}Sr/^{86}Sr$ sample spots were re-sampled at the region representing an isotope ratio shift (e.g., the Tuolumne-San Joaquin River transition).

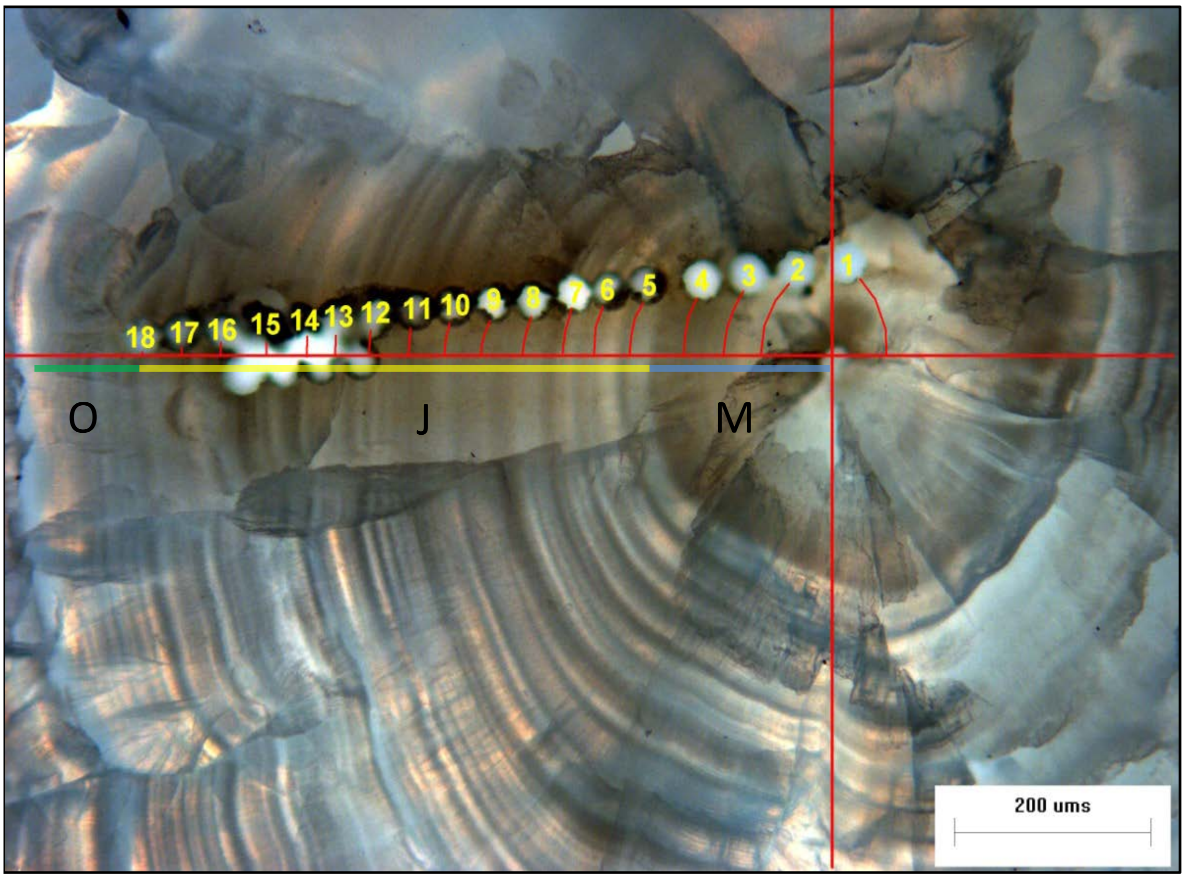

Figure 4.2-1. A typical 87Sr/86Sr transect showing spot analyses (numbered) from the core to ocean entry. The life history stages are indicated by letters: maternal (M), juvenile (J) and ocean (O). The distance at which the final 'natal spot' intersected the 90° transect (indicated by curved red lines) was used to back-calculate size at outmigration. 'Respots' occurred at positions 12.5 to 15.5 used to more accurately identify exit point. Source: Sturrock and Johnson (2014).

4.2.3 Identification of natal origin

To identify the natal origin of the otolith samples, measured $^{87}Sr/^{86}Sr$ ratios were statistically compared to a "strontium isoscape" comprised of the previously published $^{87}Sr/^{86}Sr$ baseline for California Central Valley rivers and hatcheries, additional Sr isotope values of otolith samples from juveniles and coded wire tag (CWT) adults known to originate from the Tuolumne River, and Sr isotope values from Tuolumne River and San Joaquin River water samples collected in 2014 (Ingram and Weber 1999; Sturrock and Johnson 2014). The resulting strontium isoscape included a total of 480 tissue and water samples from all potential natal sources in the California Central Valley, with many sites sampled across multiple years (1998–2013) and hydrologic regimes (Sturrock and Johnson 2014, Table 3).

Given the variability in Sr isotope values in water samples from upper to lower reaches of the lower Tuolumne River (Ingram and Weber 1999; Sturrock and Johnson 2014), juveniles collected in the Tuolumne River tend to exhibit more variable isotopic signatures within and among individuals than in other rivers in the Central Valley (Figure 4.2-2). Additionally, otolith $^{87}Sr/^{86}Sr$ values of known-origin Tuolumne River fish, Mokelumne River Hatchery and Feather River Hatchery can overlap (Figure 4.2-2), increasing the potential of misclassifying Tuolumne-origin fish. To improve assignment accuracy, any otolith samples exhibiting ambiguity in their natal assignment were also analyzed for otolith microstructural features that can discriminate hatchery from wild fish. Following methods developed for California Central Valley Chinook (Barnett-Johnson et al. 2007), individuals were classified as hatchery or wild based on the prominence of the exogenous feeding check (scored blind by 2–3 independent readers) and the mean and variance in increment width around the first 30 daily increments following onset of exogenous feeding after fry emergence from the spawning gravels.

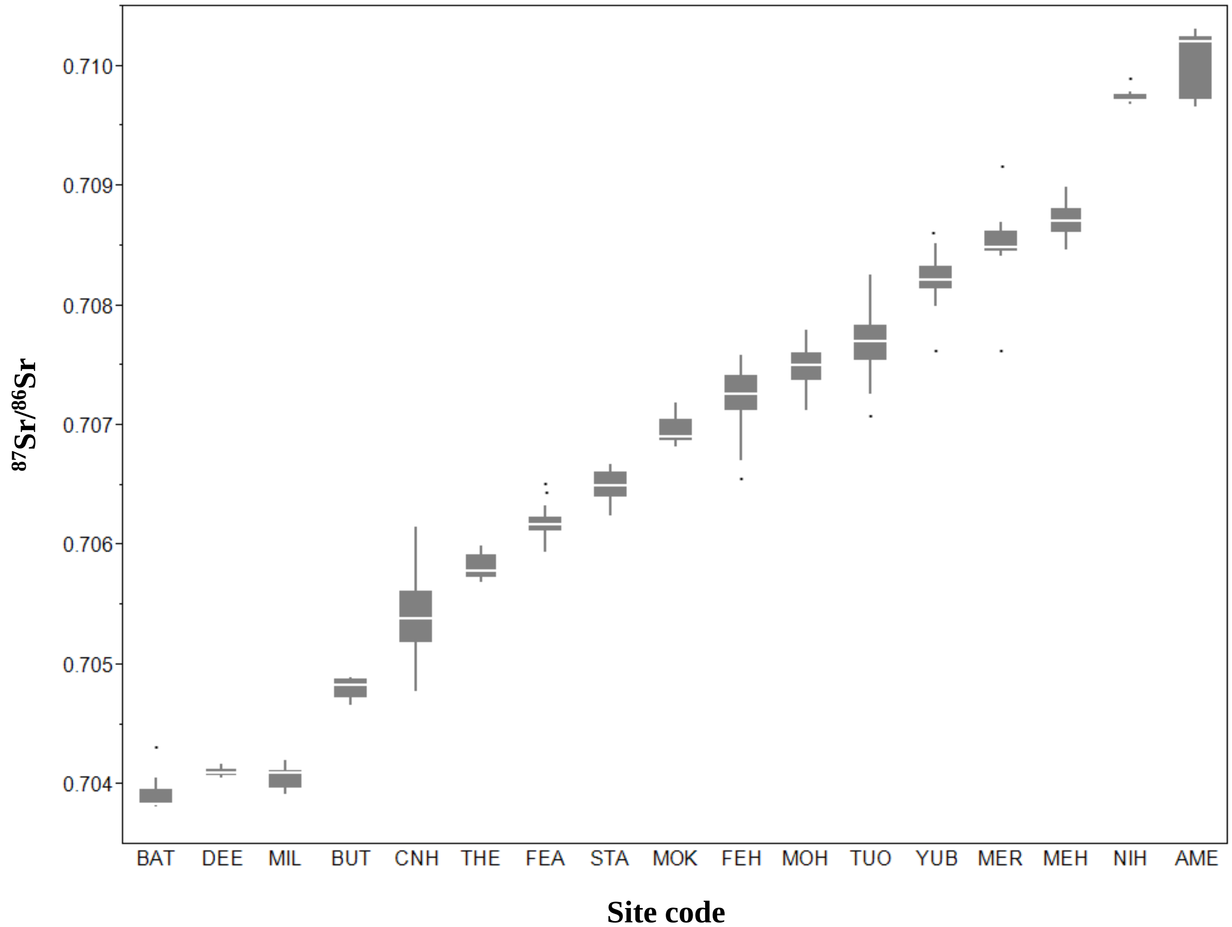

Figure 4.2-2. **Differences in 87Sr/86Sr values among sites in the California Central Valley. Source: Sturrock and Johnson (2014). Due to overlap among the Tuolumne River (TUO), Mokelumne River Hatchery (MOH), and Feather River Hatchery (FEH), all fish identified as potentially originating from the Tuolumne River using Sr isotopes were also assigned to hatchery/wild using otolith microstructure. Other side codes: Battle Creek (BAT), Deer Creek (DEE), Mill Creek (MIL), Butte Creek (BUT), Coleman National Fish Hatchery (CNH), Thermalito Rearing Annex (THE), Feather River (FEA), Stanislaus River (STA), Mokelumne River (MOK), Yuba River (YUB), Merced River (MER), Merced River Hatchery (MEH), Nimbus Hatchery (NIH), American River (AME).**

4.2.4 Reconstructing size and age at outmigration

Variations in the $^{87}Sr/^{86}Sr$ ratio along the sampling transect were used to indicate the location and thus life history timing of emigration from the Tuolumne River ('natal exit') using the distance from the otolith primordial core to the 'last natal spot'. The 'last natal spot' rather than the 'first non-natal spot' was used because to accrete sufficient new otolith material to modify the isotopic composition of the otolith, the fish would have inhabited isotopically distinct (i.e., non-natal) water for several days, after which time it would be a significant distance downstream of the Tuolumne-San Joaquin River confluence. The 'last natal spot' was identified by working backwards from the final inflection point indicative of ocean-bound migration, and using the spot just prior to the lowest point of inflection, where the latter represented likely movement through the San Joaquin River (Sturrock and Johnson 2014, Figure 3, Plots A, B, and C). The only exceptions were on occasions when the lowest point prior to ocean migration was lower than any value measured in the San Joaquin River (Sturrock and Johnson 2014, Figure 3, Plot D); on these occasions the lowest point was assumed to have been deposited while the fish was rearing in the lower Tuolumne River, which has been shown to exhibit $^{87}Sr/^{86}Sr$ values as low as 0.7066 (Sturrock and Johnson 2014).

The point of emigration from freshwater ('freshwater exit') was defined as the distance at which otolith $^{87}Sr/^{86}Sr$ values last reached 0.7080 (equivalent to a salinity of 1ppt based on Hobbs et al. 2010), determined using linear interpolation.

In order to estimate fish size at the natal and freshwater exit points, radial otolith distances to these points were measured for use with an existing relationship between otolith radius and fork length (FL) from the California Central Valley fall run Chinook salmon Evolutionarily Significant Unit (ESU) (Zabel et al. 2010). Juvenile reference samples for the Zabel et al. (2010) relationship were collected at various locations including samples from the Tuolumne River (2003; n = 6), Stanislaus River (2000 and 2002; n = 95), the Coleman National Fish Hatchery (2002; n=40) and in the San Francisco Bay at Golden Gate Bridge (2005; n = 83) (Figure 4.2-3). While the small number of Tuolumne-origin fish included in the relationship tended to sit above the mean regression line (Figure 4.2-3), there was no significant difference between the back-calculated fork length of Tuolumne vs. non-Tuolumne fish, nor any difference in the slopes (Sturrock and Johnson 2014). The uncertainty in the otolith radius-fork length regression was used to estimate 95% confidence intervals (CI) for the estimated juvenile fork lengths associated with individual adult otolith samples.

For each length estimate at natal exit from the Tuolumne River, fish were classified as fry (<50 mm FL), parr (≥50 to <70 mm FL), and smolt (≥70 mm FL) in this report. Although these size cutoffs are 5 mm larger than those from the Mokelumne River (Miller et al. 2010) used in Sturrock and Johnson (2014), the Tuolumne River size cutoffs were re-assigned here based upon operational definitions used in juvenile outmigration studies (TID/MID 2014b). For example, the smallest sized juveniles reported as smolts in historical sampling range as low as 65 mm FL in some years (Stillwater Sciences 2013a).

Fish age at outmigration was determined by counting daily growth bands and measuring widths between daily increments along the same 90° radial transect as the $^{87}Sr/^{86}Sr$ analysis, beginning at the point when the maternal yolk sac is depleted and exogenous feeding begins ("post exogenous feeding check") until freshwater exit from the Delta to the San Francisco Bay and Pacific Ocean. Some otoliths were difficult to age and given low readability scores (1-2); ages were not provided for these individuals. The ages of fish at natal exit from the lower Tuolumne River, freshwater exit from the Delta, and habitat-specific growth rates were obtained for fish with otolith readability scores of 3–5. A subset of otoliths was aged by two independent readers, providing an estimate of error associated with fish aging. The two independent reads of each fish demonstrated high agreement, with an average difference of ± 5 days (range 0–12 days).

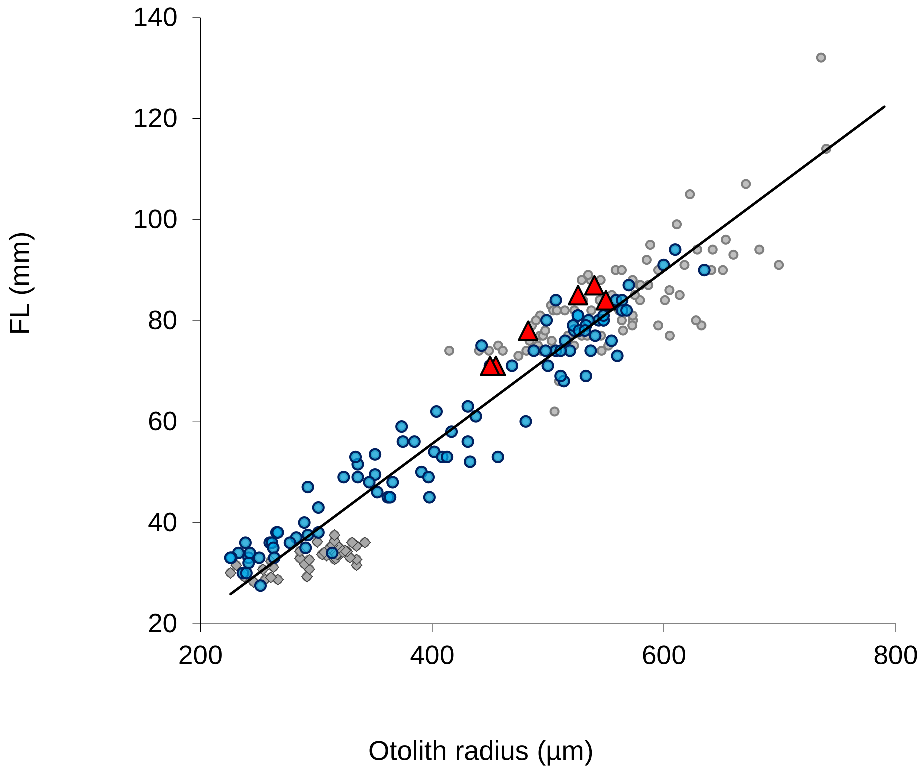

Figure 4.2-3. Relationship between otolith radius and fork length (FL) of juveniles of known origin from the California Central Valley fall run Chinook salmon Evolutionarily Significant Unit (ESU). (n=224, r2 = 0.92) Red triangles = Tuolumne River (n = 6); blue circles = Stanislaus River (n = 95); grey diamonds = Coleman National Fish Hatchery (n=40); grey circles = San Francisco Bay at Golden Gate Bridge unknown origin (n = 83). Source: Sturrock and Johnson (2014).

4.3 Analysis of Potential Flow Relationships

Tuolumne River hydrologic patterns were explored for each of the five outmigration years using available flow data for gages at La Grange (USGS #11289650), Modesto (USGS #11290000), and Vernalis (USGS #11303500). Daily flow data were pooled to develop flow metrics at 2-week and monthly intervals from January through June, including minimum, maximum, and mean Tuolumne River discharge. Each of the Tuolumne River flow metrics were used in linear regressions against fish size at natal exit and fish age at natal exit (determined by the otolith analyses) for each of the five outmigration years included in the study (1998, 1999, 2000, 2003, and 2009).

Average daily flow magnitude and timing were also examined in combination with mean fish size and age at exit from the Tuolumne River and the Delta to determine any potential relationships between flow and fish age/size at exit. This exploratory analysis was undertaken to determine whether flow may explain various early life-history emigration patterns of juvenile salmon from differing WY types.

Delta hydrologic patterns were investigated using California Department of Water Resources (CDWR) DAYFLOW data, including 24 flow parameters and indices characterizing the following (CDWR 2015):

- daily river inflows (e.g., Sacramento, Yolo, Cosumnes, Mokelumne, San Joaquin, Calaveras plus other miscellaneous creek flows);
- interior Delta flows (e.g., Delta Cross Channel and Georgiana Slough, Jersey Point, Rio Vista);
- water exports and diversions/transfers (e.g., Central Valley Project at Tracy, Contra Costa Water District Diversions at Middle River, Rock Slough, Old River, North Bay Aqueduct, State Water Project);
- estimates of Delta agriculture depletions; and,
- fish-related flows (i.e., percent water diverted, effective Western/Central Delta inflow, effective percent Western/Central Delta water diverted).

Daily average flow data for each of the DAYFLOW 24 parameters/indices were pooled into aggregated monthly averages from January through June. Each of these averages were used in exploratory linear regressions against fish size at freshwater exit and fish age at freshwater exit for each of the five outmigration years included in the study (1998, 1999, 2000, 2003, and 2009).

5.0 RESULTS

5.1 Natal Origin

Analysis of Sr isotope ratios ($^{87}Sr/^{86}Sr$) and microstructural features (see Section 4.2.3) in otoliths collected from unmarked Chinook salmon carcasses indicated both wild- and hatchery-origin fish in Tuolumne River spawning adults corresponding to outmigration years 1998, 1999, 2000, 2003, and 2009 (Figure 5.1-1). The earliest three years exhibited the highest numbers of Tuolumne River returning wild fish, with smaller numbers of wild fish exhibiting Sr isotope ratios indicating straying from the Stanislaus, Merced, and Mokelumne rivers. The hatchery component in these outmigration years was primarily from the Merced and Mokelumne river hatcheries, with smaller contributions from the Feather River and Nimbus hatcheries. Overall, returning wild fish made up 38–68% of the sample of unmarked fish for outmigration years 1998–2000 (Table 5.1-1). For outmigration years 2003 and 2009, relatively low numbers of returning wild fish were present in the sample, with larger hatchery components primarily from the Mokelumne River Hatchery (2003) and the Coleman National Fish Hatchery (2009) (Table 5.1-1). Overall, returning wild fish made up 9–25% of the sample for outmigration years 2003 and 2009 (Table 5.1-1). Considering all five outmigration years combined (n=598), 54% of the unmarked fish samples were identified as wild and of Tuolumne River origin (n=321), 43% were identified as hatchery-origin (n=255), and 4% were identified as wild strays from other rivers (n=22).

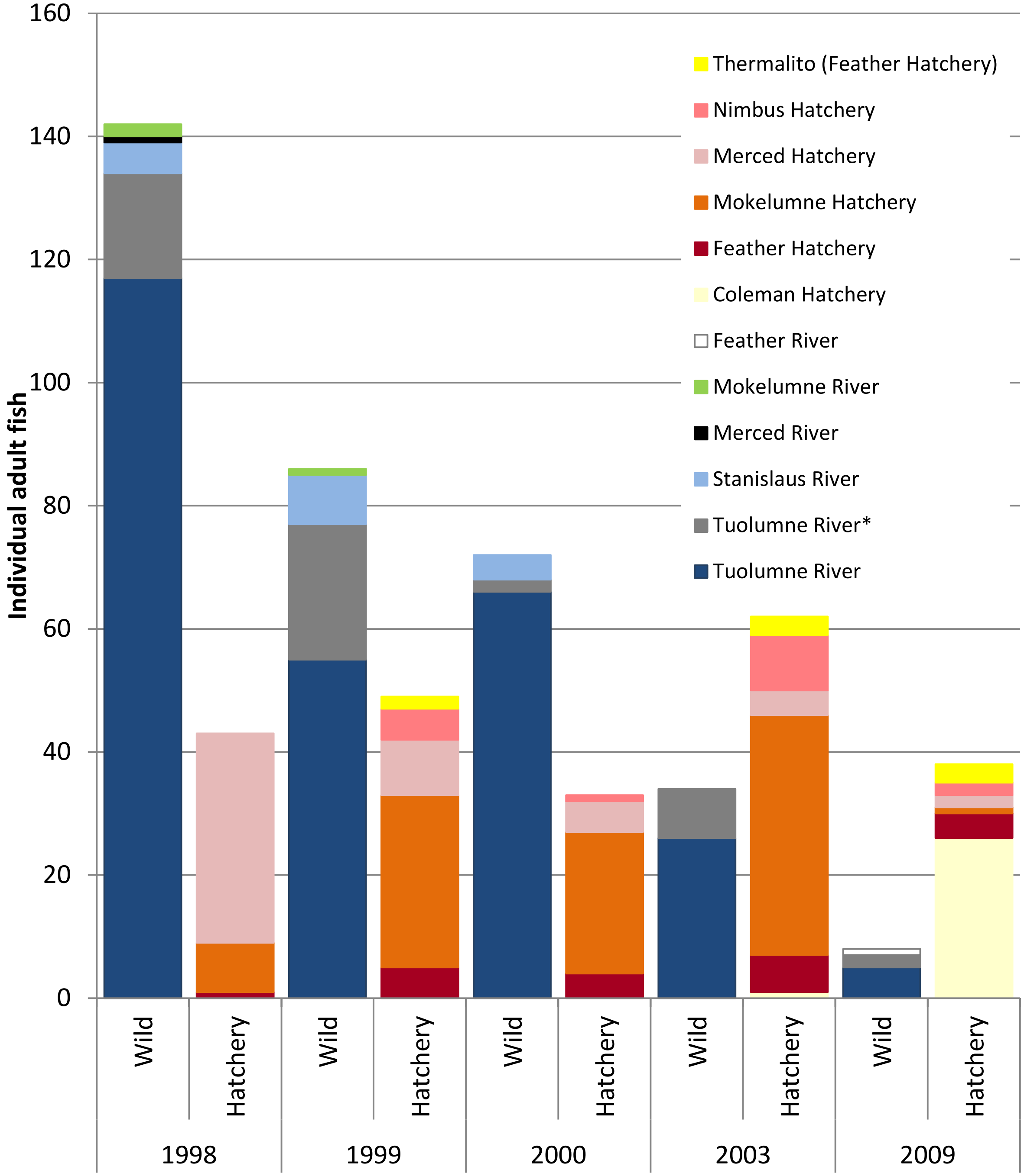

Figure 5.1-1. **Natal origin of all unmarked fish (n=598) analyzed for outmigration years 1998, 1999, 2000, 2003 and 2009. [*] indicates individuals assigned to the Tuolumne River with <0.5 posterior probability based on mean natal 87Sr/86Sr values or individuals assigned to the Tuolumne River, but with inconclusive hatchery/wild assignment based on otolith microstructure. Data from Sturrock and Johnson (2014).**

Table 5.1-1. Summary of straying and return rates to the Tuolumne River for unmarked fish (n=598). Data from Sturrock and Johnson (2014).

Outmigration year	San Joaquin River Index Water Year Type[1]	Sample size	Returns (Wild)[2]	Strays (Wild and Hatchery)[2]	Primary origin of strays
1998	Wet	200	57–68%	33–44%	Merced Hatchery
1999	Above normal	146	38–53%	47–62%	Mokelumne Hatchery
2000	Above normal	110	61–64%	36–39%	Mokelumne Hatchery
2003	Below normal	96	27–35%	65–73%	Mokelumne Hatchery
2009	Below normal	46	9–15%	85–91%	Coleman Hatchery

1 San Joaquin Basin 60-20-20 Index from CDWR Bulletin 120.
2 Range in natal assignment is based on probabilities associated with the isotope-based discriminant function analysis and reference samples from existing or ongoing projects.

5.2 Growth and Residency of Juveniles

Estimated mean fish size at exit from the Tuolumne River based on otolith analyses ranged 63.5–76.0 mm, with the lowest mean size exhibited in outmigration year 2000. The year 2000 mean size was significantly different ($p<0.005$) from that estimated for the other four years of the study. Similarly, estimated age at exit from the Tuolumne River was lower in outmigration year 2000 (68.5 days) as compared with that of other years, although there was generally higher variability in age at exit such that no single year was statistically lowest (Table 5.2-1).

Estimated mean fish size at freshwater exit from the Delta based on otolith analyses ranged 77.4–83.4 mm, with slightly greater variability within years than that of the Tuolumne River (Table 5.2-1). Examination of the distributions of age at exit from the Tuolumne River and the Delta suggests that overall the total days from the end of exogenous feeding (i.e., emergence from gravels) to ocean entry was relatively constant at 99±20 days for each of the five outmigration years, such that fewer days spent rearing in the Tuolumne River resulted in relatively more days rearing in the Delta (Figure 5.2-1).

Table 5.2-1. Summary of estimated fish size, age, and increment widths (mean ±1SD) at natal exit and freshwater exit by outmigration year for juveniles that originated in and returned to the Tuolumne River. Source: Sturrock and Johnson (2014).

Out-migration year (WY Type[2])	Sample Size	Tuolumne River			Delta		
		FL at exit (mm)	No. increments (days)	Increment width[1] (um)	FL at exit (mm)	No. increments (days)	Increment width[1] (um)
1998 (W)	117	73.3 ± 8.5	91.0 ± 16.2	3.07 ± 0.28	80.8 ± 9.0	15.8 ± 7.5	3.24 ± 0.54
1999 (AN)	55	72.6 ± 11.6	82.0 ± 13.6	3.20 ± 0.27	82.3 ± 11.5	16.5 ± 8.7	3.35 ± 0.56
2000 (AN)	66	63.5 ± 8.6	68.5 ± 18.6	3.10 ± 0.26	77.4 ± 6.9	27.6 ± 12.1	3.52 ± 0.52
2003 (BN)	26	71.0 ± 10.6	79.7 ± 17.9	3.39 ± 0.43	80.1 ± 10.0	10.5 ± 5.2	3.65 ± 0.62
2009 (BN)	5	76.0 ± 7.1	88.0 ± 20.3	3.36 ± 0.29	83.4 ± 6.8	16.0 ± 7.5	3.03 ± 0.36

1 Width between daily increments is a measure of growth rate.
2 San Joaquin Basin 60-20-20 Index from CDWR Bulletin 120.

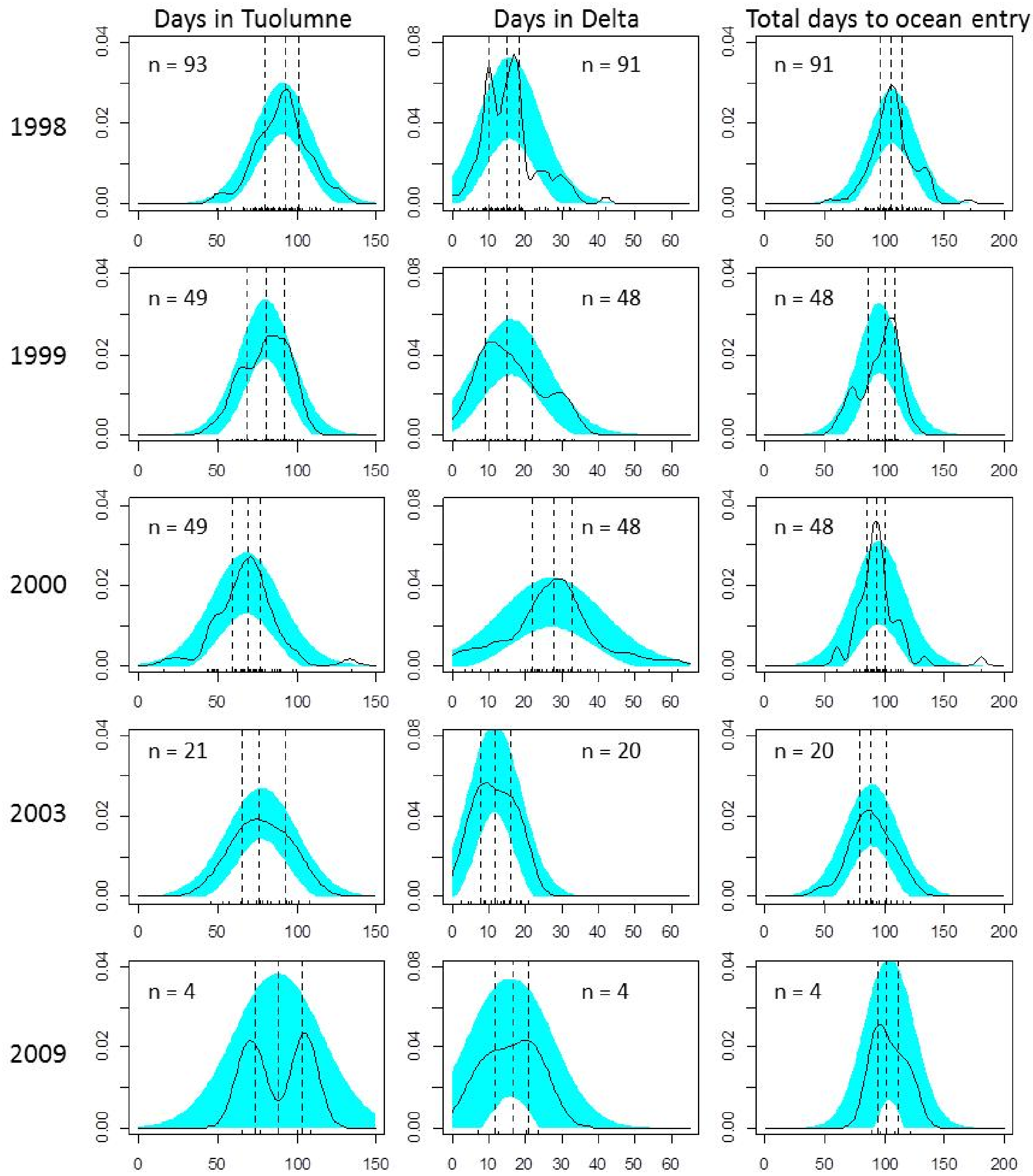

Figure 5.2-1. Estimated days of development from formation of otolith core to ocean entry. The rug plots show values for individual otoliths from unmarked adult samples. The curves are non-parametric density estimates obtained by kernel smoothing, deliberately under-smoothed. The cyan bands encode a test for normality. The vertical dashed lines mark the data quartiles.

Table 5.2-1 (and Figure 9 of Sturrock and Johnson 2014) presents the central tendency and general range of increment widths as an indication of growth rates in the Tuolumne River and the Delta for each WY included in this study. It should be noted, however, that Chinook growth rates vary with fish size among other factors (Titus et al 2004). Since juvenile outmigrants will generally have attained a larger size by the time they have reached Delta habitats, average growth rates in the Delta will generally be lower than for samples including a larger proportion of fish that completed the fry/parr transition within the natal river. To remove this potential effect from the analysis, a growth trajectory was created for each otolith sample by plotting increment number against distance along the otolith radial transect (um), with the transition point between Tuolumne River and Delta rearing based upon results of the Sr isotope analysis. The individual growth trajectories exhibit little discernable difference in slope between natal stream and Delta rearing locations for individual fish (Figure 5.2-2).

Additionally, specific otolith growth rates (um/d) were plotted as a function of fish size to allow direct growth rate comparisons between the Tuolumne River and the Delta for each WY included in this study. Figure 5.2-3 shows a high degree of growth rate variability for fish of the same estimated fork length in both riverine and Delta habitats, although some patterns are apparent. In two of the three wet WY types (1998, 1999), estimated growth rates in the Tuolumne River were greater than those of the Delta (95% confidence interval [CI]) for larger parr-sized individuals, corresponding to otolith distances of approximately 475 um (68 mm FL estimate) and greater. However, estimated growth rates of smaller juveniles, corresponding to otolith sizes of 425 um (60 mm FL estimate) and smaller fish, were not different between the river and the Delta during 1998 and 1999. Conversely, for the other above normal/wet WY type represented (2000), estimated growth rates in the Delta were greater than those of the Tuolumne River (95% CI) for parr-sized individuals, corresponding to otolith distances of approximately 425–475 um (60–68 mm FL estimate) and larger fish. The remaining comparisons for other otolith distances during WY 2000 fell within the 95% CI and are not statistically distinguishable. Lastly, in the dry WY types (2003, 2009), estimated growth rates for a given fish size were not different between the Tuolumne River and the Delta (95% CI), save for otolith distances 475‒525 um (68‒77 mm FL estimate parr and smolts) which exhibited higher estimated growth rates in the Tuolumne River.

Overall, with the exception of parr-sized individuals collected from carcasses originating from outmigration year 2000, size-standardized estimated growth rates for juveniles were generally greater in the Tuolumne River than similar-sized juveniles that reared in Delta habitats, or were not statistically distinguishable between the two rearing locations.

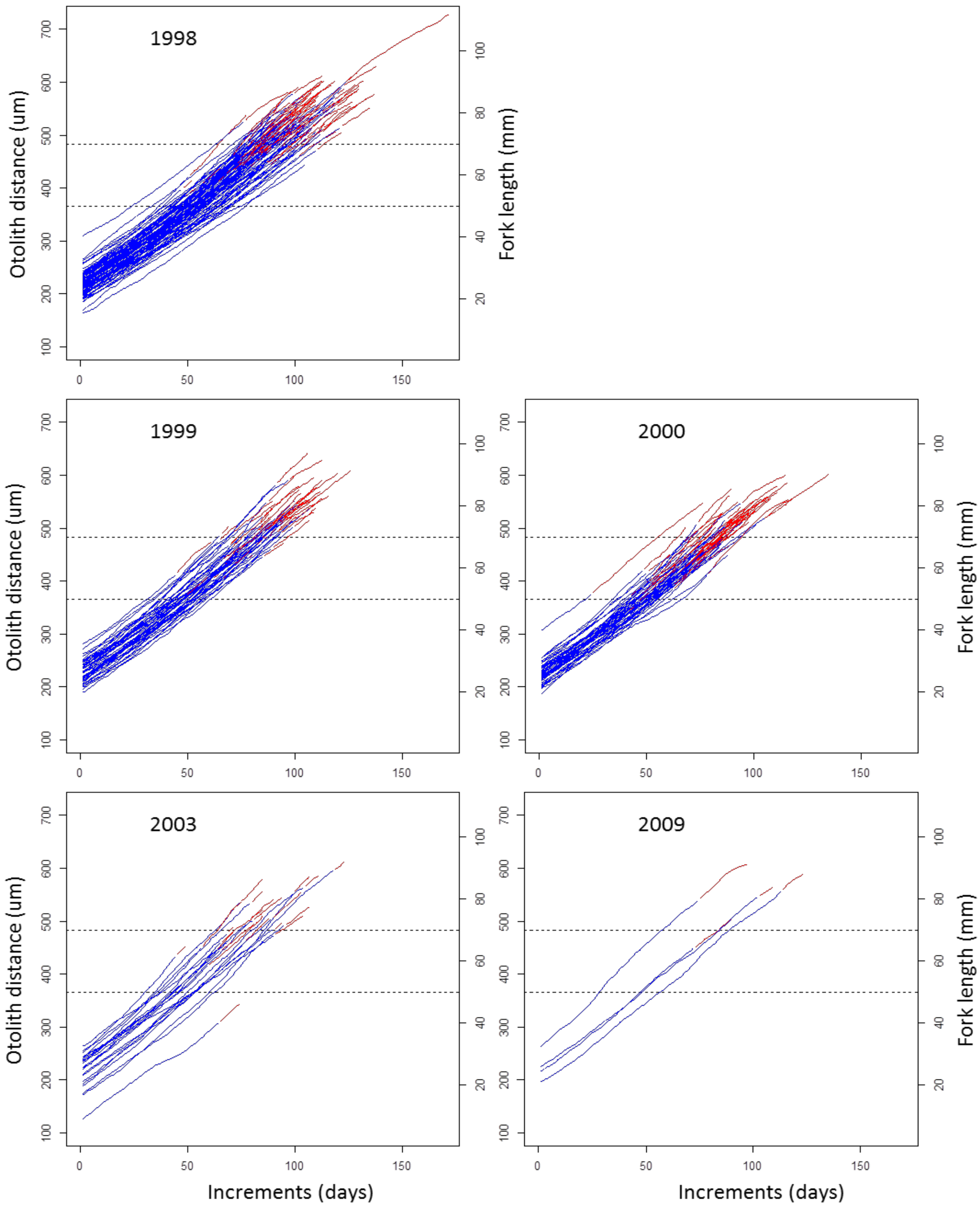

Figure 5.2-2. **Tuolumne River individual otolith growth trajectories. Each line shows data for an individual otolith. The blue portion shows growth in the Tuolumne River, the red portion shows growth after leaving the river but before entering salt water. Horizontal dashed lines indicate approximate otolith distances corresponding to the fry/parr (50 mm FL) and parr/smolt (70 mm FL) life stage transitions. Data source: Sturrock and Johnson (2014).**

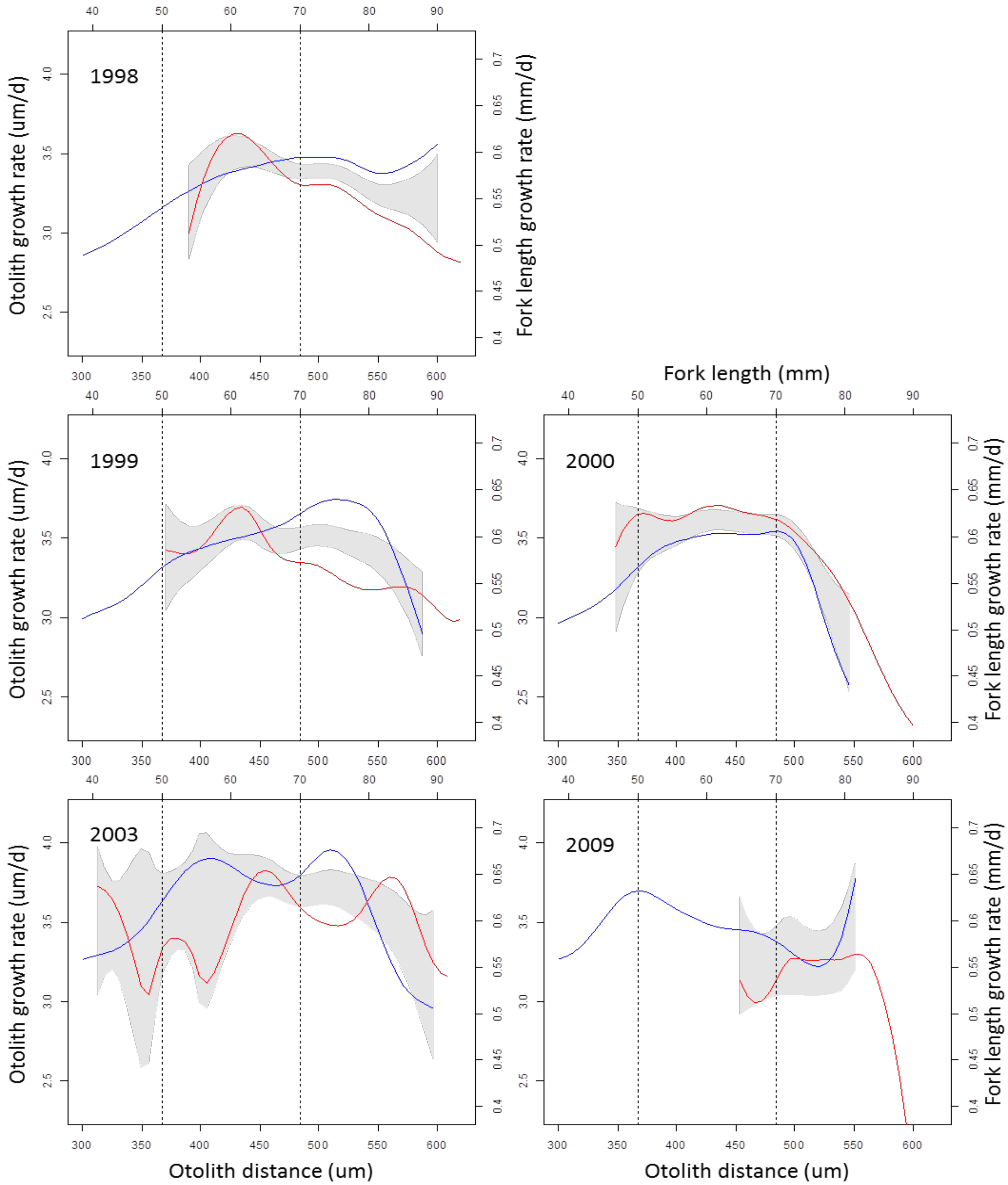

Figure 5.2-3. **Tuolumne River otolith growth rates as a function of fish size. Plots present smoothed (n=20) values of daily growth increments across all samples from a given outmigration year. The grey band encodes an approximate 95% confidence band for equality between samples from the Tuolumne River (blue line) and Delta (red line) habitats. Vertical dashed lines indicate approximate otolith distances corresponding to the fry/parr (50 mm FL) and parr/smolt (70 mm FL) life stage transitions. The fitted lines are clipped to a range in which there is some overlap between the otolith sizes. Data source: Sturrock and Johnson (2014).**

Using size cutoffs for juvenile life stage transitions in the Tuolumne River (fry <50 mm FL, parr ≥50 to <70 mm FL, and smolt ≥70 mm FL), emigrants from all juvenile life stages were represented in the returning adult spawning population. However, Tuolumne-origin adults were overwhelmingly comprised of individuals that had emigrated from the Tuolumne as parr and smolts, with only small contributions from fry-sized emigrants evident in 2000 and 2003 (Table 5.2-2). In 2000, a relatively high percentage of the returning adults had emigrated as parr (70%). In 2009, although the sample size was very low (n=5), an apparently high percentage of the returning adults had emigrated as smolts (80%) (Table 5.2-2).

Table 5.2-2. Water year type and juvenile outmigrant size classes at natal exit for unmarked fish. Life stage size cutoffs revised from fork length data presented in Sturrock and Johnson (2014).

Outmigration year	San Joaquin River Index Water Year Type	N	Fry (< 50 mm)	Parr (50–69 mm)	Smolt (≥ 70 mm)
1998	Wet	117	0%	34%	66%
1999	Above normal	55	0%	38%	62%
2000	Above normal	66[1]	5%	70%	26%
2003	Below normal	26	4%	42%	54%
2009	Below normal	5	0%	20%	80%

[1] Sample size for outmigration year 2000 incorrectly reported as 67 in Sturrock and Johnson (2014).

5.3 Hydrology

5.3.1 Daily flows

Tuolumne River hydrographs for WYs 1998, 1999, 2000, 2003, and 2009 are presented in Figure 5.3-1 and Figure 5.3-2. At the La Grange and Modesto gages, during the three above normal/wet WY types (1998, 1999, 2000), winter flows increased during December through February, typically remaining at or above 2,000 cfs until at least early/mid-summer. In WY 1998, average daily flows increased beginning in mid-January and remained high, exceeding 5,000 cfs multiple times from February through July. In WY 1999, flows increased to 2,000–3,000 cfs in December, and again in mid-January, remaining generally at or near this range through mid-May. WY 2000 experienced a relatively later increase in winter flows than either WY 1998 or 1999, with flow increases occurring in mid-February (Figure 5.3-1 and Figure 5.3-2).

Average daily flows at La Grange during the two below normal/dry WY types (2003, 2009) remained at or below approximately 200 cfs through March, with pulse flow releases peaking in mid-April at 1,500 cfs in WY 2003, and peaking in mid-May at 950 cfs in WY 2009 (Figure 5.3-1). In general, average daily flows were slightly greater further downstream at Modesto, with the exception of a short but relatively large increase in average daily flow (> 1,000 cfs) that occurred during early March in WY 2009 (Figure 5.3-2).

In the San Joaquin River at Vernalis, peak flows during the above normal/wet WY types 1998 and 1999 occurred in mid-February, although their relative magnitudes were opposite those of the Tuolumne River, with 1999 flows exceeding 1998 flows at this location (Figure 5.3-3). WY 2000 flows peaked approximately a month later in mid-March, consistent with hydrology exhibited in the Tuolumne River (Figure 5.3-1 and Figure 5.3-2). Average daily flows at Vernalis for the below normal/dry WY types exhibited the pulse flow releases in mid-April, similar to the Tuolumne River (Figure 5.3-3).

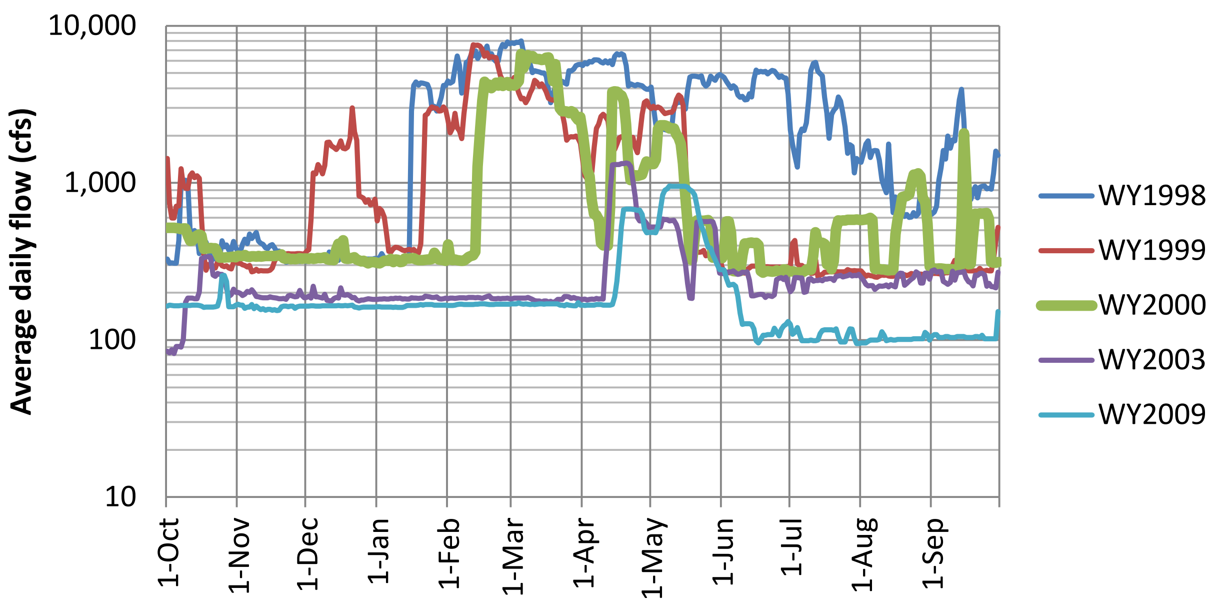

Figure 5.3-1. Tuolumne River average daily flow (cfs). Data from Tuolumne River Below La Grange Dam (USGS gage #11289650).

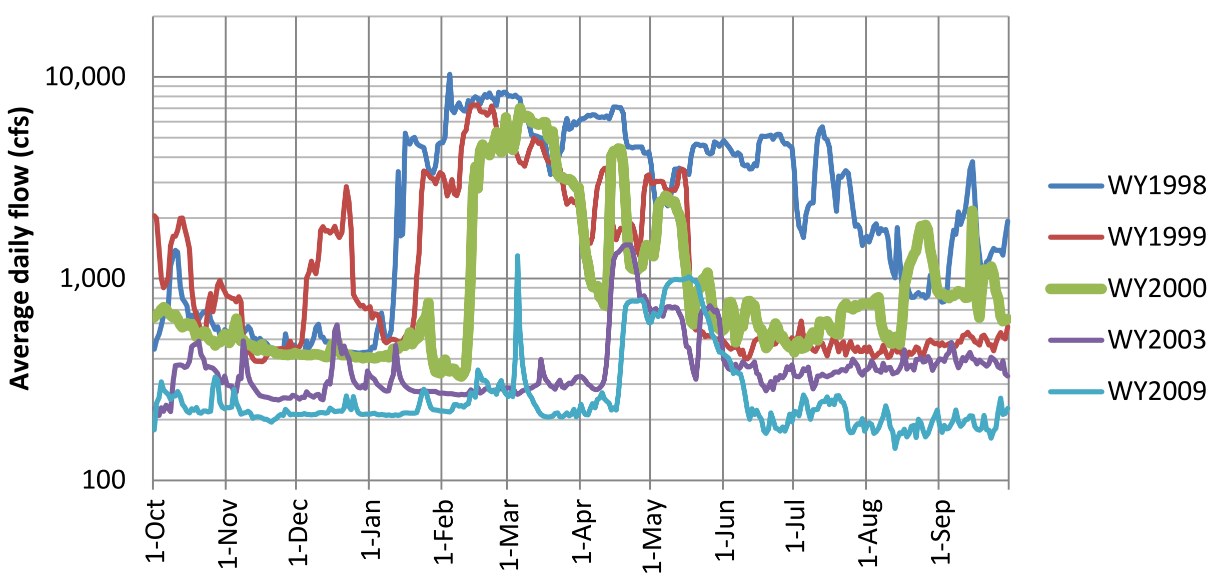

Figure 5.3-2. Tuolumne River average daily flow (cfs). Data from Tuolumne River at Modesto (USGS gage #11290000).

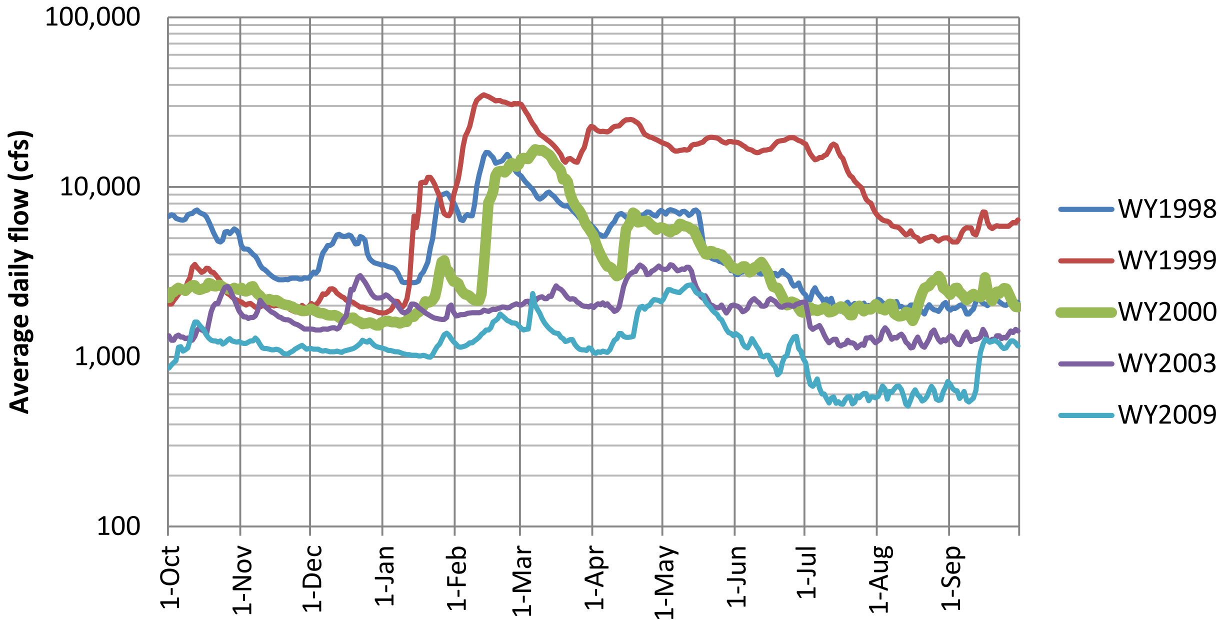

Figure 5.3-3. San Joaquin River average daily flow (cfs). Data from San Joaquin River at Vernalis (USGS gage #11303500).

5.3.2 Relationship between average daily flows and juvenile growth and residency

Average daily flow magnitude and timing was examined in relation to estimated mean fish size and age at exit for both the Tuolumne River (at La Grange and Modesto) and the Delta (at Vernalis) across above normal/wet WY types (1998, 1999, 2000) and dry WY types (2003, 2009). In 1998 and 1999, when average daily flows were sustained at relatively high levels during winter through spring months (extending into summer months in 1999), otolith data indicate that mean fish size and age at exit from the Tuolumne River for fish that returned to spawn were also relatively high, at approximately 73 mm FL (both years) corresponding to smolts, 91 days (1998), and 82 days (1999) (Table 5.2-1). Conversely, rotary screw trap data for 1998 and 1999 indicate that the majority of outmigrants were fry (< 50 mm FL) moving downstream during periods of increasing flow, with particularly high numbers (>500 per day) in WY 1999 (Figure 5.3-5 and Figure 5.3-6).

Although the pattern for 1998 and 1999 is consistent with prior observations of relatively larger sizes at emigration for above normal and wet WY types (Stillwater Sciences 2013b), mean fish size and age at natal exit (for fish that returned to spawn) were relatively lower at 64 mm and 69 days (Table 5.2-1) for outmigration year 2000, with the majority of individuals (70%) classified as parr (Figure 5.3-7). In contrast to other above normal and wet WY types examined, daily flows in the Tuolumne River did not increase until later in the winter (mid-February) in 2000, and were generally sustained through mid-May. Again, rotary screw trap data for WY 2000 indicate that the majority of outmigrants during WY 2000 were fry (< 50 mm FL), leaving in late February/early March (Figure 5.3-7).

Similar fish size associations were evident in the Delta as found at exit from the Tuolumne River, with larger mean fish size at ocean entry exhibited in outmigration years 1998–1999 than in 2000. However, the mean number of days spent rearing in the Delta was roughly twice as high in 2000 as in 1998 and 1999. As noted previously (Section 5.2), overall the total days from the end of exogenous feeding (i.e., emergence from gravels) to ocean entry was relatively constant at 99±20 days across all outmigration years included in the study, such that fewer days spent rearing in the Tuolumne River resulted in relatively more days rearing in the Delta (Figure 5.2-1).

Within the below normal WY types (2003, 2009), when average daily flows followed the FERC (1996) minimum flow schedule, including pulse flow releases from La Grange Diversion Dam, estimated mean fish size and age at exit were generally similar to those of the above normal/wet WY types 1998 and 1999. Rotary screw trap (RST) data indicate that very few or no fry were represented in the Shiloh Road RST (RM 3.4) data for the below normal/dry WY types (2003, 2009), in contrast to large number of fry that were observed outmigrating during the three wet WY types included in the study (1998, 1999, 2000) (Figure 5.3-8 and Figure 5.3-9). However, it should be noted that the traps were not installed until April 1 in WY 2003 and early March in WY 2009, so earlier fry emigration during these years would have been missed. Further, confirmation of any relationship between mean fish size and age at exit and below normal/dry WY hydrology should consider the relatively small sample size (n=31) for these WY types and for outmigration year 2009 in particular (n=5).

Lastly, additional exploratory analyses were conducted to determine whether barrier operations in the lower San Joaquin River and south Delta may have influenced the relative survival of early emigrating fry vs. later emigrating smolts. For example, the physical Head of Old River barrier (HORB) was in place in WY 2000 (Figure 5.3-7), corresponding to one of only two years in which there was a fry contribution to escapement (5%). Conversely, this physical (rock) barrier was not in place in WY's 1998 and 1999 when flows were too high to allow installation (Figure 5.3-5 and Figure 5.3-6); the estimated fry contribution to escapement for these years was zero. The physical HORB was in place for smolt outmigration in 2003 (Figure 5.3-8), the second of only two years when there was an estimated fry contribution to escapement (4%). An experimental behavioral barrier ("bubble barrier") was operated intermittently during smolt outmigration in 2009 when the estimated fry contribution was zero (Figure 5.3-9). These data suggest poor through-Delta juvenile survival in the absence of a physical HORB, consistent with prior studies evaluating survival of juvenile emigrants through the south Delta (Newman 2008, NMFS 2012).

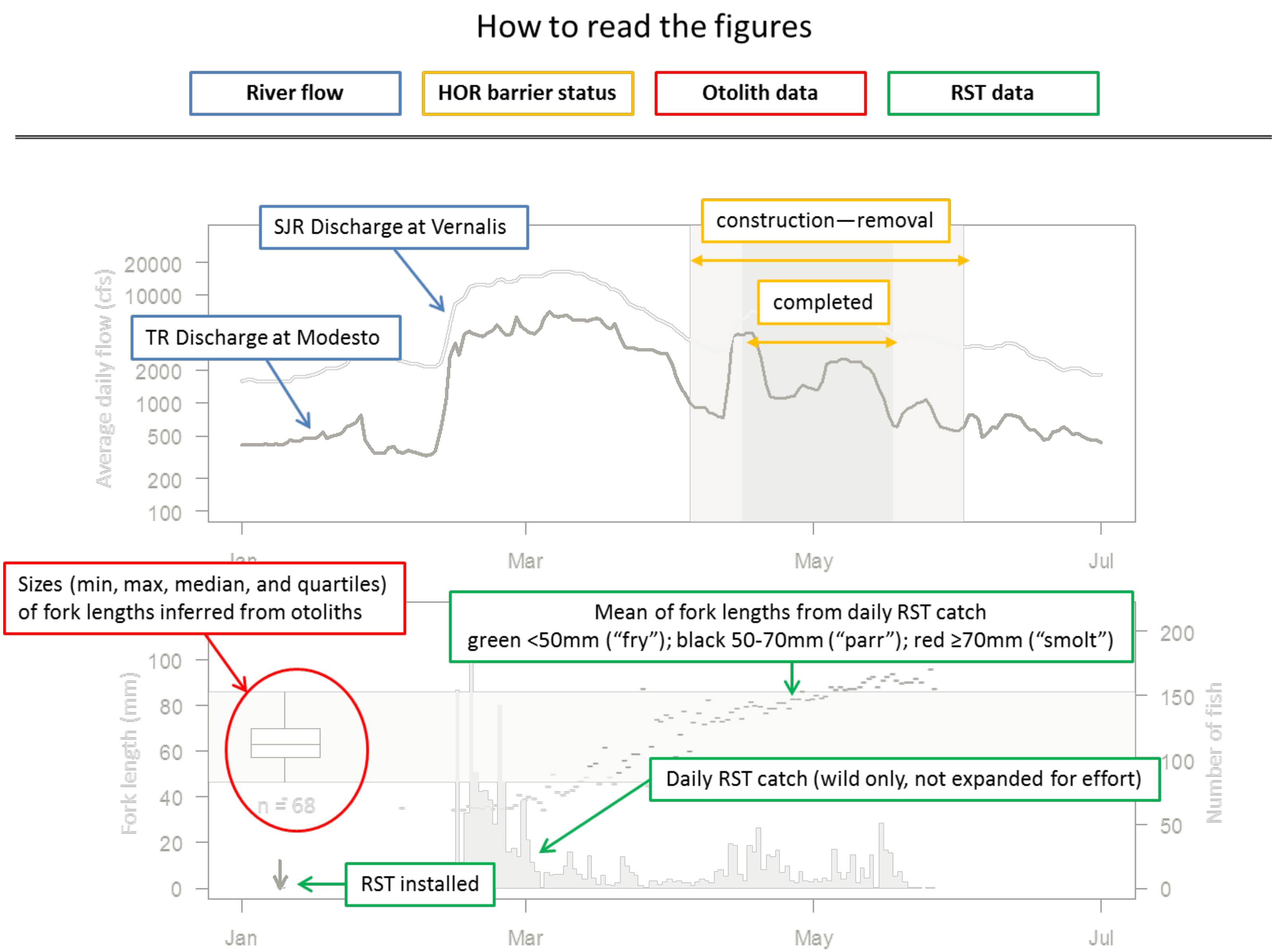

Figure 5.3-4. **Key for hydrology, rotary screw trap (RST) data, and of size-at-exit of returning fish (from otolith analysis).**

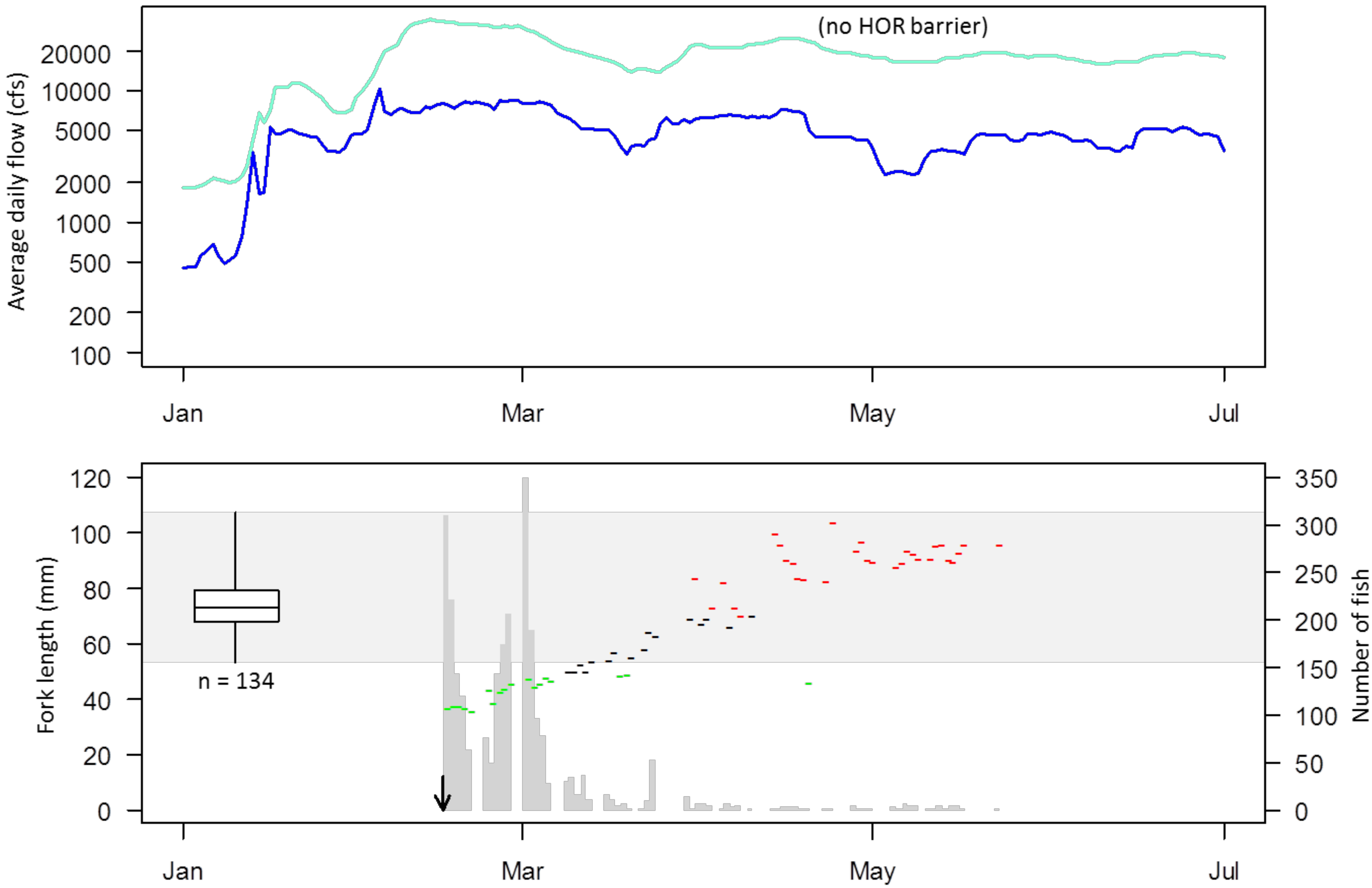

Figure 5.3-5. **1998 hydrology (Tuolumne River at Modesto [blue line] and the Delta at Vernalis [light blue line]), together with sizes and counts from the rotary screw trap (RST) near Shiloh and summary of size-at-exit of returning fish, estimated from otolith analysis (see also key in Figure 5.3-4).**

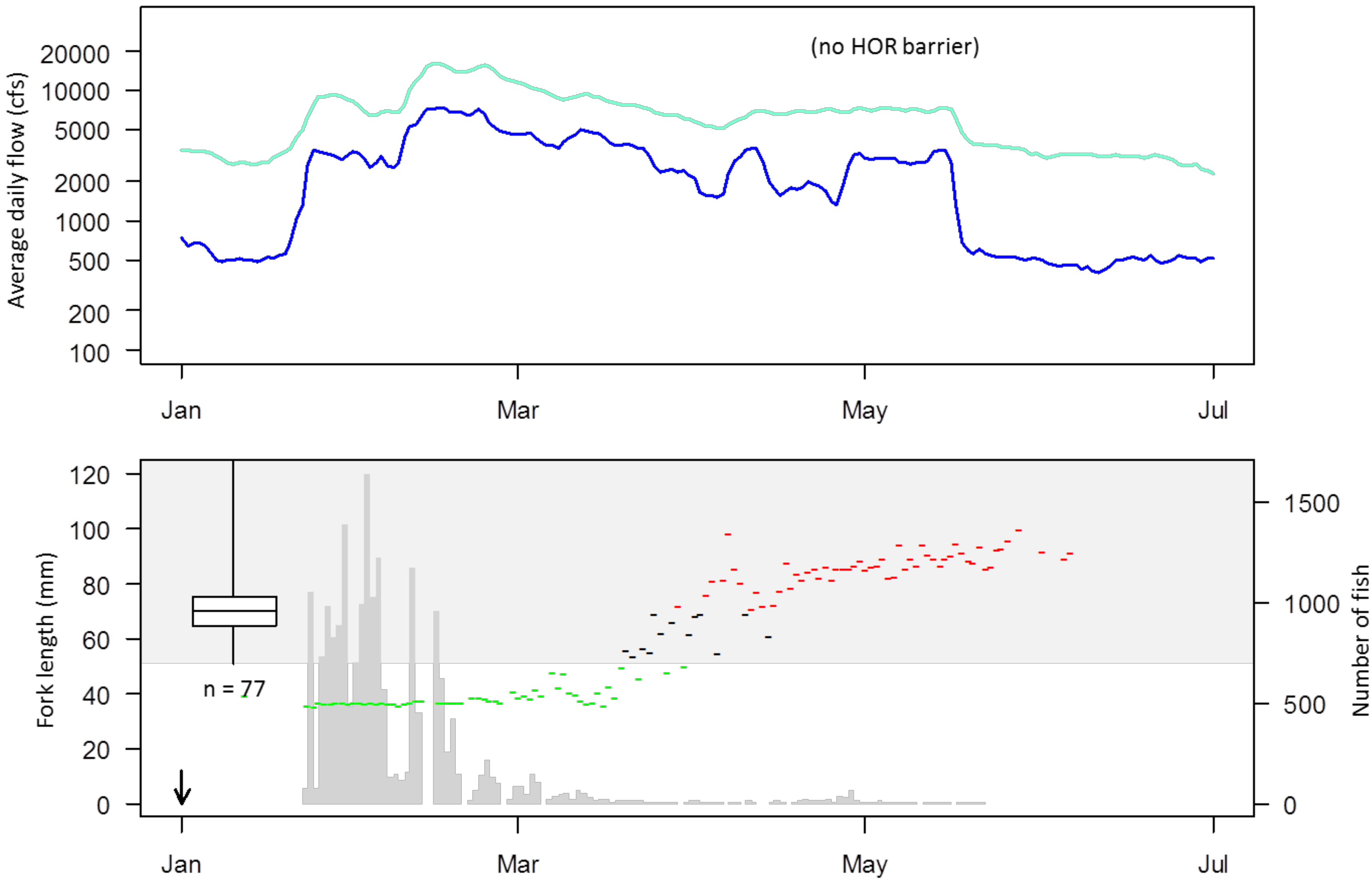

Figure 5.3-6. **1999 hydrology (Tuolumne River at Modesto [blue line] and the Delta at Vernalis [light blue line]), together with sizes and counts from the rotary screw trap (RST) near Shiloh and summary of size-at-exit of returning fish, estimated from otolith analysis (see also key in Figure 5.3-4).**

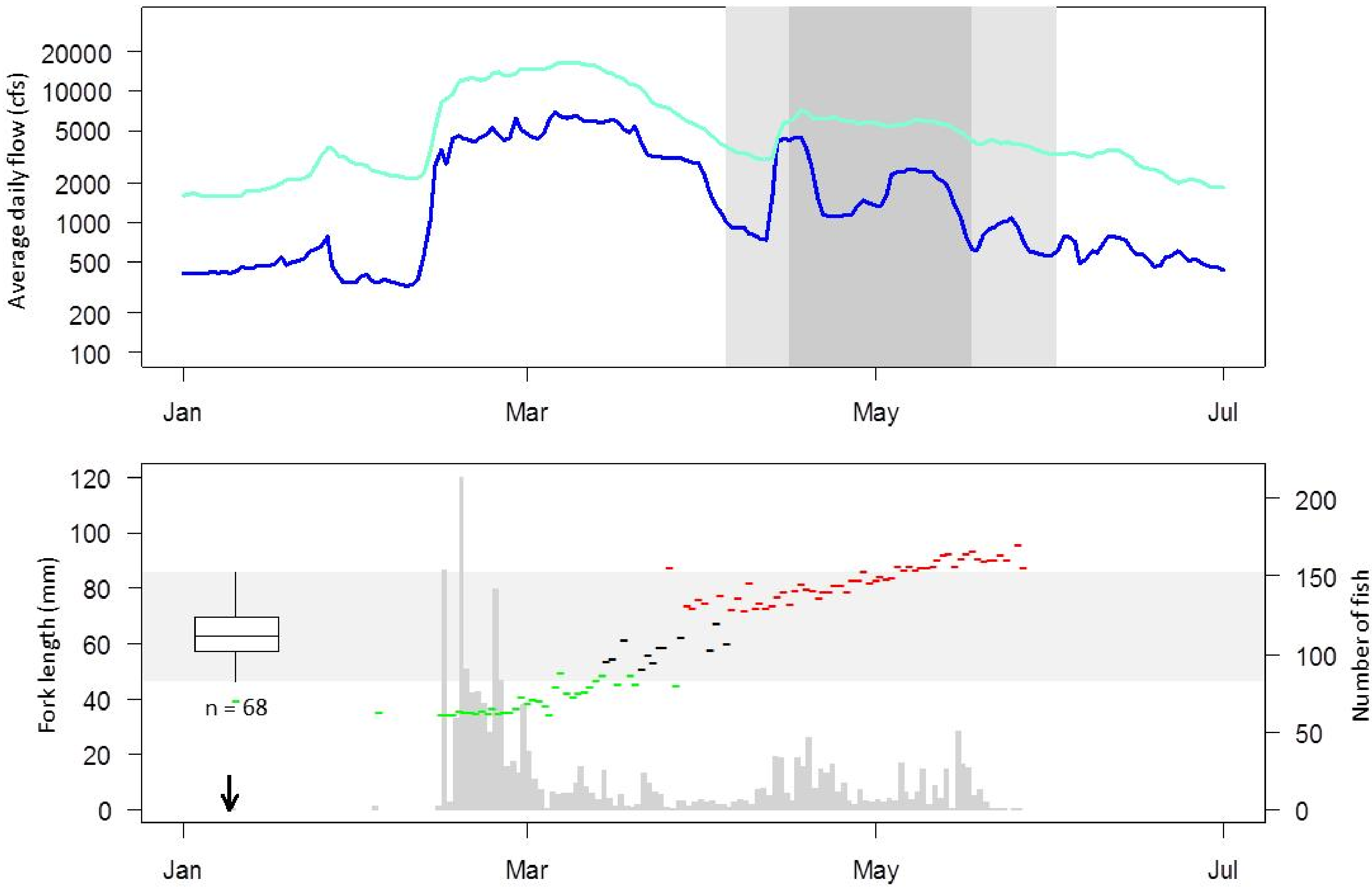

Figure 5.3-7. **2000 hydrology (Tuolumne River at Modesto [blue line] and the Delta at Vernalis [light blue line]), together with sizes and counts from the rotary screw trap (RST) near Shiloh and summary of size-at-exit of returning fish, estimated from otolith analysis (see also key in Figure 5.3-4).**

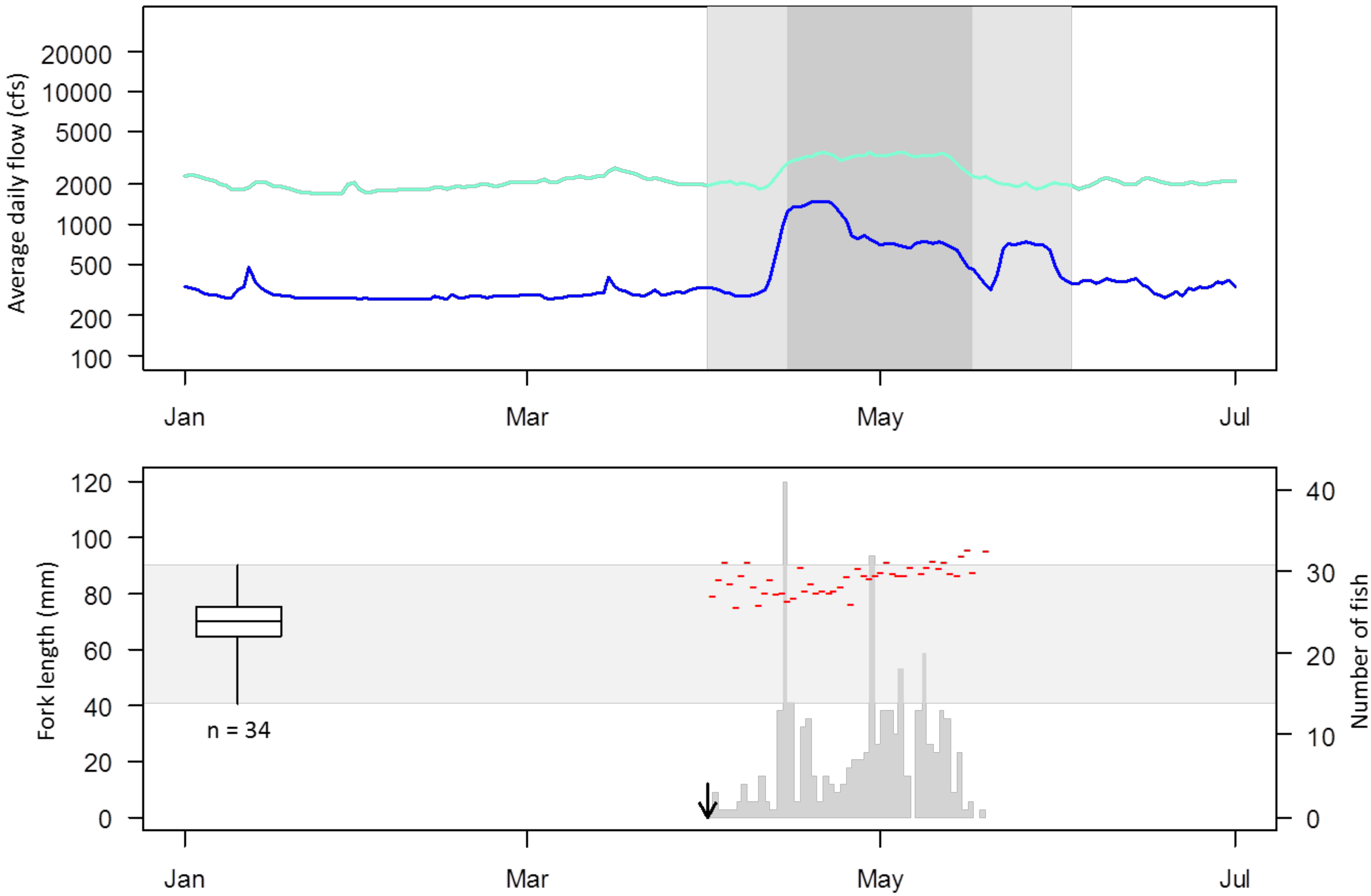

Figure 5.3-8. **2003 hydrology (Tuolumne River at Modesto [blue line] and the Delta at Vernalis [light blue line]), together with sizes and counts from the rotary screw trap (RST) near Shiloh and summary of size-at-exit of returning fish, estimated from otolith analysis (see also key in Figure 5.3-4).**

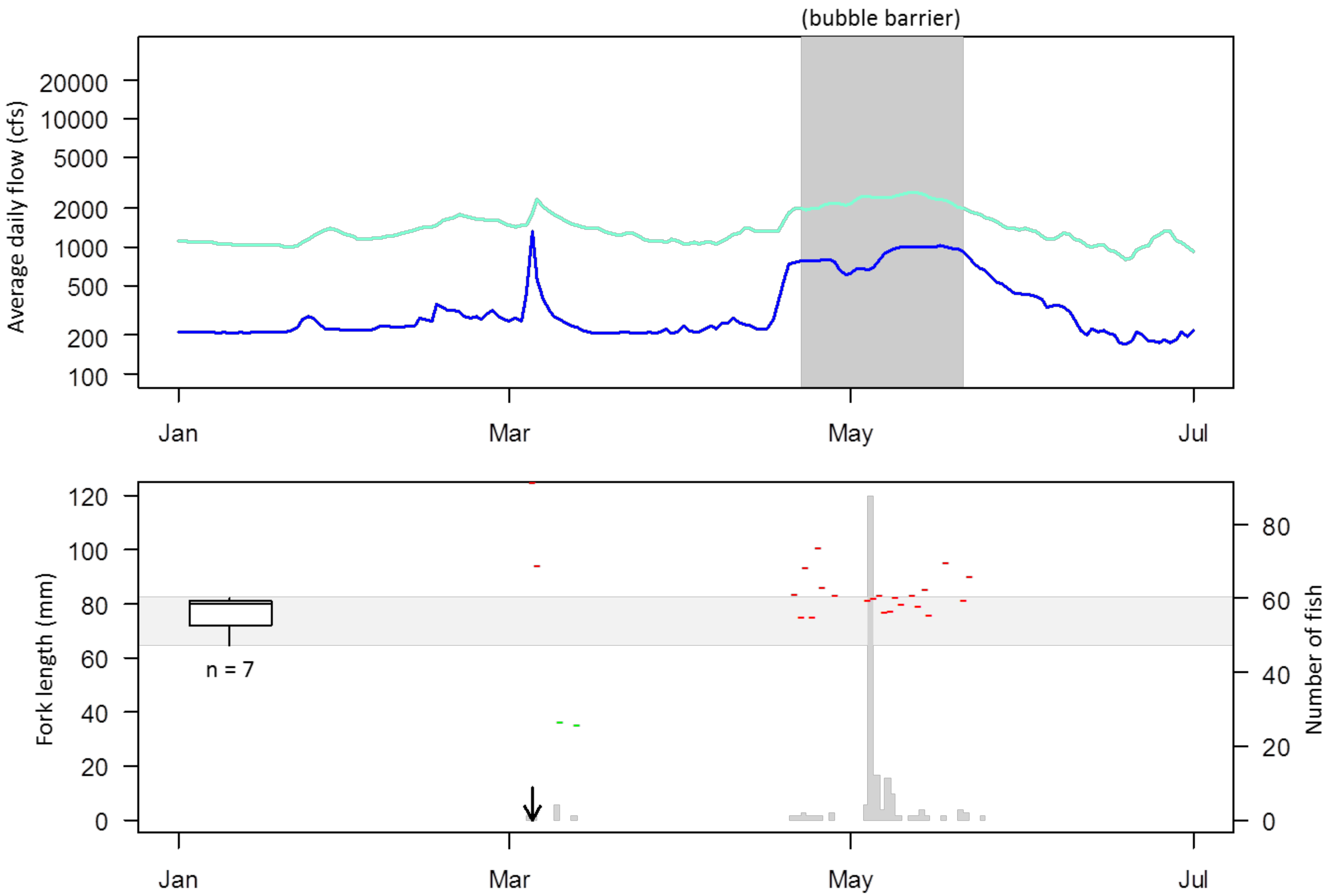

Figure 5.3-9. 2009 hydrology (Tuolumne River at Modesto [blue line] and the Delta at Vernalis [light blue line]), together with sizes and counts from the rotary screw trap (RST) near Shiloh and summary of size-at-exit of returning fish, estimated from otolith analysis (see also key in Figure 5.3-4).

5.3.3 Relationships between monthly flows and early life-history emigration patterns

Other than associations with HORB status (Section 5.3.2), examination of mean monthly discharge, minimum monthly discharge, and maximum monthly discharge in the Tuolumne River at La Grange and Modesto for January through April did not reveal a discernable relationship with respect to growth rate, size at outmigration, or age at either outmigration or ocean entry for juveniles that originated in and returned to the Tuolumne River during the five years included in this study. Delta hydrologic patterns (at Vernalis) on a monthly timescale also did not exhibit clear relationships with growth rate, fish size, or age at ocean entry. Linear regressions indicated a lack of any compelling relationship ($R^2<0.4$, $p>0.1$) for the 192 combinations of fish size, fish age, monthly average flows for each of four months (January, February, March, April), and each of the 24 DAYFLOW parameters/indices (see Section 4.3).

6.0 DISCUSSION AND FINDINGS

Results of the analyses described above met both of the study objectives of using otolith microstructural growth patterns and/or microchemistry in order to identify:

- whether returning adults originated from hatcheries or riverine environments other than the Tuolumne River; and,
- growth rates and sizes of ‘wild’ fish at exit from the Tuolumne River and from the freshwater Delta.

These are discussed further below.

6.1 Hatchery origin fish

To provide an estimate of total hatchery contributions to Tuolumne River spawning escapement for the years examined in this study, the existing proportions of adipose fin clipped (i.e., hatchery marked) fish from CDFW annual spawning surveys can be combined with the proportions of unmarked hatchery fish estimated through otolith analysis. For each of the five outmigration years included in this study, a significant number of unmarked fish were classified as hatchery-origin fish through microstructural examination of otolith samples. The proportion of returning unmarked adults that originated in Central Valley hatcheries was greatest for the two below normal WY types (2003, 2009), exceeding the contribution from wild fish by approximately 2–4 times (Figure 5.1-1). The proportion of hatchery fish was relatively lower for above normal/wet WY types (1998, 1999, 2000), with the lowest proportion (33-44%) corresponding to outmigration year 1998 (Table 5.1-1). While these patterns are suggestive of a positive relationship between flow and the successful emigration of wild fish that later return as adults, confirmation of this relationship based on WY type should consider the relatively small sample size for below normal/dry WY types (n=31) vs. above normal/wet WY types (n=238).

Table 6.1-1 shows the proportions of marked (ad-clipped) and unmarked fish identified in the eight CDFW spawner survey years that recovered fish from outmigration years 1998, 1999, 2000, 2003, and 2009. The proportion of marked hatchery fish ranged from a low of 1% in 2006 to a high of 55% in 2011. For the unmarked fish, approximately 43% were identified as hatchery-origin (n=255) using results of the otolith analysis (Section 5.1). Combining the outmigration year unmarked hatchery contribution estimates with the known marked fish from subsequent escapement year surveys, Table 6.1-1 shows the total estimated hatchery contribution ranged from 39 to 100%, with a mean of 67% and generally increasing hatchery contribution in later years. To further refine this estimate and recognizing that some years in the otolith sample inventory over- and under-represent the typical age class structure in the escapement record, the overall proportion using only 3-year old recoveries, which are expected to make up the bulk of the annual escapement, ranges from 36 to 90%, with a mean of 58% (Table 6.1-1). Further consideration of large coded wire tag (CWT) releases to the Tuolumne River up to April 2005 suggests that some of the marked fish returning to the river during this period could be from the CWT release groups and thus would not be considered true hatchery strays. Separating the Tuolumne River CWT release groups from all marked (ad-clipped) fish identified in the annual spawner surveys would reduce the estimated hatchery fractions for these years in Table 6.1-1. At the same time, large hatchery releases into the Tuolumne River may potentially have swamped the existing predator population and increased outmigrant survival of emigrating wild fish. This would have the effect of slightly increasing the number of wild fish successfully emigrating and eventually returning to spawn. Nevertheless, it is apparent that hatchery contributions make up a large proportion of the annual spawning runs and the proportions of hatchery fish have been increasing in recent years.

Table 6.1-1. Estimated total hatchery contribution to annual escapement for spawner years corresponding to the five outmigration years included in the otolith study.

Spawner Year	CDFW spawner surveys			Including unmarked hatchery fish (all otolith samples)			Including unmarked hatchery fish (Age-3 otolith samples only)		
	Escapement[1]	Fraction Marked[2]	Marked Fish[2]	Unmarked Hatchery	Total Hatchery	Fraction Hatchery	Unmarked Hatchery	Total Hatchery	Fraction Hatchery
2000	17,873	6%	1,157	5,742	6,899	39%	5,207	6,364	36%
2001	9,222	16%	1,464	2,466	3,930	43%	2,667	4,131	45%
2002	7,125	31%	2,175	1,824	3,999	56%	1,566	3,742	53%
2005	719	11%	82	396	477	66%	396	477	66%
2006	625	1%	7	481	488	78%	-	-	-
2010	766	32%	245	521	766	100%	-	-	-
2011	2,847	55%	1,566	982	2,548	90%	982	2,548	90%
2012	2,120	29%	615	753	1,367	65%	-	-	-
Mean						67%	Mean		58%

1 Data source: Stillwater Sciences (2013c).
2 Data sources: Annual CDFW spawning survey reports (e.g., CDFG 2010) and annual FishBio weir monitoring reports (e.g., Wright et al. 2013).

Overall, results of this study are consistent with observations of increasing hatchery contributions to salmon escapement in the Central Valley as a whole (Barnett-Johnson 2007, Johnson et al. 2011). The high proportions of marked and unmarked hatchery-origin fish represented in spawning runs to the Tuolumne River suggests that the influence of Project related effects upon salmon production as well as the ability to discriminate the effectiveness of potential measures intended to benefit Chinook salmon may be obscured by variations in the production and ocean survival of hatchery fish from the Merced River Fish Facility and other Central Valley hatcheries.

6.2 Growth and residence in the Tuolumne River and the Delta

Based on Sr isotope ratios ($^{87}Sr/^{86}Sr$) and otolith microstructural features, the study results suggest that mean fish size at exit from the Tuolumne River showed no apparent relationship with WY type, with the exception of outmigration year 2000 when mean fish size was significantly different ($p<0.005$) from the other four years of the study. Mean fish size at freshwater exit from the Delta also did not exhibit a relationship with WY type.

Age distributions at exit from the Tuolumne River and at exit from the Delta suggest that overall the total days of development from formation of otolith core to ocean entry for juvenile salmonids was relatively constant at 99±20 days for each of the five outmigration years included in the study. Fewer days spent rearing in the Tuolumne River resulted in relatively more days rearing in the Delta (Figure 5.2-1). The latter suggests extended rearing in the Delta for some parr-sized fish that emigrate early from the Tuolumne River. This is particularly evident in the average number of days spent in the Delta (27.6±12.1 days; Table 5.2-1) for outmigrating juveniles in 2000, which exceeded a more typical migration time of 14–21 days and suggests that some fish spent over 4 weeks in the Delta during the 2000 outmigration.

Size-standardized estimated growth rates from this study were generally greater for fish that reared in the Tuolumne River as compared with fish that reared in the Delta, but the pattern was not consistently statistically distinguishable between the two rearing locations. As discussed in the Salmonid Information Synthesis Study (Stillwater Sciences 2013b), available food resources in the Delta may be limiting growth opportunities for juvenile Chinook salmon in some conditions, with effects upon early ocean survival and long-term population levels. For example, MacFarlane and Norton (2002) found that as compared to upstream (riverine) rearing locations, juvenile Chinook grew more slowly in the Delta and San Francisco Bay estuary.

6.3 Phenotypic contributions to spawning and potential management implications

Based upon the limited number of sampling years and otoliths available for analysis by this study, it is apparent that spawning populations in the Tuolumne River exhibit low representation of early emigrating fry, with zero contributions in three out of five outmigration years analyzed and a maximum contribution of 5% in WY 2000. However, a 5% fry contribution in years when escapement on the order of 5,000–10,000 returning adults is a non-negligible number of fish (250–500 spawners) and may be on par with total spawner numbers in low escapement years. Although observations of phenotypic contributions to spawning in the Stanislaus River indicate relatively higher fry contributions during both WY 2000 (23%) and WY 2003 (10%) (Sturrock et al. 2015), parr and smolt sized emigrants represented the vast majority of returning adults in both rivers, implying a survival advantage for fish emigrating at larger sizes.

The relative spawner contributions of juvenile Chinook salmon emigrating from the Tuolumne River at size classes corresponding to fry (<50 mm FL), parr (≥50 to <70 mm FL), and smolt (≥70 mm FL) did not vary consistently with WY type or discharge in this study. The relatively high parr (70%) and fry (5%) representation in returning adults for outmigration year 2000 is interesting, especially given that year 2000 exhibited lower and later-peaking average daily flows than the other two above normal/wet years included in the study (1998, 1999). Although the timing of juvenile life stage transitions and timing of outmigration are relatively consistent from year-to-year, we conducted additional analyses to explore the potential effects of brood-year spawner timing as well as the effects of flow and barrier operations during juvenile outmigration.

For the above normal/wet WY types represented in the otolith samples, consideration of spawner run timing in 1997, 1998, and 1999, which corresponds to outmigration years 1998, 1999, and 2000, suggests that the peak of spawning occurred 7–9 days earlier in 1997 and 1998 than the 1999 run, where the latter corresponds to the year 2000 outmigration (Figure 6.3-1). By comparison, the peak of spawner run timing for the two below normal/dry WY types (i.e., spawner years 2002 and 2008) differ by only 3-days (Figure 6.3-1). One potential explanation of the lower fry representation of spawners originating from outmigration years 1998 and 1999 is the combination of earlier spawning during 1997 and 1998 and the extended high flows that occurred during 1998 and 1999 (Figure 5.3-5 and Figure 5.3-6). These factors may have resulted in extended in-river rearing and relatively higher numbers of fish emigrating at larger (i.e., smolt) sizes in these years than occurred in 2000. Another potential explanation of differing representation of fry contributions to subsequent spawning is that the two years of extended high flows during spring 1998 and 1999 may have disrupted nesting and other essential reproductive behaviors of predators such as black bass (Loppnow et al. 2013, Cavallo et al. 2012, Kleinschmidt 2008, Montgomery et al. 1980) and led to reduced predator populations and greater numbers of fry emigrating from the Tuolumne River and into the Delta during WY 2000 (Figure 5.3-7).

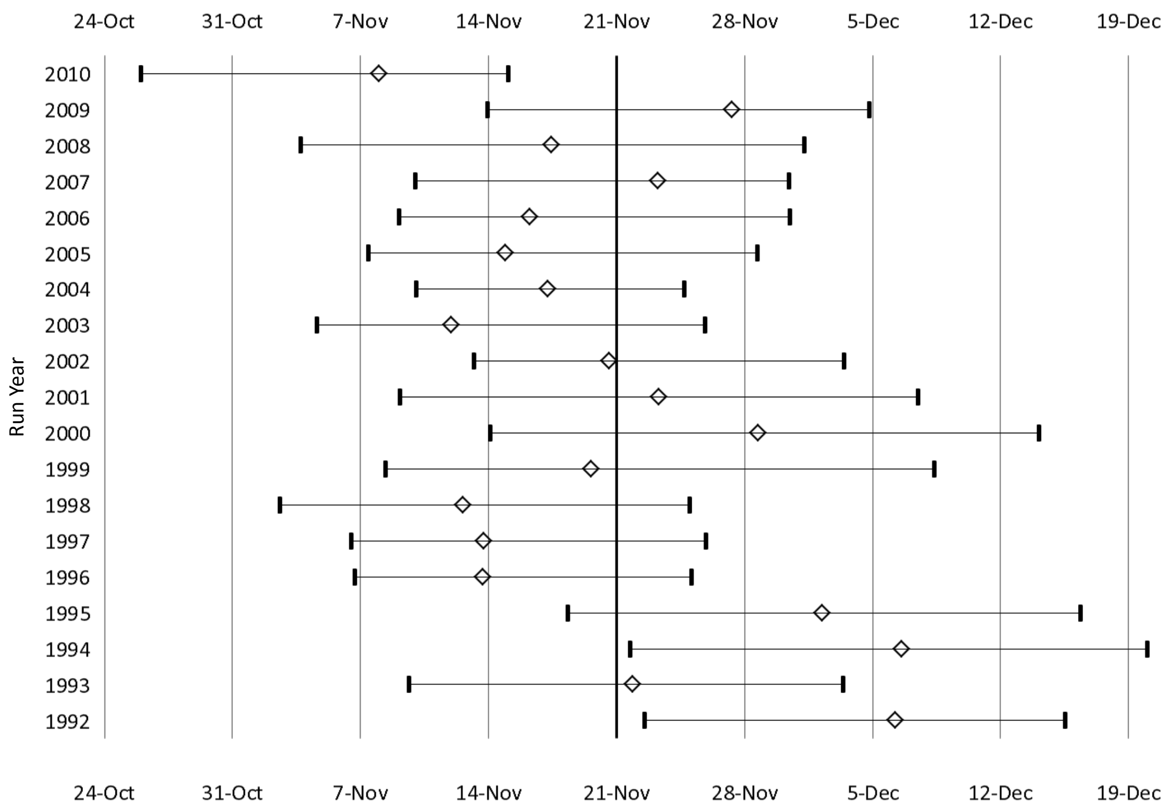

Figure 6.3-1. Tuolumne River spawner run-timing. Data sources: Annual CDFW spawning survey reports (e.g., CDFG 2010) and annual FishBio weir monitoring reports since 2009 (e.g., Wright et al. 2013).

The low fry contributions identified in this study for both wet and dry WY types suggest that flow-related increases in the number of juvenile Chinook salmon leaving the Tuolumne River as fry may not necessarily result in corresponding increases in subsequent escapement. In addition to spawner timing and flow related effects upon phenotypic contributions to spawning populations discussed above, we also examined the influence of barrier operations in the south Delta. Among the three above normal/wet WY types represented in the otolith samples, the physical HORB was only installed in WY 2000. This may have increased fry contribution to subsequent spawner returns relative to WY 1998 and 1999 when the HORB was not in place. Based upon the statistically significant improvements in through-Delta survival of juvenile Chinook salmon with the HORB in place (Newman 2008), HORB operation in WY 2003 may have also reduced mortality of later emigrating fry in this year as well, when 4% of returning spawners appear to have emigrated as fry. By WY 2009, the physical HORB was no longer used and it is possible that the low contribution from fry originating in this year may be due to a combination of fry entrainment into Old River as well as increased rates of predation.

As previously stated, the conclusions of this study are based upon a relatively small otolith sample size (n=31) for spawners originating from below normal/dry WY types as compared to samples (n=238) from the above normal/wet WY types. Additional analysis of adult otoliths from individuals emigrating under current Delta flow management for both above normal/wet as well as below normal/dry WY types in the future may help better discern whether variations in spring discharge are associated with greater or lower juvenile size class representation in subsequent spawning populations.

7.0 STUDY VARIANCES AND MODIFICATIONS

The study was conducted in conformance to the FERC-approved *Chinook Salmon Otolith Study Plan* (W&AR-11) approved in FERC's December 22, 2011 Determination. There are no variances.

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Study Report W&AR-11
Chinook Salmon Otolith Study

Appendix A

Tuolumne River Chinook Salmon Otolith Study – Analysis of Archival Otoliths Using Stable Isotope Microchemistry

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TUOLUMNE RIVER CHINOOK SALMON OTOLITH STUDY - ANALYSIS OF ARCHIVAL OTOLITHS USING STABLE ISOTOPE MICROCHEMISTRY

Prepared by Drs. Anna Sturrock and Rachel Johnson as part of Don Pedro Project Relicensing (FERC No. 2299)

UNIVERSITY OF CALIFORNIA DAVIS

PERIOD 11/13-6/14

EXECUTIVE SUMMARY

Processes occurring in freshwater, estuarine, and marine habitats strongly influence the growth, survival and reproductive success of salmonids. One of the fundamental challenges in understanding salmon population dynamics lies in our inability to link and evaluate the relative importance of processes occurring throughout the complex salmon life cycle. For example, a critical unknown is the extent to which environmental conditions and management actions in the freshwater contribute to the expression and survivorship of different juvenile outmigration strategies into adulthood.

Here, we use Sr isotope ratios ($^{87}Sr/^{86}Sr$) and daily growth information recorded in Central Valley fall-run Chinook salmon, *Oncorhynchus tshawytcha,* otoliths ("earbones") to reconstruct the stream or hatchery-of-origin and early life movements of adult salmon collected on the Tuolumne River in the San Joaquin River Basin, California. A total of 598 paired otolith and scale samples were used to reconstruct and compare size-specific outmigration patterns for fish emigrating from the Tuolumne River in the spring of 1998, 1999, 2000, 2003 and 2009, incorporating dry, below normal, above normal and wet water year types. First, we identified adults that originated from the Tuolumne River (i.e. removed strays) using an updated 'strontium isoscape' and otolith growth characteristics exhibited by hatchery and wild salmon in the Central Valley [1, 2]. For each individual, otolith isotopic and microstructural data were linked with otolith radius in order to reconstruct the size and age at which they had exited from their natal river and from freshwater. Back-calculated fork lengths (± 95% CI) were used to classify outmigrants into one of three life history stages: fry (≤55mm), parr (>55mm to ≤75mm) or smolt (>75 mm).

Our study shows that a significant number of adults spawning in the Tuolumne River in fall of 2000-2012 were strays from other rivers and hatcheries in the Central Valley. The earliest three outmigration years examined had relatively low straying rates of unmarked fish, with a greater proportion of spawners having originated in and reared in the Tuolumne River (1998: 57-68% returns, 33-44% strays; 1999: 38-53% returns, 47-62% strays; 2000: 61-64% returns, 36-39% strays). Outmigration year 2003 exhibited an intermediary straying rate (27-35% returns, 65-73% strays) while outmigration year 2009 was subject to particularly high straying rates (9-15% returns, 85-91% strays, primarily from the Coleman National Fish Hatchery on Battle Creek in the Sacramento River watershed, which comprised 57% of the unmarked sample).

All size classes of juvenile outmigrants were represented in the adult spawning populations. Tuolumne-origin adults were largely comprised of individuals that had emigrated from the Tuolumne River as parr and smolts, however, in outmigration year 2000, 20% of the returning adults had outmigrated as fry. Comparable with findings on other rivers in the San Joaquin Basin, parr outmigrants were consistently the most commonly observed phenotype in the returning adults.

INTRODUCTION

Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) exhibit significant variation in the size, timing and age that they emigrate from their natal rivers [14]. Typically, juveniles rear in the freshwater for one to three months before smoltification prompts downstream migration towards the ocean; however, early spring flows are often also coupled with large pulses of emigrating fry [5, 14, 17]. In some years, fry-sized individuals are the most numerous size-class leaving natal rivers and entering the delta [17, 18]. The contribution of these smaller outmigrants to the adult population is often assumed to be negligible, as juvenile survival is generally positively correlated with body size [e.g. 19] and there is little evidence for significant downstream rearing in the San Francisco estuary [20]. Hatcheries tend to release larger smolts to maximize survival rates and their contribution to the ocean fishery, but a recent study indicated that the majority of California Central Valley (CCV) adults captured in the Oregon troll fishery had emigrated as fry and parr [21]. Scale analyses have also inferred greater survival rates of intermediate-sized juveniles [22]. Understanding the relative survivorship of different outmigrant size classes is critical to our understanding of population dynamics and evaluation of freshwater management actions and water operations.

Quantifying the relative contribution of different size classes and/or developmental stages of juvenile salmon to the adult spawning population has largely been limited by the methodological challenges associated with reconstructing early life history movements of the adults. Mark-recapture studies using coded wire tags (CWT) have provided empirical indices of juvenile survival rates through the Sacramento-San Joaquin system [28], but are hindered by low rates of return and often use hatchery fish, which may exhibit different behavior and survival than their wild counterparts [29]. No study to date has tracked habitat use of individual salmon over an entire lifecycle to estimate the relative success or survivorship of juvenile outmigration phenotypes, let alone under different flow conditions or between different rivers in the same year. Most have relied on correlations between environmental conditions (e.g. flow) experienced during juvenile outmigration periods and abundance of returns [16, 30].

Recent advances in techniques using chemical markers recorded in biomineralized tissues provide rare opportunity to retrospectively "geolocate" individual fish in time and space [31]. Otoliths are metabolically inert, calcium carbonate "earbones" found in all bony fishes, that grow incrementally from birth (the otolith "primordia") to death (the outer edge of the otolith). The otolith microstructure features daily and annual growth rings that can be determined visually using light microscopy [32]. In Chinook salmon, as the otoliths grow proportionally to fish length during juvenile stages, daily increment widths can be used to reconstruct individual growth trajectories, providing a means to compare growth rates across life stages, hydrologic regimes and contrasting environments. Otolith microstructure can therefore provide insights into how juvenile salmon growth is affected by biotic and abiotic factors such as food availability and water temperature. When microstructural and microchemical techniques are combined, otoliths can provide a powerful natural tag for reconstructing movement patterns of individual fish [33]. The technique relies on differences in the physicochemical environment producing a distinct and reproducible "chemical fingerprint" in the otolith. In the CCV, strontium isotopes ($^{87}Sr/^{86}Sr$) are ideal markers because the water signature varies with the parent geology, differing among many of the rivers and salmon outmigration paths, and is faithfully recorded in the otoliths of Chinook salmon [1, 34]. Changes in otolith $^{87}Sr/^{86}Sr$ values can be used to reconstruct time- and age-resolved movements as salmon migrate through the freshwater, estuarine, and ocean environments [1, 34]. Furthermore, in salmon, otolith size is significantly related to body size [32, 35, 36], allowing back-calculation of individual fork length (FL) at specific life history events.

Here, we used otolith $^{87}Sr/^{86}Sr$ ratios and microstructure to identify natal origin and reconstruct size/age at emigration of adults that spawned in the Tuolumne River in 1996-2008. These adults represent cohorts that emigrated as juveniles from the freshwater in 1998, 1999, 2000, 2003 or 2009. First we used the otolith data to differentiate between adults that strayed from other rivers from adults that were born and returned to the Tuolumne River. After removing strays from other rivers, we used otolith $^{87}Sr/^{86}Sr$ ratios, growth increments and radii to determine the size and age at which returning (i.e. "successful") adults had originally emigrated from the Tuolumne River and from the freshwater system. We aimed to address the following questions:

1. What was the early fresh-water life history of the adult Chinook salmon? More specifically, at what age (days from exogenous feeding) and estimated size did the returning adult leave the Tuolumne River as a juvenile?
2. What was the origin of the adult Chinook salmon? More specifically, what portion of the adult Chinook salmon escaping to the Tuolumne River originated from the Tuolumne River separate from hatcheries and other riverine environments of the Sacramento and San Joaquin Central Valley drainages?

STUDY AREA

The Tuolumne River is one of the southernmost tributaries of the San Joaquin River (SJR) (Fig. 1). The lower basin typically experiences a Mediterranean climate with wet winters and dry summers, and the tributaries are predominantly fed by snowmelt from the Sierra Nevada Mountains. The Tuolumne watershed encompasses a 1,900 square-mile area of the central Sierra Nevada and northern San Joaquin Valley and includes the northern half of Yosemite National Park. The Tuolumne is the largest tributary to the SJR, producing an average annual unimpaired yield of 1,906,000 acre-feet. The river flows for 150 miles from its headwaters at over 13,000 ft on Mt. Dana and Mt. Lyell to its confluence with the SJR at an elevation of 30 ft . The lower Tuolumne extends from its confluence with the SJR to La Grange Dam at river mile (rm) 52.2, which has been the upstream barrier to anadromous fish movements since at least 1871 [10].

Around 90% of the annual precipitation on the Tuolumne River occurs between November and April, with an annual minimum flow schedule including migration pulse flows in April and May required by the Federal Energy Regulatory Commission (FERC 1996).

METHODS

ADULT SAMPLING AND COHORT RECONSTRUCTION

Otoliths were extracted from age 2, 3 and 4 year old adults in the Tuolumne River during carcass surveys conducted by CDFW in the fall of 2000-2012 (Table 1). The five focus years of the current study (1998, 1999, 2000, 2003 and 2009) encompassed a range of hydrologic conditions (wet, above normal, above normal, below normal and dry, respectively) based on the San Joaquin valley water index (http://cdec.water.ca.gov). Carcass surveys were typically run from October to early-January depending on abundance and hydrologic conditions. Sample selection was temporally stratified to follow the same cohort across different escapement years, as fish return at different ages. This approach was taken to capture the age structure typically observed for salmon in the San Joaquin tributaries. This was deemed important in order to capture a representative sample that accounted for the potential for the outmigration strategy to co-vary with age-at-return. For example, it is unclear the extent to which larger outmigrants may have a higher likelihood of returning as younger (age 2) adults. Our sampling design was not intended to explicitly test whether there was a linkage between outmigration strategies and return age, however. Ages and outmigration cohorts were determined by counting scale winter annuli by experts at CDFW La Grange, as per established and validated techniques [41].

Otolith treatment and $^{87}Sr/^{86}Sr$ analyses

Otoliths were prepared and analyzed for $^{87}Sr/^{86}Sr$ ratios by multi-collector laser ablation inductively coupled plasma mass spectrometry (MC-LA-ICPMS) using the methods described in Barnett-Johnson et al. [2]. In brief, otoliths were rinsed 2-3 times with deionized water and cleaned of adhering tissue. Once dry, otoliths were stored in clean microcentrifuge tubes then mounted in Crystalbond™ resin and polished (600 grit, 1500 grit, 3 µm then 1 µm lapping film) until the primordia were exposed. $^{87}Sr/^{86}Sr$ analyses were carried out on a Nu plasma HR (Nu Instruments Inc.) interfaced with a Nd:YAG 213 nm laser (New Wave Research) at the UC Davis Interdisciplinary Center for Plasma Mass Spectrometry. Contrasting with the line transects used to establish natal signatures of tributaries in the CCV [1, 2] we used spot analyses to prevent cross-contamination of ablated material and to allow coupling of chemical data with discrete microstructural features. A 40µm or 55µm laser beam diameter was used (roughly equivalent to 10-14 days of growth) with pulse rate of 20 or 10 Hz at 70 or 65% power and a dwell time of 25 or 35 seconds. Helium was used as the carrier gas to improve sensitivity and was mixed with argon before reaching the plasma source. Gas blank and background signals were monitored following sample changes and measured for 30 seconds prior to each batch of spot analyses. A modern coral sample was analyzed at the start of each analytical session and the outer (marine) portion of adult salmon otoliths was analyzed between every otolith. The measured $^{87}Sr/^{86}Sr$ ratio was normalized to $^{86}Sr/^{88}Sr = 0.1194$ and to maximize accuracy, batches of unknowns were corrected to the global $^{86}Sr/^{88}Sr$ value (0.70918) by correcting to the mean of three spot analyses on the marine portion of an adult salmon otolith analyzed immediately afterwards.

A standardized 90° transect was used for $^{87}Sr/^{86}Sr$ and otolith radius measurements, starting at the post-rostrum primordia going in the dorsal direction (Fig. 2). Juvenile otoliths of known origin (from previous studies) were used to assign natal origins of adults in the current project. In the juvenile otoliths, the transect was terminated at the otolith edge to ensure analysis of the most recently deposited material in order to characterize capture site (natal) signature. In the adult otoliths of unknown origin, the transect was terminated past the ocean entry check or to a distance of c.800µm (c. 120mm FL) to ensure inclusion of the full freshwater outmigration period. To improve the spatial resolution and accuracy of exit spot identification and back-calculated FL, additional $^{87}Sr/^{86}Sr$ analyses were carried out around the Tuolumne-SJR transition. These additional spots ("respots") meant that generally, subweekly resolution could be achieved.

Strontium isoscape

As part of ongoing work to provide better resolution on the determination of fish origin useful in this study, Sr isotope values of known-origin otolith samples from juveniles and CWT adults were combined with the previously published $^{87}Sr/^{86}Sr$ baseline [1]. Water samples (A. Sturrock, unpublished) were combined with data from Ingram and Weber (1999) and P. Weber (unpublished). The resulting 'strontium isoscape' was comprised of 480 samples from all potential natal sources in the CCV, with many sites sampled across multiple years (1998-2013) and hydrologic regimes (Table 3). Thus, the isoscape can be quantitatively characterized by the mean $^{87}Sr/^{86}Sr$ isotope values and the standard deviations for the different salmon rivers and hatcheries in the CCV.

Otoliths from juveniles collected from their natal tributary or hatchery were analyzed for $^{87}Sr/^{86}Sr$ using the same type of transect as the adults, and the natal signature determined from otolith material deposited immediately after onset of exogenous feeding (~250μm from the core, see [2]). Material deposited prior to this point exhibits an elevated signature due to the influence of maternally-derived strontium from the yolk, which for fall-run salmon, was formed while the mother was in the ocean.

Identification of natal origin

In order to reconstruct juvenile outmigration strategies for the Tuolumne River salmon population, it was critical to remove any fish that had strayed from other tributaries or hatcheries. Given that hatcheries tend to release at larger sizes [21], not detecting and removing hatchery strays in our analyses would likely bias the representation of smolt outmigrants. To identify the origin of our unknown fish, we measured the natal $^{87}Sr/^{86}Sr$ and then statistically determined which river or hatchery in the strontium isoscape (see previous section) had the most similar $^{87}Sr/^{86}Sr$ to the unknown fish. The utility of using a linear discriminant function analysis (DFA) to classify unknown origin fish into their likely rivers/hatcheries of origin, is that it allows one to use additional sources of information. In this case, we can use previous observations of hatchery strays from coded wire tag recoveries in the Constant Fractional Marking Report (probabilities/group weightings) and use that information to help weight our statistical model to more accurately account for hatchery strays (Table 2) [42, 43]. Thus, the DFA approach allowed us to incorporate empirical data of stray-rates from the major hatcheries into our statistical model to account for non-random patterns in salmon straying and improve classification accuracy. As the majority of Chinook salmon return to freshwater at 3 years old [14], the more recent report (escapement year 2011 [42]) was cohort-matched to outmigration year 2009 (escapement year – outmigration year + 1). All adults from previous outmigration cohorts were assigned using priors from the earlier CFM report [43].

The natal signature was determined by averaging the $^{87}Sr/^{86}Sr$ values that corresponded with the otolith material deposited immediately after onset of exogenous feeding (but prior to emigration from the natal river). The DFA assignments for the mean natal value were used to determine the river or hatchery of origin. Juveniles collected in the Tuolumne River exhibit more variable isotopic signatures within and among individuals than in other rivers in the CCV (see Results). Some juveniles that were collected in the Tuolumne River exhibited $^{87}Sr/^{86}Sr$ values that appeared to imply movement into the SJR or Stanislaus River immediately after emergence and then return to the Tuolumne (e.g. Fig. 3C). However, given that the changes in isotopic values tended to occur at early stages, when individuals are unlikely to be strong enough swimmers to move freely up and downstream, we interpreted this pattern to represent geographic variations in the $^{87}Sr/^{86}Sr$ signature within the Tuolumne River, confirmed with additional water sampling carried out as part of other projects (Fig. 1 & 8).

As the Tuolumne River exhibits variable water chemistry from upper to lower reaches (P. Weber, A. Sturrock, unpublished), and otolith $^{87}Sr/^{86}Sr$ values of known-origin fish from the Tuolumne River, Mokelumne River Hatchery and Feather River Hatchery can overlap (see Results), there is a potential of misclassifying Tuolumne-origin fish. Thus, to improve our assignment accuracy, any individuals exhibiting ambiguity in their natal assignment were also analyzed for otolith microstructural features that can discriminate hatchery from wild fish. We used the methods developed for CCV Chinook [44], where individuals are classified as hatchery or wild based on the prominence of the exogenous feeding check (scored blind by 2-3 independent readers) and the mean and variance in increment width around the first 30 daily increments following onset of exogenous feeding.

Reconstructing size and age at outmigration

Emigration from the Tuolumne River ('natal exit') was determined using the distance from the core to the 'last natal spot' rather than the 'first non-natal spot', because to accrete sufficient new otolith material to modify the isotopic composition of the otolith, the fish would have inhabited isotopically distinct (i.e. non-natal) water for several days, after which time it would be a significant distance downstream of the confluence. The method used to identify the 'last natal spot' was to work backwards from the final inflection point indicative of ocean-bound migration (Fig. 3A-C). We assumed that the lowest point of this final inflection represented movement through the SJR, and thus used the spot prior as the last natal spot. The only exceptions were on occasions when the lowest point prior to ocean migration was lower than any value measured in the SJR (e.g. Fig. 3D); on these occasions the lowest point was assumed to have been deposited while the fish was rearing in the lower Tuolumne River, which has been shown to exhibit values as low as 0.7066 (P. Weber, A. Sturrock, unpublished). Emigration from freshwater ('freshwater exit') was defined as the distance at which otolith $^{87}Sr/^{86}Sr$ values last reached 0.7080 (equivalent to 1ppt based on [45]), determined using linear interpolation.

To back-calculate fish size at natal and freshwater exit, the relationship between otolith radius and FL was quantified using fall run Chinook salmon juveniles from the same "Evolutionarily Significant Unit" (ESU), which is of utmost importance for producing relevant and unbiased back calculation models [46]. Otolith radius was measured using a Leica DM1000 microscope and Image Pro Plus 7. Reference samples were collected as part of other projects from the Tuolumne River (2003; n = 6), Stanislaus River (2000 and 2002; n = 95), the Coleman National Fish Hatchery (2002; n=40) and in the San Francisco Bay at Golden Gate Bridge (2005; n = 83) (Fig. 5). The Tuolumne-origin fish tended to sit above the mean regression line (Fig. 5), but there was no significant difference between the back-calculated FL of Tuolumne vs. non-Tuolumne fish (ANCOVA: $p = 0.08$), nor any difference in the slopes (ANCOVA: $p = 0.8$). As such, we assumed that the overall OR-FL relationship was suitable for reconstructing FLs of juveniles from the Tuolumne River, however it would be advisable to increase representation of Tuolumne-origin juveniles in future analyses. The error around the OR-FL calibration line (Fig. 5) was used to estimate 95% confidence intervals (CI) around individual FL reconstructions. Individuals were categorized as fry, parr or smolt outmigrants based on FL: ≤55mm, >55 to <75mm, and >75mm FL, respectively (after [21]).

Daily growth bands were counted and widths between daily increments were measured along the same 90 degree transect as the geochemical analysis, beginning at the post exogenous feeding check until freshwater exit. Some otoliths were difficult to age and given low readability scores (1-2); ages are not provided for these individuals. The ages of fish at Tuolumne River exit, Freshwater exit, and habitat-specific growth rates were obtained for fish with otolith readability scores of 3-5. A subset of otoliths were aged by two independent readers, providing an estimate of error associated with fish aging. The two independent reads of each fish demonstrated high agreement, with an average difference of ± 5 days (range 0-12 days).

RESULTS

ACCURACY OF NATAL ASSIGNMENTS

The DFA assigned 63% of samples back to the correct site of origin (Table 4), with the majority of misclassified sites being among the Mokelumne River Hatchery (MOH), Feather River Hatchery (FEH) and the Tuolumne River (TUO), which overlap in their chemical composition (Fig. 6). The use of otolith microstructure (~10% error rate for hatchery vs. wild assignments) [44] and weighted priors helped to separate TUO-origin fish from MOH and FEH strays, however there remains potential for misclassifications between the two hatchery sites (FEH and MOH), particularly given that (except for outmigration year 2009) the priors used were not cohort-specific. We prepared and processed 13 CWT fish from outmigration years 1999 and 2000 of known hatchery origin. However, the presence of these samples was withheld from the individuals preparing the samples, collecting the $^{87}Sr/^{86}Sr$ data, as well as statistically assigning them to natal origin. Thus, these known samples were treated in the same way as all the unknowns in the study. Once the assignments were made, the true identify of these fish were revealed to the analysts. All fish were correctly classified to the Merced River Hatchery (MEH).

PATTERNS IN $^{87}SR/^{86}SR$ VALUES WITHIN THE TUOLUMNE RIVER

Contrary to the stable $^{87}Sr/^{86}Sr$ profiles observed in other CCV rivers, the Tuolumne River is characterized by variable $^{87}Sr/^{86}Sr$ values from the upper spawning reaches to the confluence with the San Joaquin River (A. Sturrock, unpublished). This variability was first observed in some water analyses (P. Weber, unpublished) and known-origin juveniles (Fig. 3C & D), and subsequently in adult otolith $^{87}Sr/^{86}Sr$ profiles from outmigration years 2000 and 2003 [47]. The lower isotopic values in the lower river were originally hypothesized to result from inputs of Stanislaus River water via Dry Creek (a tributary to the Tuolumne River at river mile [rm] 17). However, subsequent water analyses (carried out as part of other studies) indicated declines in $^{87}Sr/^{86}Sr$ values as far upstream as rm46, with rm 22 to the confluence exhibiting relatively stable signatures around 0.7065 (Fig. 8). The average variability (2SD) of the water analyses based on analyses of multiple standard reference materials was 0.000020, providing high confidence in these data. The geographic trends in Tuolumne River water $^{87}Sr/^{86}Sr$ cannot be explained by inputs from Dry Creek alone (rm 17), implying additional sources of isotopically light water to the upper and mid reaches of the river.

These patterns have clear implications for identifying fish origin, determining rearing location(s) within the Tuolumne River, and the rules used to identify transitions between the Tuolumne and San Joaquin rivers (Fig. 2, 3). Trace elemental analyses of water samples carried out as part of past and ongoing projects (P. Weber, A. Sturrock, unpublished) indicate clear differences in water Sr/Ca and Ba/Ca ratios between the Tuolumne and San Joaquin Rivers (Fig. 9). Thus, future studies attempting to identify fish transition across this confluence might benefit from a multi-elemental approach, combining otolith Sr isotopes with Sr/Ca and Ba/Ca analyses [48].

STRAYING AND RETURN RATES TO THE TUOLUMNE RIVER

Overall, straying rates of unmarked fish have increased over time coincident with increasingly dry environmental conditions. The earliest three outmigration years examined had relative low straying rates of unmarked fish (1998: 57-68% returns, 33-44% strays, 1999: 38-53% returns, 47-62% strays, 2000: 61-64% returns, 36-39% strays). Outmigration year 2003 had intermediary straying rates (27-35% returns, 65-73% strays), while outmigration year 2009 was characterized by particularly high straying rates (9-15% returns, 85-91% strays, primarily from the Coleman National Fish Hatchery on Battle Creek, which comprised 57% of the total sample).

SIZE AND AGE AT OUTMIGRATION

Given the variance around the mean OR-FL regression line (approximately ±10mm FL; Fig. 5), it is not advisable to place too much emphasis on any one particular FL reconstruction; with the upper and lower FL estimates often resulting in fish spanning multiple life stages (Appendix 1A & B). However, given a lack of bias in the OR-FL relationship, and its consistency between Sacramento and San Joaquin basin-origin fish (Fig. 5), the average FLs and overall life stage assignments (Tables 6 and 7) were deemed relatively robust and representative population-level metrics.

All size classes of juvenile outmigrants were represented in the adult spawning population. Tuolumne-origin adults were largely comprised of individuals that had emigrated from the Tuolumne as parr and smolts, however, in outmigration year 2000, 20% of the returning adults had outmigrated as fry (Table 6). Consistent with observations of other populations in the San Joaquin Basin, parr outmigrants were generally the most commonly observed phenotype in the returning adults, implying a potential survival advantage despite being smaller than smolts. There were significant differences in size, age and growth rate between outmigration years ($p<0.05$, Fig. 9, Table 7), but no inter-annual difference in growth rate variability (as tested through comparisons of the coefficient of variation in increment width; $p>0.05$). In general, outmigration year 2000 was characterized by younger, smaller outmigrants; however, the number of days in the freshwater delta was longer (Fig. 9), implying a higher frequency of non-natal rearing during this season.

TABLES

Table 1. Numbers of otolith samples sampled randomly from unclipped salmon carcasses in the Tuolumne River between 2000 and 2012. Ages were obtained from CDFW scale readings and samples matched to outmigration years 1998, 1999, 2000, 2003 and 2009 before Sr isotope analysis.

Cohort		**Adult carcass sampling year**	**Age at return (yr)**	**Number of individuals**	**% of total sample**
Brood year	**Outmigration year (WYT†)**				
1997	1998 (Wet)	2000	3	124	62%
		2001	4	76	38%
1998	1999 (Above normal)	2000	2	9	6%
		2001	3	64	44%
		2002	4	73	50%
1999	2000 (Above normal)	2001	2	31	28%
		2002	3	79	72%
		2003	4	0	0%
2002	2003 (Below normal)	2004	2	0	0%
		2005	3	87	91%
		2006	4	9	9%
2008	2009 (Dry)	2010	2	14	30%
		2011	3	30	65%
		2012	4	2	4%
TOTAL				598	

† San Joaquin Valley Index Water year type during juvenile rearing & outmigration

Table 2. Discriminant Function Analysis (DFA) priors used in the current study to predict natal origin of adults obtained in the Tuolumne River Carcass Survey corresponding to outmigration years 1998, 1999, 2000, 2003 and 2009. The probabilities are based on the CWT-derived proportions of hatchery strays in the Tuolumne in escapement year 2010 and 2011 constant fractional marking (CFM) reports and an assumed natural straying rate of 5% [49], removed from the proportion of "natural" fish reported in the CFM report and divided equally among the remaining salmon rivers in the California Central Valley. Priors from CFM escapement year 2010 were applied to all cohorts pre-2009, while priors from CFM escapement year 2011 were applied to outmigration year 2009, given cohort-matching to the dominant year class. Note that Feather River Hatchery and Thermalito Rearing Annex were not distinguished between in the CFM reports, so the priors for the former were divided equally between the two sites.

Natal origin	**Site code**	**"Wild" or hatchery**	**Prior probability based on CFM 2010 escapement** *(all outmigration years <2009)*	**Prior probability based on CFM 2011 escapement** *(outmigration year 2009 only)*
Tuolumne River (RETURNS)	TUO	W	0.4845	0.2565
Merced River Hatchery	MEH	H	0.1060	0.2081
Feather River Hatchery	FEH	H	0.0624	0.0684
Thermalito Rearing Annex	THE	H	0.0624	0.0684
Nimbus Hatchery	NIM	H	0.0433	0.0116
Coleman National Fish Hatchery	CNH	H	0.1345	0.0848
Mokelumne River Hatchery	MOH	H	0.0569	0.2524
Battle Creek	BAT	W	0.005	0.005
Deer Creek	DEE	W	0.005	0.005
Mill Creek	MIL	W	0.005	0.005
Butte Creek	BUT	W	0.005	0.005
Feather River	FEA	W	0.005	0.005
Stanislaus River	STA	W	0.005	0.005
Mokelumne River	MOK	W	0.005	0.005
Yuba River	YUB	W	0.005	0.005
Merced River	MER	W	0.005	0.005
American River	AME	W	0.005	0.005

Table 3. Details of samples and mean $^{87}Sr/^{86}Sr$ included in the DFA to assign natal origin (n=480), where "matrix" includes juvenile otoliths (J), CWT adult otoliths (CWT) and water samples (W). All analyses were carried out as part of existing or ongoing projects ([1], [34], P. Weber, A. Sturrock, unpublished), and used to predict the origin of adults collected in the current study. Site codes are provided in Table 2.

Site	Matrix	Year	N	Mean 87Sr/86Sr	SD
AME	J	1999	5	0.71025	0.00004
AME	W	1998	4	0.70979	0.00017
BAT	J	1999	9	0.70391	0.00017
BUT	W	1998	5	0.70481	0.00009
CNH	CWT	2000	1	0.70527	
CNH	CWT	2009	7	0.70547	0.00043
CNH	CWT	2010	3	0.70557	0.00013
CNH	J	2000	5	0.70531	0.00020
CNH	J	2002	8	0.70535	0.00038
DEE	J	2002	8	0.70412	0.00004
DEE	W	1998	5	0.70409	0.00003
FEA	J	1999	5	0.70622	0.00012
FEA	J	2000	5	0.70621	0.00020
FEA	J	2002	8	0.70615	0.00003
FEA	W	1998	7	0.70620	0.00011
FEH	CWT	2007	14	0.70728	0.00013
FEH	CWT	2008	19	0.70741	0.00014
FEH	J	1999	5	0.70673	0.00012
FEH	J	2000	5	0.70736	0.00017
FEH	J	2002	17	0.70717	0.00020
FEH	J	2004	5	0.70709	0.00014
MEH	CWT	1998	5	0.70888	0.00009
MEH	CWT	1999	5	0.70886	0.00006
MEH	CWT	2001	6	0.70854	0.00006
MEH	CWT	2003	6	0.70872	0.00006
MEH	CWT	2004	2	0.70862	0.00004
MEH	CWT	2006	5	0.70892	0.00007
MEH	CWT	2009	6	0.70871	0.00002
MEH	CWT	2010	6	0.70865	0.00010
MEH	J	1999	1	0.70885	
MEH	J	2002	9	0.70861	0.00003
MEH	J	2004	5	0.70869	0.00011
MER	J	2003	13	0.70852	0.00010
MER	W	1998	4	0.70846	0.00063
MIL	J	2002	10	0.70412	0.00003
MIL	W	1998	5	0.70396	0.00002
MOH	CWT	1998	2	0.70742	0.00003
MOH	CWT	1999	6	0.70767	0.00011
MOH	CWT	2000	13	0.70757	0.00009
MOH	CWT	2001	7	0.70751	0.00009
MOH	CWT	2002	4	0.70757	0.00012
MOH	CWT	2007	8	0.70736	0.00010
MOH	CWT	2008	5	0.70744	0.00014
MOH	CWT	2009	6	0.70737	0.00009
MOH	CWT	2010	8	0.70723	0.00007
MOH	J	1999	4	0.70768	0.00008
MOH	J	2000	5	0.70760	0.00007
MOH	J	2002	11	0.70755	0.00013
MOK	J	2000	4	0.70709	0.00005
MOK	J	2002	10	0.70690	0.00004
MOK	W	1998	4	0.70696	0.00016
NIH	J	2002	9	0.70974	0.00006
STA	J	1999	7	0.70663	0.00002
STA	J	2000	7	0.70663	0.00004
STA	J	2002	10	0.70656	0.00011
STA	J	2011	3	0.70646	0.00005
STA	J	2012	12	0.70643	0.00007
STA	J	2013	7	0.70641	0.00011
STA	W	2012	5	0.70639	0.00002
THE	J	2004	5	0.70581	0.00011
TUO	J	1999	3	0.70783	0.00042
TUO	J	2003	6	0.70757	0.00022
TUO	J	2007	34	0.70763	0.00019
TUO	J	2010	7	0.70780	0.00014
TUO	J	2011	4	0.70780	0.00003
TUO	W	1998	5	0.70789	0.00025
TUO	W	2013	2	0.70785	0.00006
YUB	J	2002	19	0.70823	0.00021

Table 4. Performance of the unweighted DFA for natal assignments. For the unknown samples in this study, weighted priors were used (Table 2) and hatchery vs. wild assignments based on otolith microstructure improved classification accuracy [44].

Site	BAT	DEE	MIL	BUT	CNH	THE	FEA	STA	MOK	FEH	MOH	TUO	YUB	MER	MEH	NIH	AME	Total	% Correct
BAT	**7**	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	78%
DEE	0	**8**	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	62%
MIL	5	9	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	7%
BUT	0	0	0	**5**	0	0	0	0	0	0	0	0	0	0	0	0	0	5	100%
CNH	0	0	0	4	**14**	5	1	0	0	0	0	0	0	0	0	0	0	24	58%
THE	0	0	0	0	0	**5**	0	0	0	0	0	0	0	0	0	0	0	5	100%
FEA	0	0	0	0	0	1	**22**	2	0	0	0	0	0	0	0	0	0	25	88%
STA	0	0	0	0	0	0	4	**47**	0	0	0	0	0	0	0	0	0	51	92%
MOK	0	0	0	0	0	0	0	0	**15**	3	0	0	0	0	0	0	0	18	83%
FEH	0	0	0	0	0	0	0	2	13	**26**	24	0	0	0	0	0	0	65	40%
MOH	0	0	0	0	0	0	0	0	0	19	**35**	25	0	0	0	0	0	79	44%
TUO	0	0	0	0	0	0	0	0	1	2	18	**35**	5	0	0	0	0	61	57%
YUB	0	0	0	0	0	0	0	0	0	0	0	1	**14**	4	0	0	0	19	74%
MER	0	0	0	0	0	0	0	0	0	0	0	1	0	**12**	4	0	0	17	71%
MEH	0	0	0	0	0	0	0	0	0	0	0	0	0	14	**42**	0	0	56	75%
NIH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**9**	0	9	100%
AME	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	**6**	9	67%
OVERALL																			63%

Table 5. Natal origin of all unclipped fish analyzed for 5 outmigration years (1998, 1999, 2000, 2003 and 2009). Note that adclipped fish have been removed (1 from OMY1999, 12 from OMY 2000 - all correctly assigned to Merced Hatchery).

			1998		**1999**		**2000**		**2003**		**2009**	
	Site	**Code**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Wild	Tuolumne R.	TUO	117	59%	55	38%	66	61%	26	27%	5	11%
	Tuolumne R.*	TUO*	17	9%	22	15%	2	2%	8	8%	2	4%
	Stanislaus R.	STA	5	3%	8	5%	4	4%	0	0%	0	0%
	Merced R.	MER	1	1%	0	0%	0	0%	0	0%	0	0%
	Mokelumne R.	MOK	2	1%	1	1%	0	0%	0	0%	0	0%
	Feather R.	FEA	0	0%	0	0%	0	0%	0	0%	1	2%
Hatchery	Coleman H.	CNH	0	0%	0	0%	0	0%	1	1%	26	57%
	Feather H.	FEH	1	1%	5	3%	4	4%	6	6%	4	9%
	Mokelumne H.	MOH	8	4%	28	19%	23	21%	39	41%	1	2%
	Merced H.	MEH	34	17%	9	6%	5	5%	4	4%	2	4%
	Nimbus H.	NIH	0	0%	5	3%	1	1%	9	9%	2	4%
	Thermalito (Feather H.)	THE	0	0%	2	1%	0	0%	3	3%	3	7%
	Habitat X ‡	X	15	8%	11	8%	5	5%	0	0%	0	0%
	Total		**200**		**146**		**110**		**96**		**46**	

* Individuals assigned to the Tuolumne with <0.5 posterior probability based on mean natal $^{87}Sr/^{86}Sr$ values.

‡ Individuals assigned as hatchery-origin based on otolith microstructure, but where natal $^{87}Sr/^{86}Sr$ values are outside of the observed range of any hatchery in the CCV.

Table 6. Life stage † at natal exit for fish assigned to the Tuolumne River with high confidence

Outmigration year	N	Fry	Parr	Smolt
1998	117	2%	56%	43%
1999	55	4%	62%	35%
2000	67	20%	73%	8%
2003	26	4%	65%	31%
2009	5	0%	40%	60%

† Life stage defined as fry (≤55mm), parr (>55mm to ≤75mm) or smolt (>75 mm) after [21]

Table 7. Summary of average forklength (FL) at exit, number of increments (days) and increment width (growth rate) in the natal river and freshwater delta by outmigration year for juveniles that originated in and returned to the Tuolumne River (identified as "TUO" in Appendix Table 1). Trends are also visualized in Figure 9 in the form of box plots (i.e. displaying median values as opposed to means), alongside the results of statistical comparisons among years.

		Natal river			Freshwater delta		
Outmigration year	Sample size	FL at exit (mm)	No. increments (days)	Increment width (μm)	FL at exit (mm)	No. increments (days)	Increment width (μm)
1998	117	73.3 ± 8.5	91.0 ± 16.2	3.07 ± 0.28	80.8 ± 9.0	15.8 ± 7.5	3.24 ± 0.54
1999	55	72.6 ± 11.6	82.0 ± 13.6	3.20 ± 0.27	82.3 ± 11.5	16.5 ± 8.7	3.35 ± 0.56
2000	66	63.5 ± 8.6	68.5 ± 18.6	3.10 ± 0.26	77.4 ± 6.9	27.6 ± 12.1	3.52 ± 0.52
2003	26	71.0 ± 10.6	79.7 ± 17.9	3.39 ± 0.43	80.1 ± 10.0	10.5 ± 5.2	3.65 ± 0.62
2009	5	76.0 ± 7.1	88.0 ± 20.3	3.36 0.29	83.4 ± 6.8	16.0 ± 7.5	3.03 ± 0.36

FIGURES

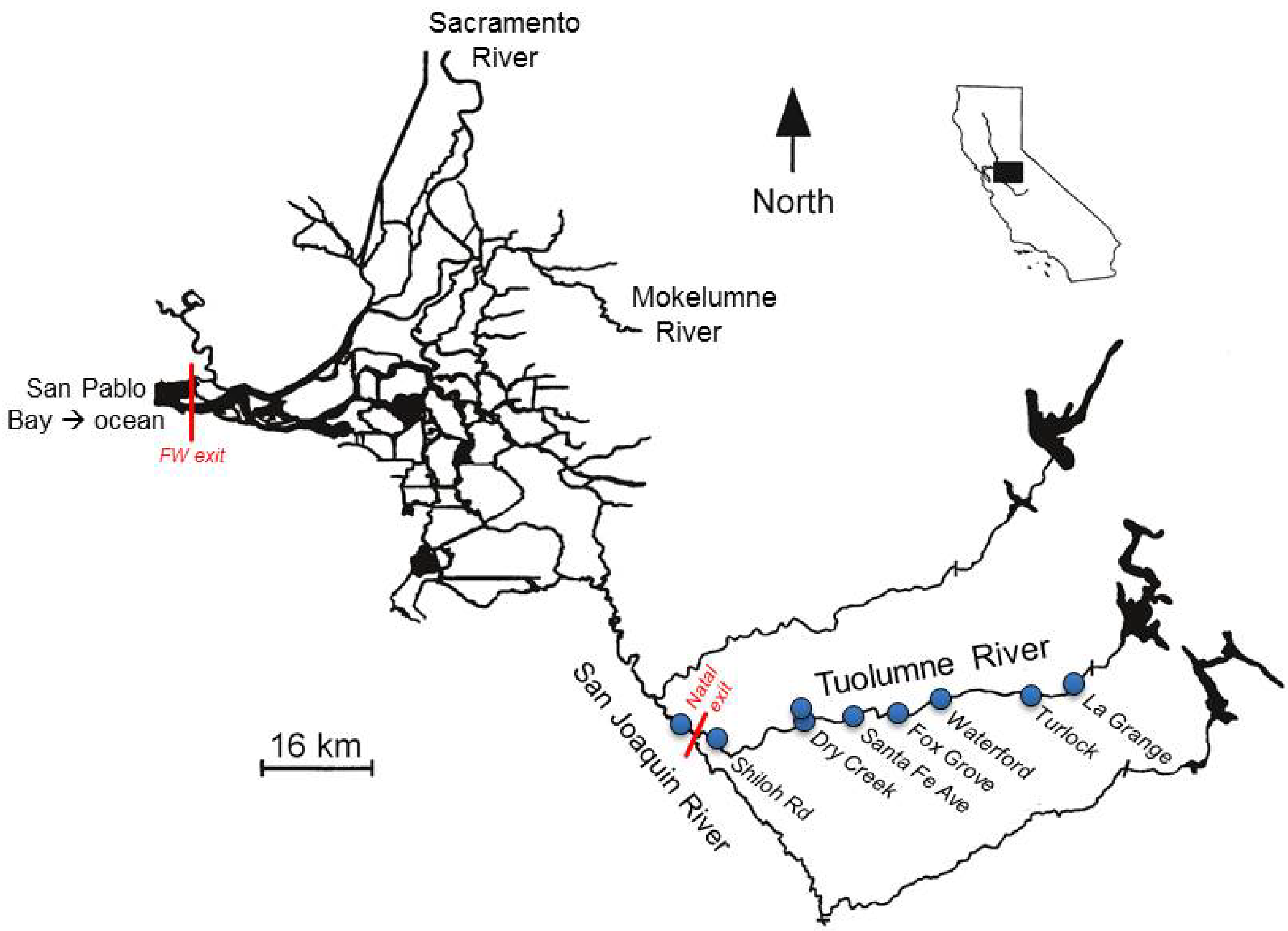


Fig. 1 Map to show location of the Tuolumne and San Joaquin rivers, and the sites sampled for water isotope analyses as part of a different project (blue circles; A. Sturrock, unpublished). The locations defined as natal and freshwater (FW) exit are indicated by red lines.

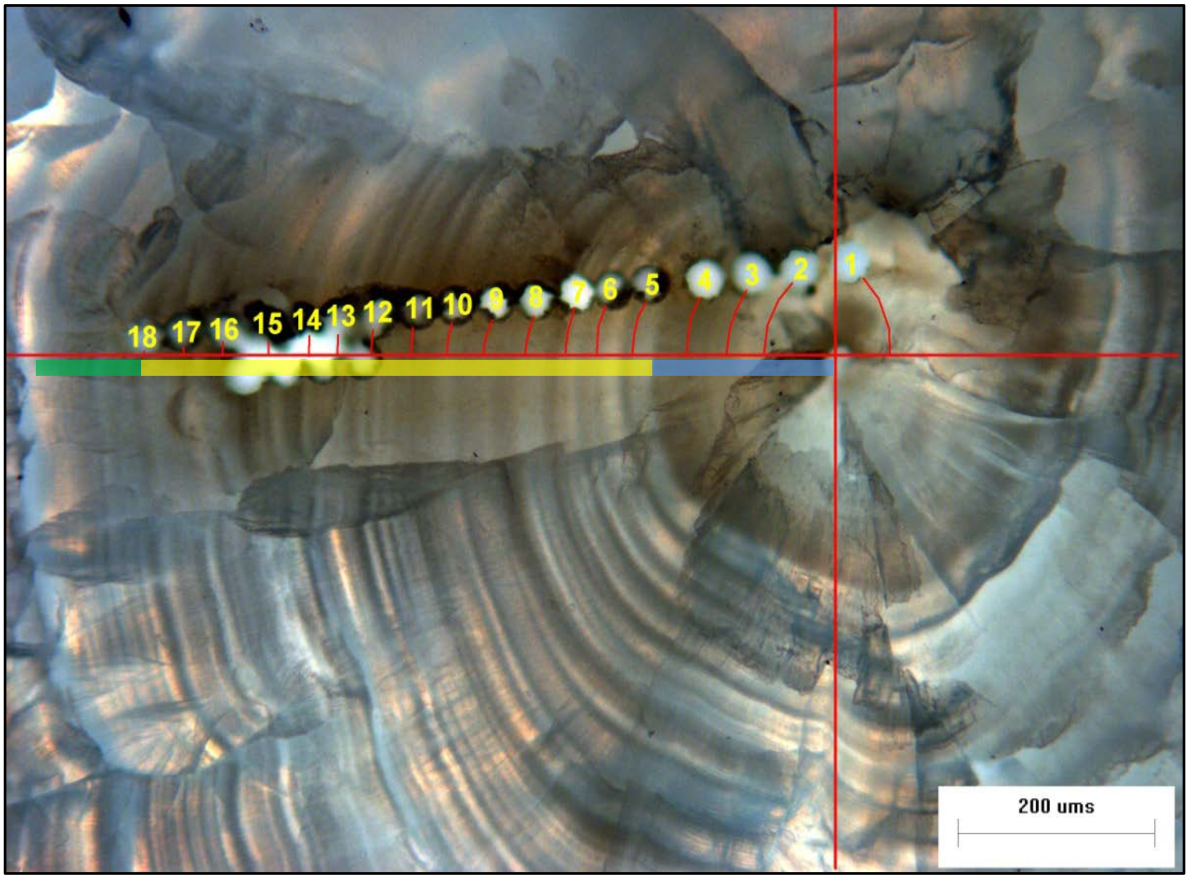


Fig. 2 A typical $^{87}Sr/^{86}Sr$ transect showing spot analyses (numbered) from the core to ocean entry. The life history stages are indicated by letters: maternal (M), juvenile (J) and ocean (O). The distance at which the final 'natal spot' intersected the 90° transect (indicated by curved red lines) was used to back-calculate size at outmigration. Note the 'respots' at positions 12.5 to 15.5 (located under the yellow bar) used to more accurately identify exit point.

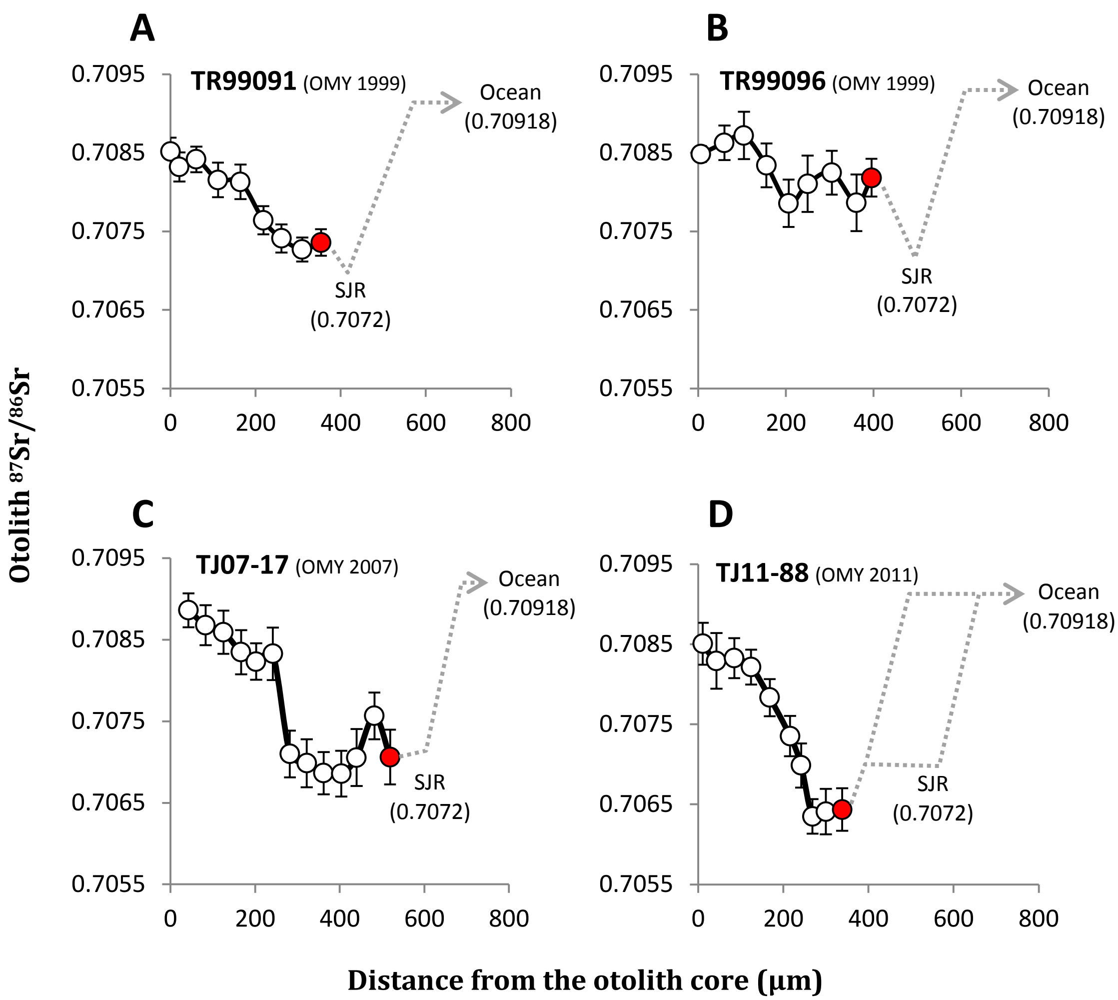


Fig. 3 Otolith $^{87}Sr/^{86}Sr$ profiles from four juvenile salmon captured in the lower Tuolumne River in outmigration years (OMY) 1999, 2007 and 2011. The natal exit spot ("last natal value") is indicated in red, along with the expected profile trajectory (dotted lines) through the San Joaquin River (SJR) to the ocean, had the fish not been captured as a juvenile and was instead being sampled as a returning adult. Note that the juvenile in plot D had moved to the lower river (or Dry Creek) immediately after emergence (~250um from the core) and the dotted lines indicate two possible trajectories, one with extended rearing in the SJR prior to leaving freshwater and the other with direct outmigration to the ocean.

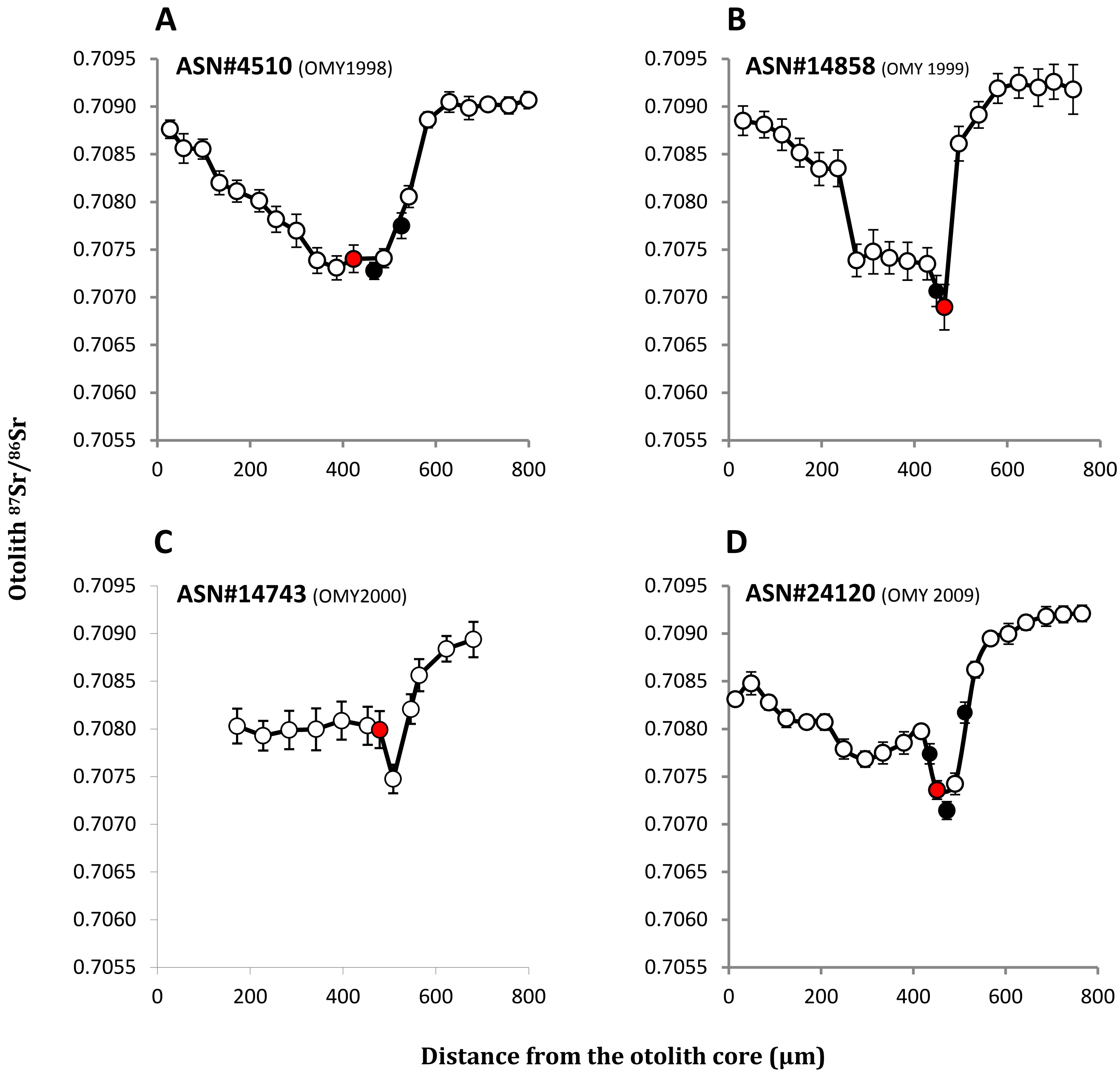


Fig. 4 Examples of otolith $^{87}Sr/^{86}Sr$ profiles from adult salmon carcasses collected in the lower Tuolumne River that were assigned to the Tuolumne River, having outmigrated as juveniles in 1998-2009. The inferred 'last natal spot' prior to outmigration to the SJR and ocean is shown in red. Black symbols indicate respots.

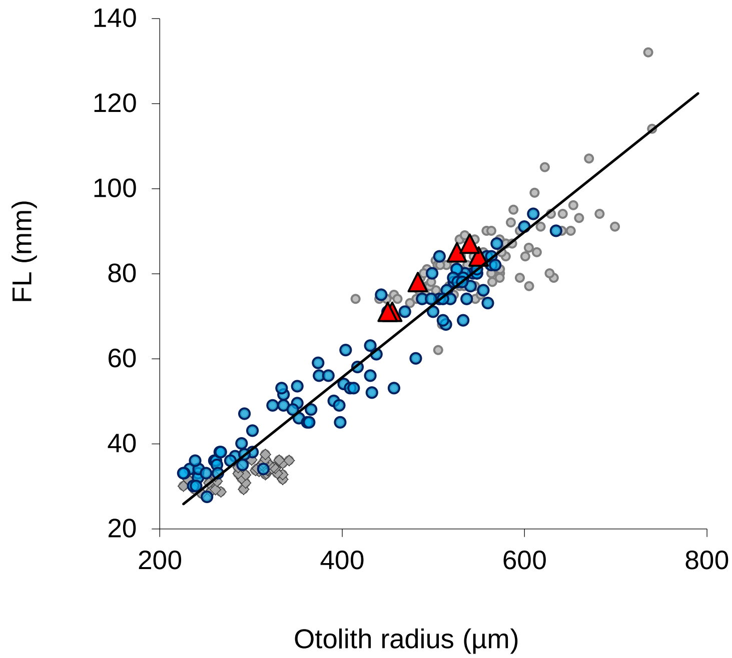


Fig. 5 Relationship between otolith radius and fork length (FL) of juveniles of known origin (Sturrock, unpublished) (n=224, $r^2 = 0.92$) used to reconstruct size at outmigration in returning adults from the current study. The 224 reference samples are all in the same Evolutionary Significant Unit (California Central Valley fall run salmon) and include individuals from the Tuolumne River (n=6; red triangles), the Stanislaus River (n=95; blue circles), Coleman National Fish Hatchery (n=40; grey diamonds) and the San Francisco Bay at Golden Gate Bridge of unknown origin within the CCV (n=83; grey circles).

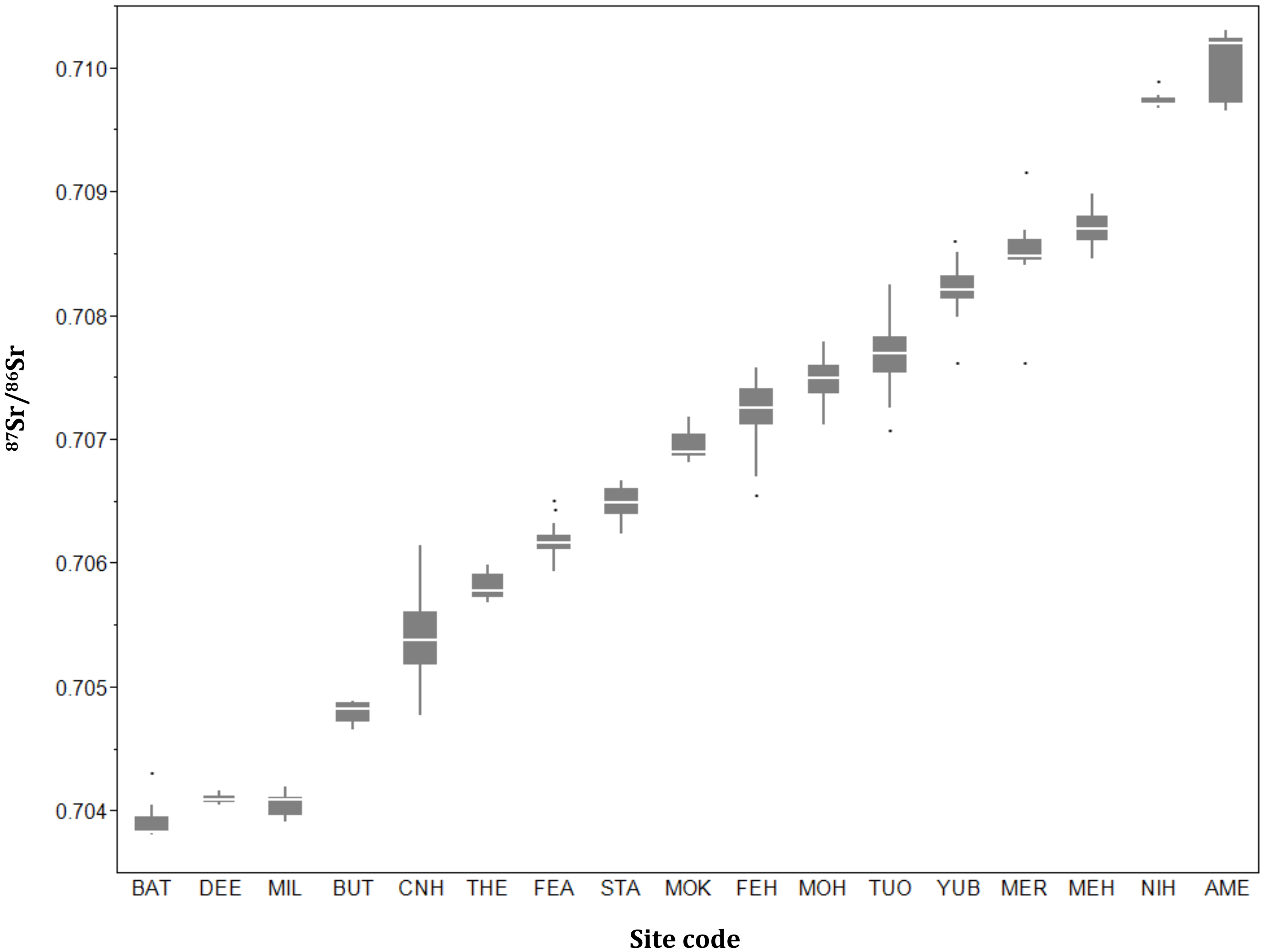


Fig. 6 Differences in $^{87}Sr/^{86}Sr$ values among sites in the CCV, modified from [1] using additional water samples and otoliths from known-origin juveniles and adult CWT fish analyzed as part of existing and ongoing projects ([34], P. Weber & A. Sturrock, unpublished). Site codes identified in Table 2. These data were used to predict the origin of adults collected in the current study. Due to overlap among TUO, MOH and FEH, all fish identified as potentially originated in the Tuolumne River (TUO) using Sr isotopes were also assigned to hatchery/wild using otolith microstructure (Barnett-Johnson et al., 2007).

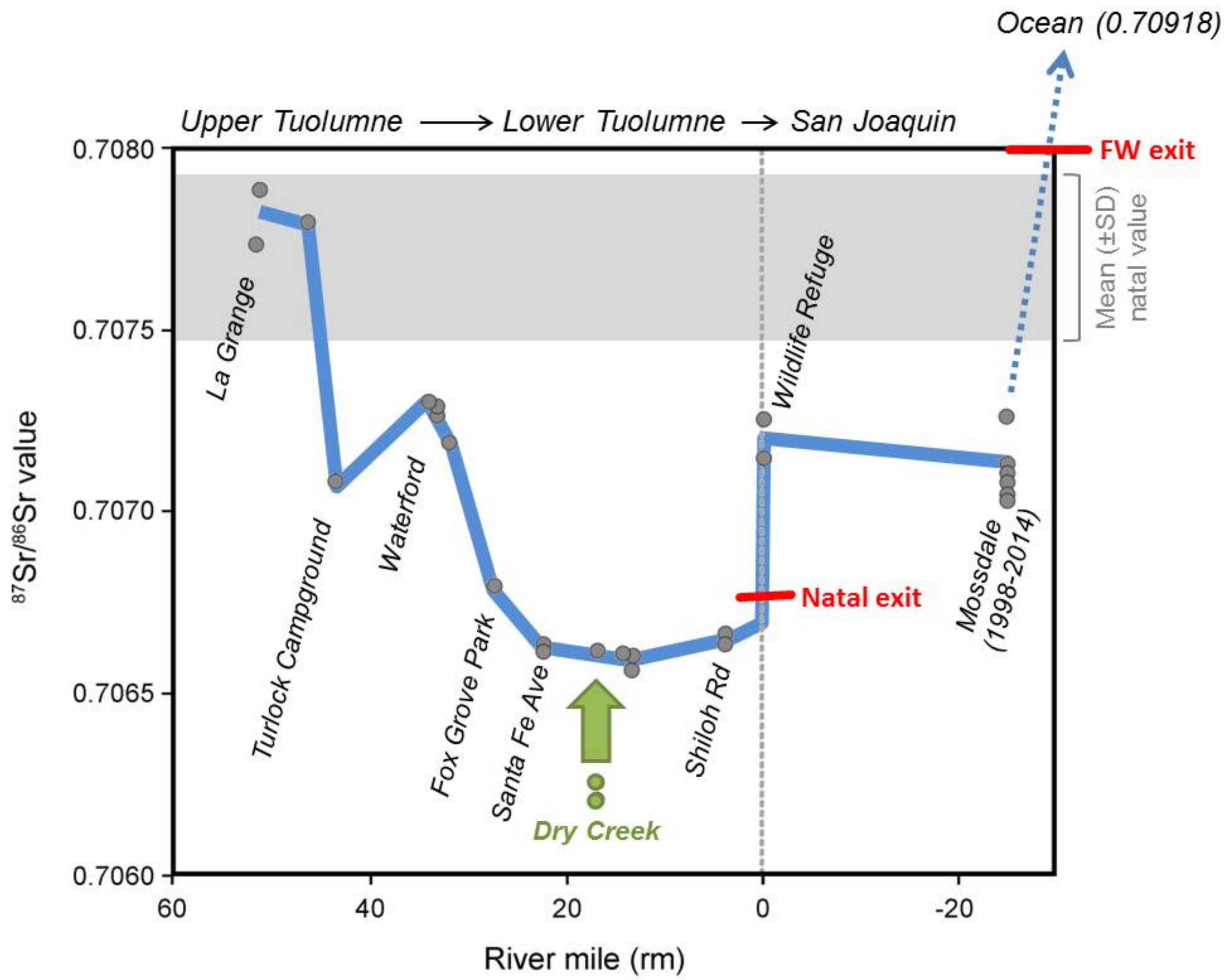


Fig. 7 Trends in water $^{87}Sr/^{86}Sr$ in the mainstem Tuolumne and San Joaquin Rivers (samples collected as part of other studies). The majority of measurements were collected in January and February 2014; however, additional years are included where available. The shaded grey bar indicates the mean natal value allocated to the Tuolumne (±SD), based on otolith analyses of juveniles captured in a rotary screw trap close to Shiloh Road (i.e., prior to outmigration). The blue trend line within the Tuolumne River is driven by sources of isotopically light water entering the river downstream of the spawning reaches (~rm50). At the time of writing, Dry Creek (rm 16.7) is the only known example of such a source.

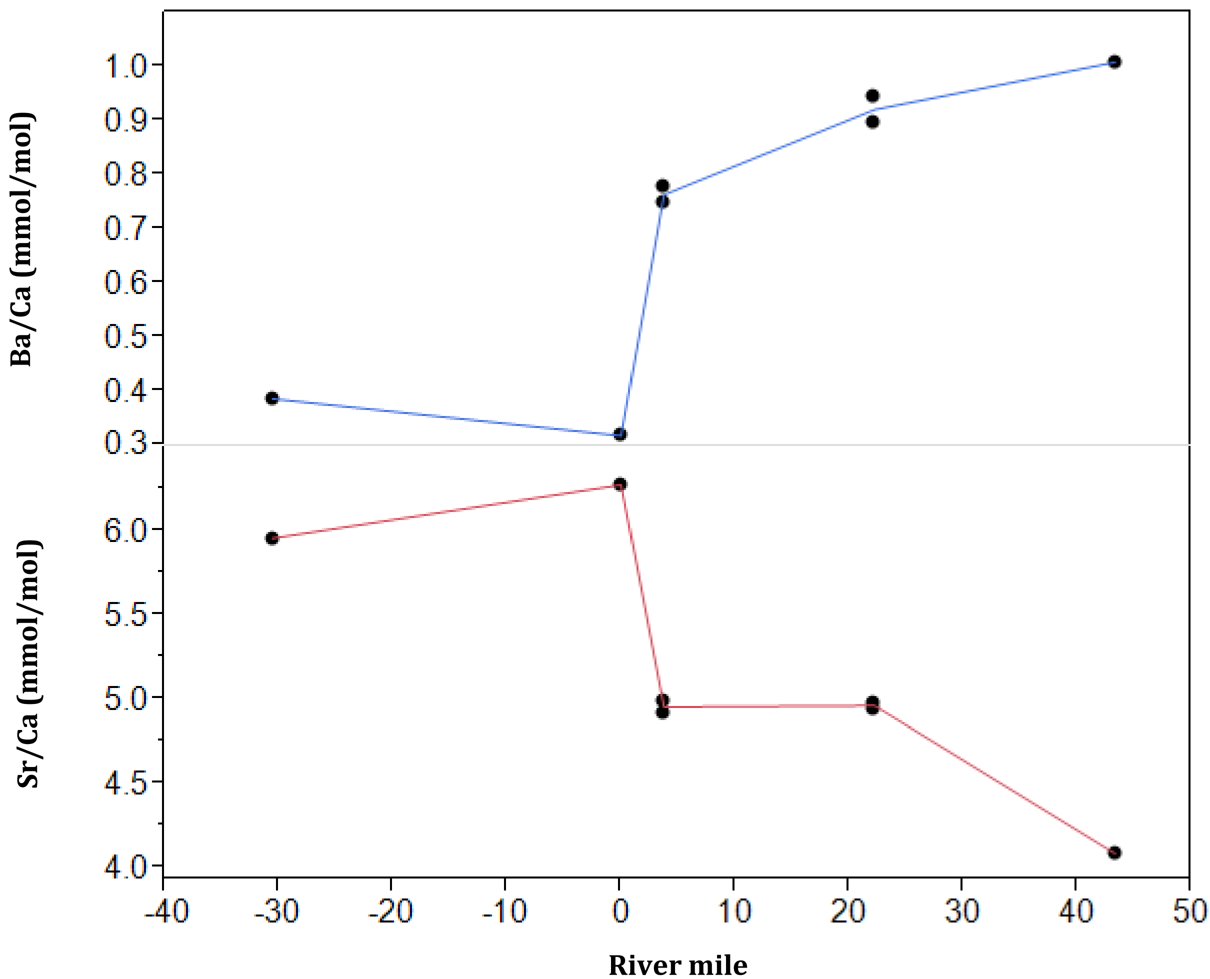
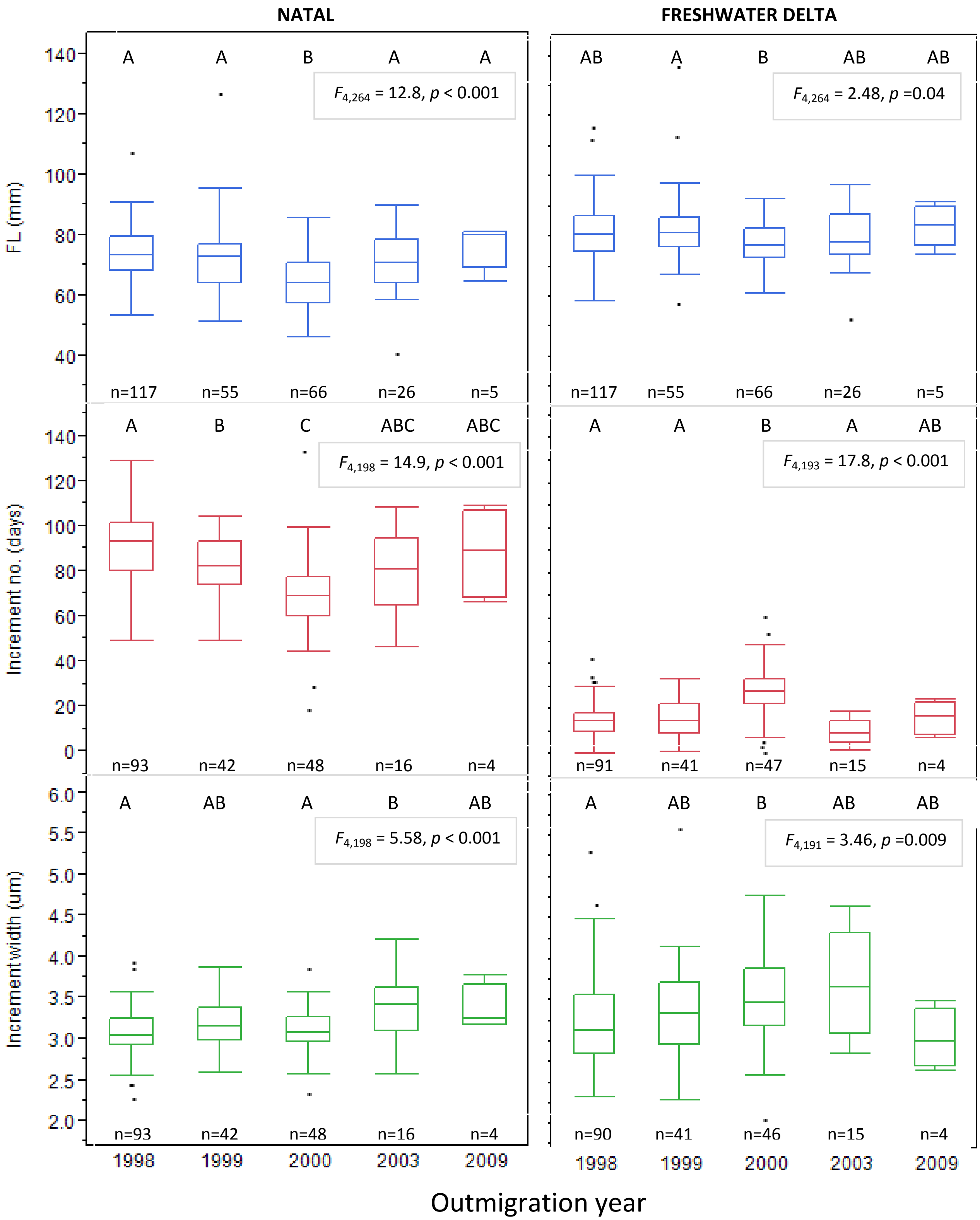


Fig. 8 Trends in water Ba/Ca and Sr/Ca between the Tuolumne and San Joaquin rivers (samples collected as part of other studies). Note the sharp inflection between the lower Tuolumne (~river mile 3) and the San Joaquin (river mile 0) rivers.

Fig. 9 Trends in median fork length at exit (FL), number of otolith increments (age) and increment width (growth rate) in the natal river (left) and freshwater delta (right) of juveniles that originated in and returned to the Tuolumne River. Overall differences among years were tested by ANOVA (results exhibited on each plot). Bars not connected by the same letter are significantly different (p<0.05, Tukey's test).



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Appendix 1A Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the Tuolumne River (natal exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive (“INC”), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable. The life stage at natal river exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

						Natal Sr ratio				Natal exit	Predicted FL at natal exit (mm)			Predicted life stage at natal exit [3]				Increment width (um)		
Sample ID	Capture date	Capture FL (cm)	Scale age	Sex	Outmi-gration year	Mean natal value	Prob to TUO [1]	H vs. W [2]	Natal location	Otolith distance (um)	FL	Lower 95% CI	Upper 95% CI	Life stage	Lower 95% CI	Upper 95% CI	Increment no (days)	Mean	CV	Notes
4175	10/10/00	98	3	M	1998	0.70799	0.97	W	TUO	576.6	85.8	77.2	95.9	S	S	S	109	3.26	0.19	
4176	10/10/00	91	3	M	1998	0.70774	0.95	W	TUO	544.4	80.3	71.7	90.4	S	P	S	96	3.53	0.21	
4182	10/17/00	76	3	M	1998	0.70803	0.96	W	TUO	544.1	80.3	71.7	90.3	S	P	S	112	2.96	0.19	
4183	10/17/00	90	3	M	1998	0.70797	0.97	W	TUO	494.3	71.8	63.2	81.8	P	P	S	94	2.74	0.22	
4185	10/17/00	84	3	F	1998	0.70728	0.64	W	TUO	522.7	76.6	68.0	86.7	S	P	S	107	3.17	0.26	
4189	10/24/00	90	3	F	1998	0.70806	0.94	W	TUO	452.6	64.6	56.1	74.7	P	P	P	83	2.90	0.23	
4192	10/24/00	87.5	3	F	1998	0.70807	0.93	W	TUO	487.5	70.6	62.0	80.7	P	P	S	87	3.22	0.23	
4196	10/24/00	67.9	3	F	1998	0.70800	0.97	W	TUO	493.3	71.6	63.0	81.7	P	P	S	98 †	2.62	0.20	† Microstructure ran out 33um before last natal spot (inferred 12 increments)
4197	10/24/00	78.6	3	F	1998	0.70740	0.61	W	TUO	423.2	59.6	51.0	69.7	P	F	P	79	2.74	0.26	
4200	10/24/00	68.6	3	F	1998	0.70760	0.88	W	TUO	569.4	84.6	76.0	94.7	S	S	S	102	3.20	0.27	
4210	10/24/00	88.3	3	M	1998	0.70764	0.91	W	TUO	488.9	70.8	62.2	80.9	P	P	S	93	2.98	0.28	
4211	10/24/00	72	3	F	1998	0.70783	0.97	W	TUO	581.0	86.6	78.0	96.6	S	S	S	.			
4212	10/24/00	78.1	3	M	1998	0.70765	0.91	W	TUO	541.0	79.7	71.2	89.8	S	P	S	93	2.93	0.20	
4215	10/25/00	79	3	F	1998	0.70802	0.96	W	TUO	552.5	81.7	73.1	91.8	S	P	S	111	3.03	0.20	
4226	10/25/00	80	3	F	1998	0.70770	0.93	W	TUO	446.6	63.6	55.0	73.7	P	P	P	70	3.11	0.33	
4232	10/25/00	88.5	3	M	1998	0.70821	0.53	W	TUO	519.3	76.0	67.5	86.1	S	P	S	.			
4233	10/25/00	72	3	F	1998	0.70795	0.98	W	TUO	452.6	64.6	56.1	74.7	P	P	P	74	3.02	0.20	
4234	10/25/00	77	3	F	1998	0.70823	0.45	W	TUO*	579.9	86.4	77.8	96.5	S	S	S	*Inconclusive natal assignment*			
4240	10/26/00	80	3	F	1998	0.70726	0.28	W	TUO*	426.2	60.1	51.5	70.2	P	F	P	*Inconclusive natal assignment*			
4249	10/30/00	80	3	F	1998	0.70737	0.54	W	TUO	485.8	70.3	61.7	80.4	P	P	S	.			
4253	10/30/00	80	3	M	1998	0.70810	0.90	W	TUO	554.2	82.0	73.4	92.1	S	P	S	101	3.05	0.26	
4266	10/30/00	77	3	F	1998	0.70740	0.60	W	TUO	461.1	66.1	57.5	76.2	P	P	S	100	2.43	0.25	
4267	10/30/00	75	3	F	1998	0.70812	0.86	W	TUO	476.3	68.7	60.1	78.8	P	P	S	.			
4269	10/30/00	80	3	F	1998	0.70732	0.43	W	TUO*	581.6	86.7	78.1	96.8	S	S	S	*Inconclusive natal assignment*			
4275	10/31/00	79	3	F	1998	0.70721	0.18	W	TUO*	416.1	58.4	49.8	68.5	P	F	P	*Inconclusive natal assignment*			
4278	10/31/00	83	3	F	1998	0.70802	0.96	W	TUO	480.1	69.3	60.7	79.4	P	P	S	.			
4279	10/31/00	87.5	3	F	1998	0.70798	0.97	W	TUO	568.8	84.5	75.9	94.6	S	S	S	120	3.18	0.22	

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4281	10/31/00	91	3	M	1998	0.70728	0.31	W	TUO*	454.0	64.9	56.3	74.9	P	P	P	*Inconclusive natal assignment*			
4292	10/31/00	74	3	F	1998	0.70733	0.44	W	TUO*	526.1	77.2	68.6	87.3	S	P	S	*Inconclusive natal assignment*			
4294	10/31/00	86	3	F	1998	0.70800	0.97	W	TUO	560.6	83.1	74.5	93.2	S	P	S	.			
4295	10/31/00	72	3	F	1998	0.70816	0.77	W	TUO	495.0	71.9	63.3	81.9	P	P	S	87	3.13	0.23	
4297	11/01/00	74	3	F	1998	0.70805	0.95	W	TUO	576.9	85.9	77.3	96.0	S	S	S	109	2.98	0.18	
4299	11/06/00	81	3	F	1998	0.70801	0.97	W	TUO	527.8	77.5	68.9	87.6	S	P	S	.			
4300	11/06/00	96	3	M	1998	0.70735	0.50	W	TUO*	452.0	64.5	55.9	74.6	P	P	P	*Inconclusive natal assignment*			
4306	11/06/00	85	3	F	1998	0.70801	0.97	W	TUO	520.7	76.3	67.7	86.3	S	P	S	93	3.27	0.17	
4309	11/06/00	84	3	F	1998	0.70807	0.93	W	TUO	453.7	64.8	56.2	74.9	P	P	P	.			
4311	11/06/00	74	3	F	1998	0.70752	0.81	W	TUO	432.7	61.2	52.6	71.3	P	F	P	73	3.03	0.22	
4316	11/06/00	81	3	F	1998	0.70738	0.55	W	TUO	383.9	52.9	44.3	63.0	F	F	P	.			
4317	11/06/00	79	3	F	1998	0.70786	0.97	W	TUO	488.2	70.7	62.1	80.8	P	P	S	94 †	2.82	0.26	† Microstructure ran out 55um before last natal spot (inferred 19 increments)
4321	11/06/00	70	3	F	1998	0.70742	0.65	W	TUO	500.4	72.8	64.2	82.9	P	P	S	73	3.54	0.36	
4331	11/07/00	86	3	M	1998	0.70798	0.97	W	TUO	571.5	85.0	76.4	95.0	S	S	S	127	3.00	0.20	
4334	11/07/00	85	3	F	1998	0.70739	0.59	W	TUO	384.6	53.0	44.4	63.1	F	F	P	54	3.44	0.23	
4337	11/07/00	74	3	F	1998	0.70733	0.45	W	TUO*	535.3	78.8	70.2	88.8	S	P	S	*Inconclusive natal assignment*			
4340	11/07/00	75.5	3	F	1998	0.70783	0.97	W	TUO	490.2	71.1	62.5	81.1	P	P	S	.			
4343	11/07/00	81	3	F	1998	0.70768	0.92	W	TUO	509.5	74.4	65.8	84.4	P	P	S	109	2.96	0.26	
4352	11/07/00	73	3	F	1998	0.70788	0.97	W	TUO	563.0	83.5	74.9	93.6	S	P	S	81	3.09	0.20	
4360	11/08/00	76.5	3	F	1998	0.70818	0.67	W	TUO	578.2	86.1	77.5	96.2	S	S	S	.			
4376	11/09/00	85	3	F	1998	0.70733	0.46	W	TUO*	571.8	85.0	76.4	95.1	S	S	S	*Inconclusive natal assignment*			
4378	11/09/00	88	3	M	1998	0.70728	0.33	W	TUO*	607.4	91.1	82.5	101.2	S	S	S	*Inconclusive natal assignment*			
4381	11/13/00	90	3	M	1998	0.70816	0.75	W	TUO	455.0	65.0	56.5	75.1	P	P	S	75	3.02	0.20	
4383	11/13/00	79	3	M	1998	0.70756	0.85	W	TUO	529.2	77.7	69.1	87.8	S	P	S	.			
4384	11/13/00	80	3	F	1998	0.70786	0.97	W	TUO	506.8	73.9	65.3	84.0	P	P	S	85	3.16	0.23	
4397	11/13/00	67	3	F	1998	0.70819	0.66	W	TUO	474.7	68.4	59.8	78.5	P	P	S	84	2.93	0.26	
4403	11/14/00	77	3	F	1998	0.70808	0.92	W	TUO	501.7	73.0	64.4	83.1	P	P	S	90	2.99	0.23	
4414	11/14/00	81	3	F	1998	0.70749	0.77	W	TUO	467.5	67.2	58.6	77.3	P	P	S	.			
4418	11/14/00	86	3	F	1998	0.70742	0.66	W	TUO	460.1	65.9	57.3	76.0	P	P	S	65	3.84	0.34	
4424	11/14/00	77	3	F	1998	0.70783	0.97	W	TUO	552.9	81.8	73.2	91.8	S	P	S	125	2.95	0.21	
4441	11/20/00	72	3	F	1998	0.70823	0.45	W	TUO*	485.5	70.3	61.7	80.3	P	P	S	*Inconclusive natal assignment*			

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4442	11/20/00	95	3	M	1998	0.70771	0.94	W	TUO	592.1	88.5	79.9	98.6	S	S	S	114	3.25	0.28	
4443	11/20/00	100	3	M	1998	0.70735	0.50	W	TUO*	475.3	68.5	59.9	78.6	P	P	S	*Inconclusive natal assignment*			
4450	11/20/00	82	3	F	1998	0.70817	0.73	W	TUO	447.6	63.8	55.2	73.8	P	P	P	104	2.26	0.24	
4451	11/20/00	92	3	M	1998	0.70817	0.72	W	TUO	472.3	68.0	59.4	78.1	P	P	S	108	2.82	0.25	
4455	11/20/00	74	3	F	1998	0.70769	0.93	W	TUO	514.6	75.2	66.6	85.3	S	P	S	78	3.29	0.22	
4458	11/21/00	80	3	F	1998	0.70792	0.98	W	TUO	543.4	80.2	71.6	90.2	S	P	S	92	3.33	0.26	
4476	11/22/00	100	3	M	1998	0.70804	0.95	W	TUO	514.9	75.3	66.7	85.4	S	P	S	111	2.68	0.32	
4484	11/27/00	77	3	F	1998	0.70788	0.97	W	TUO	528.8	77.7	69.1	87.7	S	P	S	90	3.06	0.26	
4487	11/27/00	84	3	F	1998	0.70800	0.97	W	TUO	493.6	71.6	63.1	81.7	P	P	S	.			
4504	12/04/00	100	3	M	1998	0.70826	0.30	W	TUO*	480.4	69.4	60.8	79.5	P	P	S	*Inconclusive natal assignment*			
4506	12/04/00	80	3	F	1998	0.70756	0.85	W	TUO	406.6	56.8	48.2	66.8	P	F	P	60	3.23	0.24	
4508	12/04/00	89	3	F	1998	0.70806	0.94	W	TUO	466.5	67.0	58.4	77.1	P	P	S	85	2.76	0.18	
4509	12/04/00	70.5	3	F	1998	0.70812	0.86	W	TUO	489.9	71.0	62.4	81.1	P	P	S	91	3.14	0.22	
4510	12/05/00	77	3	F	1998	0.70776	0.95	W	TUO	422.9	59.5	51.0	69.6	P	F	P	49	3.30	0.28	
4514	12/05/00	78	3	F	1998	0.70794	0.98	W	TUO	462.1	66.3	57.7	76.3	P	P	S	.			
4515	12/05/00	77	3	F	1998	0.70815	0.80	W	TUO	481.1	69.5	60.9	79.6	P	P	S	80	3.39	0.21	
4516	12/05/00	82	3	F	1998	0.70818	0.69	W	TUO	471.3	67.8	59.2	77.9	P	P	S	75	3.31	0.22	
4517	12/05/00	88.5	3	F	1998	0.70798	0.97	W	TUO	526.8	77.3	68.7	87.4	S	P	S	95	3.04	0.20	
4518	12/05/00	83	3	F	1998	0.70789	0.97	W	TUO	519.3	76.0	67.5	86.1	S	P	S	94	3.30	0.24	
4521	12/06/00	78.5	3	F	1998	0.70788	0.97	W	TUO	537.6	79.2	70.6	89.2	S	P	S	83	3.24	0.22	
4527	12/11/00	83	3	M	1998	0.70819	0.66	W	TUO	543.4	80.2	71.6	90.2	S	P	S	93	3.40	0.27	
4535	12/19/00	78	3	F	1998	0.70814	0.82	W	TUO	503.1	73.3	64.7	83.3	P	P	S	100	3.14	0.22	
9536	07/07/00	75	3	F	1998	0.70775	0.95	W	TUO	700.5	107.0	98.4	117.1	S	S	S	.			
11015	11/16/01	86.5	4	F	1998	0.70789	0.97	W	TUO	486.3	70.4	61.8	80.5	P	P	S	80	3.53	0.28	
11036	12/11/01	86	4	F	1998	0.70772	0.94	W	TUO	580.3	86.5	77.9	96.5	S	S	S	95	3.56	0.21	
11037	12/11/01	110	4	M	1998	0.70792	0.98	W	TUO	538.6	79.3	70.8	89.4	S	P	S	93	3.02	0.27	
11038	12/11/01	78	4	F	1998	0.70821	0.53	W	TUO	477.7	68.9	60.3	79.0	P	P	S	.			
11040	12/11/01	98	4	F	1998	0.70812	0.86	W	TUO	549.8	81.3	72.7	91.3	S	P	S	114	3.02	0.30	
11056	11/20/01	78	4	F	1998	0.70779	0.96	W	TUO	504.4	73.5	64.9	83.6	P	P	S	115	2.67	0.23	
11064	11/20/01	95	4	M	1998	0.70745	0.71	W	TUO	541.0	79.7	71.2	89.8	S	P	S	92	3.92	0.34	
11072	11/20/01	112	4	M	1998	0.70816	0.75	W	TUO	468.6	67.4	58.8	77.4	P	P	S	75	3.05	0.19	
11085	11/20/01	87	4	F	1998	0.70737	0.55	W	TUO	411.3	57.6	49.0	67.6	P	F	P	.			
11089	11/20/01	104	4	M	1998	0.70816	0.76	W	TUO	479.1	69.2	60.6	79.2	P	P	S	90	2.79	0.19	

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11097	11/30/01	82	4	M	1998	0.70743	0.67	W	TUO	518.3	75.9	67.3	85.9	S	P	S	88	3.23	0.39	
11098	11/30/01	87	4	F	1998	0.70807	0.93	W	TUO	530.2	77.9	69.3	88.0	S	P	S	93	3.20	0.20	
11140	11/26/01	88	4	F	1998	0.70769	0.93	W	TUO	479.4	69.2	60.6	79.3	P	P	S	79	2.90	0.27	
11154	11/26/01	87	4	F	1998	0.70794	0.98	W	TUO	518.7	75.9	67.3	86.0	S	P	S	91	3.25	0.27	
11176	12/07/01	92.5	4	F	1998	0.70821	0.54	W	TUO	544.7	80.4	71.8	90.5	S	P	S	.			
11177	12/07/01	90	4	F	1998	0.70781	0.96	W	TUO	484.1	70.0	61.4	80.1	P	P	S	.			
11181	12/18/01	87	3	F	1998	0.70819	0.63	W	TUO	604.7	90.6	82.0	100.7	S	S	S	129	3.21	0.22	
11182	12/17/01	99	4	M	1998	0.70798	0.97	W	TUO	397.8	55.3	46.7	65.3	P	F	P	51	3.10	0.23	
11190	11/23/01	90	3	M	1998	0.70821	0.53	W	TUO	506.8	73.9	65.3	84.0	P	P	S	95	2.99	0.24	
11216	11/21/01	94	4	F	1998	0.70821	0.54	W	TUO	517.6	75.8	67.2	85.8	S	P	S	122	2.55	0.27	
19680	11/15/01	103	4	M	1998	0.70766	0.92	W	TUO	603.0	90.3	81.8	100.4	S	S	S	.			
19684	11/15/01	92	3.5	M	1998	0.70776	0.95	W	TUO	508.2	74.1	65.5	84.2	P	P	S	.			
19685	11/15/01	87	4	F	1998	0.70811	0.89	W	TUO	513.2	75.0	66.4	85.1	S	P	S	.			
19687	11/15/01	82	3.5	M	1998	0.70806	0.95	W	TUO	515.3	75.4	66.8	85.4	S	P	S	96	2.97	0.21	
19691	11/15/01	91	4	M	1998	0.70721	0.19	W	TUO*	421.8	59.4	50.8	69.4	P	F	P	*Inconclusive natal assignment*			
19719	11/19/01	94.5	3.5	F	1998	0.70806	0.94	W	TUO	510.5	74.5	66.0	84.6	P	P	S	89	2.88	0.23	
19772	11/28/01	97	4	F	1998	0.70769	0.93	W	TUO	467.9	67.2	58.7	77.3	P	P	S	84	2.81	0.24	
19776	11/28/01	90	4	F	1998	0.70821	0.53	W	TUO	522.7	76.6	68.0	86.7	S	P	S	101	3.10	0.19	
19777	11/28/01	91	4	F	1998	0.70816	0.76	W	TUO	489.2	70.9	62.3	81.0	P	P	S	96	2.67	0.30	
19781	11/28/01	86	4	F	1998	0.70824	0.37	W	TUO*	532.5	78.3	69.7	88.4	S	P	S	*Inconclusive natal assignment*			
19783	11/28/01	89	4	F	1998	0.70793	0.98	W	TUO	432.7	61.2	52.6	71.3	P	F	P	68	3.03	0.26	
19785	11/28/01	88	4	F	1998	0.70765	0.91	W	TUO	446.2	63.5	55.0	73.6	P	F	P	67	3.16	0.25	
19790	11/28/01	94	4	F	1998	0.70818	0.68	W	TUO	504.1	73.4	64.9	83.5	P	P	S	104	2.44	0.24	
19796	12/03/01	81	4	F	1998	0.70811	0.88	W	TUO	509.9	74.4	65.8	84.5	P	P	S	83	3.31	0.24	
19798	12/03/01	93	4	M	1998	0.70814	0.83	W	TUO	474.7	68.4	59.8	78.5	P	P	S	101	3.02	0.23	
19800	12/03/01	114	4	M	1998	0.70776	0.95	W	TUO	569.8	84.7	76.1	94.7	S	S	S	.			
19802	12/03/01	97	4	F	1998	0.70824	0.40	W	TUO*	539.3	79.5	70.9	89.5	S	P	S	*Inconclusive natal assignment*			
19805	12/03/01	88	4	F	1998	0.70821	0.56	W	TUO	496.7	72.2	63.6	82.2	P	P	S	95	3.15	0.25	
19806	12/03/01	89	4	F	1998	0.70769	0.93	W	TUO	542.4	80.0	71.4	90.0	S	P	S	103	3.04	0.28	
19810	12/03/01	85	4	F	1998	0.70765	0.91	W	TUO	479.1	69.2	60.6	79.2	P	P	S	74	3.56	0.28	
19820	12/03/01	105	4	M	1998	0.70779	0.96	W	TUO	492.6	71.5	62.9	81.5	P	P	S	88	3.37	0.28	
19821	12/03/01	94	4	F	1998	0.70812	0.86	W	TUO	494.3	71.8	63.2	81.8	P	P	S	95	2.63	0.30	
19838	12/03/01	73	4	F	1998	0.70765	0.91	W	TUO	462.1	66.3	57.7	76.3	P	P	S	77	3.16	0.24	

Appendix 1A Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the Tuolumne River (natal exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive ("INC"), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable. The life stage at natal river exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

19840	12/03/01	81	4	F	1998	0.70813	0.84	W	TUO	436.1	61.8	53.2	71.9	P	F	P	84	2.87	0.24	
19857	12/04/01	97	4	M	1998	0.70776	0.95	W	TUO	538.0	79.2	70.6	89.3	S	P	S	93	3.20	0.20	
19864	12/04/01	99	4	M	1998	0.70813	0.84	W	TUO	514.9	75.3	66.7	85.4	S	P	S	109	3.02	0.27	
19867	12/04/01	86	4	F	1998	0.70808	0.93	W	TUO	478.7	69.1	60.5	79.2	P	P	S	95	2.99	0.26	
19872	12/10/01	84	4	F	1998	0.70815	0.78	W	TUO	463.1	66.4	57.8	76.5	P	P	S	77	2.88	0.19	
19875	12/10/01	83	4	F	1998	0.70823	0.42	W	TUO*	478.7	69.1	60.5	79.2	P	P	S	*Inconclusive natal assignment*			
19879	12/10/01	76	4	F	1998	0.70766	0.91	W	TUO	464.2	66.6	58.0	76.7	P	P	S	84	3.01	0.21	
19880	12/10/01	89	4	F	1998	0.70765	0.91	W	TUO	447.6	63.8	55.2	73.8	P	P	P	72	2.95	0.23	
19881	12/10/01	99	4	F	1998	0.70813	0.85	W	TUO	528.5	77.6	69.0	87.7	S	P	S	73	2.85	0.21	
20183	11/28/01	101	4	F	1998	0.70773	0.94	W	TUO	525.4	77.1	68.5	87.2	S	P	S	98	3.30	0.31	
4492	11/28/00	57	2	M	1999	0.70804	0.95	W	TUO	578.6	86.2	77.6	96.2	S	S	S	104 †	3.21	0.25	† Microstructure ran out 18um before last natal spot (inferred 5 increments)
4526	12/11/00	67	2	F	1999	0.70800	0.97	W	TUO	815.6	126.7	118.1	136.8	S	S	S	.			
11009	11/16/01	.	3	F	1999	0.70757	0.86	W	TUO	441.7	62.8	54.2	72.8	P	F	P	.			
11016	11/16/01	79.5	3	F	1999	0.70731	0.40	W	TUO*	369.6	50.4	41.9	60.5	F	F	P	49	2.84	0.25	
11019	11/16/01	60	3	F	1999	0.70743	0.67	INC	TUO*	476.5	68.7	60.1	78.8	P	P	S	.			Unreadable, so cannot assign natal location or do ageing
11021	11/16/01	73	3	F	1999	0.70731	0.39	W	TUO*	478.8	69.1	60.5	79.2	P	P	S	84	2.75	0.21	
11041	12/11/01	77	3	F	1999	0.70805	0.95	W	TUO	509.5	74.4	65.8	84.4	P	P	S	93	2.97	0.24	
11094	11/30/01	80	3	F	1999	0.70756	0.85	W	TUO	444.0	63.2	54.6	73.2	P	F	P	64	2.98	0.29	
11096	11/30/01	77	3	F	1999	0.70764	0.91	W	TUO	503.0	73.3	64.7	83.3	P	P	S	97	2.94	0.23	
11099	11/30/01	73	3	F	1999	0.70733	0.44	W	TUO*	467.2	67.1	58.5	77.2	P	P	S	*Inconclusive natal assignment*			
11100	11/30/01	83	3	F	1999	0.70748	0.75	W	TUO	442.6	62.9	54.3	73.0	P	F	P	.			
11132	11/26/01	76	3	F	1999	0.70734	0.46	W	TUO*	462.1	66.3	57.7	76.3	P	P	S	91	2.91	0.24	
11141	11/26/01	77	3	F	1999	0.70741	0.63	W	TUO	395.6	54.9	46.3	65.0	F	F	P	.			
11146	11/26/01	81	3	F	1999	0.70722	0.20	W	TUO*	434.2	61.5	52.9	71.6	P	F	P	*Inconclusive natal assignment*			
11157	11/26/01	80	3	M	1999	0.70740	0.61	W	TUO	405.4	56.6	48.0	66.6	P	F	P	64	3.00	0.32	
11161	11/26/01	74	3	F	1999	0.70792	0.98	W	TUO	426.3	60.1	51.6	70.2	P	F	P	.			
11162	11/26/01	78	3	F	1999	0.70724	0.25	W	TUO*	469.1	67.5	58.9	77.5	P	P	S	68	3.56	0.26	
11174	12/07/01	80	3	F	1999	0.70754	0.83	W	TUO	404.9	56.5	47.9	66.6	P	F	P	61	3.15	0.21	
11192	11/23/01	74	3	F	1999	0.70772	0.94	W	TUO	478.8	69.1	60.5	79.2	P	P	S	74	3.02	0.28	
11209	11/21/01	97	3	M	1999	0.70771	0.94	W	TUO	551.4	81.5	72.9	91.6	S	P	S	85	3.72	0.31	

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11213	11/21/01	83	3	F	1999	0.70771	0.94	W	TUO	483.5	69.9	61.3	80.0	P	P	S	.			
11217	11/21/01	40.5	3	M	1999	0.70764	0.90	W	TUO	447.2	63.7	55.1	73.8	P	P	P	84	2.59	0.23	
14499	11/04/02	93	4	F	1999	0.70814	0.83	W	TUO	542.7	80.0	71.5	90.1	S	P	S	92	2.99	0.21	
14568	11/05/02	107	4	M	1999	0.70761	0.89	W	TUO	591.8	88.4	79.9	98.5	S	S	S	82	3.39	0.25	
14621	11/12/02	104	4	M	1999	0.70776	0.95	W	TUO	538.8	79.4	70.8	89.4	S	P	S	88	2.84	0.25	
14623	11/12/02	85	4	F	1999	0.70782	0.97	W	TUO	492.8	71.5	62.9	81.6	P	P	S	90	2.96	0.20	
14627	11/12/02	97	4	F	1999	0.70754	0.83	W	TUO	437.0	62.0	53.4	72.0	P	F	P	.			
14635	11/12/02	101	4	M	1999	0.70777	0.96	W	TUO	510.0	74.4	65.9	84.5	P	P	S	74	3.37	0.20	
14647	11/12/02	96	4	F	1999	0.70805	0.95	W	TUO	466.8	67.1	58.5	77.1	P	P	S	.			
14669	11/12/02	104	4	M	1999	0.70761	0.89	W	TUO	475.1	68.5	59.9	78.6	P	P	S	80	3.09	0.22	
14687	11/12/02	91	4	F	1999	0.70738	0.56	W	TUO	510.5	74.5	65.9	84.6	P	P	S	81	3.57	0.27	
14693	11/12/02	99	4	M	1999	0.70751	0.80	W	TUO	521.6	76.4	67.8	86.5	S	P	S	84	3.04	0.19	
14716	11/13/02	97	4	M	1999	0.70757	0.85	W	TUO	522.6	76.6	68.0	86.7	S	P	S	80	3.05	0.25	
14729	11/13/02	96	4	M	1999	0.70726	0.28	W	TUO*	462.6	66.3	57.8	76.4	P	P	S	69	3.08	0.21	
14759	11/14/02	101	4	M	1999	0.70766	0.91	W	TUO	508.1	74.1	65.5	84.2	P	P	S	94	2.95	0.24	
14774	11/14/02	86	4	F	1999	0.70786	0.97	W	TUO	483.1	69.9	61.3	79.9	P	P	S	.			
14804	11/14/02	93	4	F	1999	0.70768	0.93	W	TUO	488.6	70.8	62.2	80.9	P	P	S	78	3.07	0.17	
14824	11/15/02	98	4	M	1999	0.70733	0.44	W	TUO*	517.4	75.7	67.1	85.8	S	P	S	*Inconclusive natal assignment*			
14850	11/18/02	92	4	F	1999	0.70722	0.19	W	TUO*	465.4	66.8	58.2	76.9	P	P	S	*Inconclusive natal assignment*			
14884	11/18/02	89	4	F	1999	0.70749	0.77	W	TUO	499.0	72.6	64.0	82.6	P	P	S	.			
14889	11/18/02	88	4	M	1999	0.70754	0.82	W	TUO	508.5	74.2	65.6	84.3	P	P	S	80	3.11	0.22	
14892	11/18/02	100	4	M	1999	0.70725	0.26	W	TUO*	471.9	67.9	59.4	78.0	P	P	S	*Inconclusive natal assignment*			
14904	11/18/02	100	4	M	1999	0.70745	0.70	W	TUO	480.2	69.4	60.8	79.4	P	P	S	61	3.65	0.25	
14919	11/18/02	88	4	F	1999	0.70729	0.35	W	TUO*	409.7	57.3	48.7	67.4	P	F	P	*Inconclusive natal assignment*			
14953	11/19/02	103	4	M	1999	0.70787	0.97	W	TUO	489.5	71.0	62.4	81.0	P	P	S	92	2.91	0.18	
14955	11/19/02	94	4	F	1999	0.70813	0.84	W	TUO	527.1	77.4	68.8	87.4	S	P	S	96	3.28	0.25	
14976	11/19/02	102	4	M	1999	0.70765	0.91	W	TUO	496.3	72.1	63.5	82.2	P	P	S	94	3.21	0.26	
14999	11/20/02	104	4	M	1999	0.70726	0.27	W	TUO*	489.5	71.0	62.4	81.0	P	P	S	67	3.88	0.22	
15001	11/20/02	101	4	M	1999	0.70787	0.97	W	TUO	431.7	61.1	52.5	71.1	P	F	P	74	2.92	0.25	
15052	11/20/02	105	4	M	1999	0.70776	0.95	W	TUO	557.9	82.6	74.1	92.7	S	P	S	.			
15064	11/20/02	98	4	M	1999	0.70775	0.95	W	TUO	415.1	58.2	49.6	68.3	P	F	P	49	3.21	0.25	
15097	11/21/02	104	4	M	1999	0.70774	0.95	W	TUO	539.3	79.5	70.9	89.5	S	P	S	101	3.22	0.26	

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15146	11/24/02	107	4	M	1999	0.70721	0.19	W	TUO*	451.0	64.4	55.8	74.4	P	P	P	*Inconclusive natal assignment*			
15150	11/24/02	108	4	M	1999	0.70761	0.89	W	TUO	436.4	61.9	53.3	71.9	P	F	P	64	3.34	0.28	
15165	11/24/02	100	4	M	1999	0.70726	0.27	W	TUO*	406.9	56.8	48.2	66.9	P	F	P	*Inconclusive natal assignment*			
19679	11/15/01	78	3	F	1999	0.70754	0.83	W	TUO	514.2	75.2	66.6	85.2	S	P	S	98	3.26	0.26	
19686	11/15/01	81	3	F	1999	0.70780	0.96	W	TUO	518.4	75.9	67.3	85.9	S	P	S	96	3.40	0.22	
19688	11/15/01	72.5	3	F	1999	0.70772	0.94	W	TUO	554.6	82.1	73.5	92.1	S	P	S	.			
19705	11/15/01	76	3	F	1999	0.70729	0.35	W	TUO*	373.8	51.2	42.6	61.2	F	F	P	*Inconclusive natal assignment*			
19722	11/19/01	87	3	F	1999	0.70733	0.44	W	TUO*	553.2	81.8	73.3	91.9	S	P	S	*Inconclusive natal assignment*			
19775	11/28/01	83	3	F	1999	0.70736	0.52	W	TUO	509.5	74.4	65.8	84.4	P	P	S	81	3.44	0.25	
19779	11/28/01	70	3	F	1999	0.70760	0.88	W	TUO	477.0	68.8	60.2	78.9	P	P	S	65	3.63	0.22	
19782	11/28/01	76	3	M	1999	0.70779	0.96	W	TUO	514.6	75.2	66.7	85.3	S	P	S	89	3.03	0.19	
19786	11/28/01	85	3	M	1999	0.70746	0.73	W	TUO	549.0	81.1	72.5	91.2	S	P	S	101	3.30	0.26	
19791	11/28/01	79	3	F	1999	0.70735	0.49	W	TUO*	461.2	66.1	57.5	76.2	P	P	S	*Inconclusive natal assignment*			
19792	11/28/01	76	3	F	1999	0.70814	0.83	W	TUO	486.8	70.5	61.9	80.5	P	P	S	82	3.78	0.25	
19797	12/03/01	84	3	F	1999	0.70735	0.48	W	TUO*	458.1	65.6	57.0	75.6	P	P	S	*Inconclusive natal assignment*			
19816	12/03/01	81	3	M	1999	0.70770	0.93	W	TUO	632.3	95.4	86.8	105.4	S	S	S	.			
19836	12/03/01	88	3	M	1999	0.70726	0.29	W	TUO*	451.4	64.4	55.8	74.5	P	P	P	*Inconclusive natal assignment*			
19841	12/03/01	74	3	F	1999	0.70724	0.23	W	TUO*	457.9	65.5	57.0	75.6	P	P	S	*Inconclusive natal assignment*			
19845	12/04/01	87	3	M	1999	0.70788	0.97	W	TUO	514.2	75.2	66.6	85.2	S	P	S	93	2.96	0.20	
19855	12/04/01	85	3	M	1999	0.70768	0.92	W	TUO	441.7	62.8	54.2	72.8	P	F	P	61	3.15	0.32	
19861	12/04/01	74	3	F	1999	0.70775	0.95	W	TUO	494.2	71.7	63.2	81.8	P	P	S	80	3.13	0.22	
19866	12/04/01	86	3	M	1999	0.70724	0.23	W	TUO*	467.7	67.2	58.6	77.3	P	P	S	63	3.24	0.27	
19868	12/04/01	74	3	F	1999	0.70736	0.51	W	TUO	583.5	87.0	78.4	97.1	S	S	S	97	3.86	0.29	
19874	12/10/01	75	3	F	1999	0.70756	0.84	W	TUO	372.4	50.9	42.3	61.0	F	F	P	61	3.21	0.26	
19876	12/10/01	71	3	M	1999	0.70765	0.91	W	TUO	507.2	74.0	65.4	84.0	P	P	S	79	3.48	0.20	
11055	11/20/01	56	2	M	2000	0.70770	0.93	W	TUO	354.0	47.8	39.2	57.8	F	F	P	.			
11063	11/20/01	58	2	M	2000	0.70763	0.90	W	TUO	524.0	76.8	68.3	86.9	S	P	S	81	3.13	0.22	
11076	11/20/01	81	2	F	2000	0.70807	0.93	W	TUO	509.0	74.3	65.7	84.3	P	P	S	98	2.98	0.23	
11083	11/20/01	59	2	M	2000	0.70742	0.65	W	TUO	419.0	58.9	50.3	69.0	P	F	P	49	3.28	0.23	
11111	11/08/01	54.5	2	F	2000	0.70775	0.95	W	TUO	477.0	68.8	60.2	78.9	P	P	S	81	3.00	0.23	
11133	11/26/01	59	2	F	2000	0.70797	0.97	W	TUO	472.0	68.0	59.4	78.0	P	P	S	.			
11167	11/26/01	60	2	F	2000	0.70752	0.81	W	TUO	451.0	64.4	55.8	74.4	P	P	P	61	2.99	0.29	
11212	11/21/01	65.5	2	F	2000	0.70760	0.88	W	TUO	465.0	66.8	58.2	76.8	P	P	S	60	3.38	0.26	

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11215	11/21/01	60	2	F	2000	0.70795	0.98	W	TUO	508.0	74.1	65.5	84.2	P	P	S	69	3.84	0.26	
11220	10/31/01	62	2	F	2000	0.70789	0.97	W	TUO	548.0	80.9	72.4	91.0	S	P	S	84	3.37	0.30	
11223	10/31/01	54	2	M	2000	0.70784	0.97	W	TUO	494.0	71.7	63.1	81.8	P	P	S	77	3.05	0.21	
11228	10/31/01	60	2	M	2000	0.70778	0.96	W	TUO	407.0	56.8	48.2	66.9	P	F	P	66	3.11	0.19	
14528	11/04/02	95	3	M	2000	0.70813	0.85	W	TUO	513.0	75.0	66.4	85.0	P	P	S	84	2.93	0.24	
14539	11/04/02	72	3	F	2000	0.70789	0.97	W	TUO	451.0	64.4	55.8	74.4	P	P	P	69	2.97	0.19	
14540	11/04/02	69	3	F	2000	0.70777	0.96	INC	TUO*	438.0	62.1	53.6	72.2	P	F	P	.			Unreadable, so cannot assign natal location or do ageing
14544	11/05/02	78	3	F	2000	0.70782	0.96	W	TUO	429.0	60.6	52.0	70.7	P	F	P	48	2.90	0.22	
14545	11/05/02	92	3	M	2000	0.70792	0.98	W	TUO	404.0	56.3	47.7	66.4	P	F	P	.			
14548	11/05/02	72	3	F	2000	0.70801	0.97	W	TUO	574.0	85.4	76.8	95.5	S	S	S	.			
14550	11/05/02	80	3	M	2000	0.70789	0.97	W	TUO	387.0	53.4	44.8	63.5	F	F	P	62	2.75	0.25	
14556	11/05/02	73	3	F	2000	0.70742	0.64	W	TUO	433.0	61.3	52.7	71.4	P	F	P	71	3.15	0.26	
14559	11/05/02	89	3	M	2000	0.70768	0.92	W	TUO	382.0	52.6	44.0	62.6	F	F	P	.			
14560	11/05/02	78	3	F	2000	0.70756	0.85	W	TUO	434.0	61.5	52.9	71.5	P	F	P	69	2.96	0.22	
14566	11/05/02	79	3	F	2000	0.70786	0.97	W	TUO	431.0	60.9	52.4	71.0	P	F	P	.			
14571	11/05/02	97	3	M	2000	0.70763	0.90	W	TUO	502.0	73.1	64.5	83.1	P	P	S	77	2.91	0.24	
14575	11/05/02	73	3	F	2000	0.70795	0.98	W	TUO	438.0	62.1	53.6	72.2	P	F	P	72	3.07	0.22	
14578	11/05/02	73	3	F	2000	0.70745	0.71	W	TUO	411.0	57.5	48.9	67.6	P	F	P	.			
14579	11/05/02	93	3	M	2000	0.70742	0.65	W	TUO	413.0	57.9	49.3	67.9	P	F	P	60	3.41	0.30	
14584	11/05/02	81	.	M	2000	0.70772	0.94	W	TUO	464.0	66.6	58.0	76.7	P	P	S	.			
14587	11/05/02	80	3	F	2000	0.70780	0.96	W	TUO	508.0	74.1	65.5	84.2	P	P	S	.			
14596	11/05/02	80	3	F	2000	0.70800	0.97	W	TUO	516.0	75.5	66.9	85.5	S	P	S	99	2.97	0.22	
14597	11/05/02	91	3	M	2000	0.70756	0.85	W	TUO	409.0	57.2	48.6	67.2	P	F	P	57	3.05	0.29	
14600	11/05/02	75	3	F	2000	0.70774	0.95	W	TUO	383.0	52.7	44.1	62.8	F	F	P	.			
14616	11/12/02	94	3	M	2000	0.70768	0.92	W	TUO	344.0	46.1	37.5	56.1	F	F	P	18	2.56	0.13	
14626	11/12/02	91	3	M	2000	0.70735	0.50	W	TUO	461.0	66.1	57.5	76.1	P	P	S	.			
14629	11/12/02	74	3	F	2000	0.70772	0.94	W	TUO	486.0	70.3	61.8	80.4	P	P	S	.			
14661	11/12/02	94	3	M	2000	0.70761	0.89	W	TUO	412.0	57.7	49.1	67.8	P	F	P	73	2.64	0.31	
14668	11/12/02	90	3	M	2000	0.70785	0.97	W	TUO	466.0	66.9	58.3	77.0	P	P	S	75	2.93	0.21	
14673	11/12/02	90	3	M	2000	0.70770	0.93	W	TUO	447.0	63.7	55.1	73.7	P	P	P	61	3.28	0.22	
14689	11/12/02	93	3	M	2000	0.70803	0.96	W	TUO	465.0	66.8	58.2	76.8	P	P	S	87	3.34	0.23	Microstructure ran out 13um before last natal spot (inferred 4

Appendix 1A Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the Tuolumne River (natal exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive ("INC"), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable. The life stage at natal river exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

																				increments)
14701	11/13/02	93	3	M	2000	0.70803	0.96	W	TUO	456.0	65.2	56.6	75.3	P	P	S	60	2.32	0.25	Strange profile (used same distance for natal and FW exit)
14721	11/13/02	76	3	F	2000	0.70804	0.95	W	TUO	453.0	64.7	56.1	74.8	P	P	P	75	3.05	0.25	
14735	11/13/02	92	3	M	2000	0.70763	0.90	W	TUO	367.0	50.0	41.4	60.1	F	F	P	44	3.19	0.17	
14743	11/13/02	76	3	F	2000	0.70802	0.96	W	TUO	479.0	69.1	60.6	79.2	P	P	S	89	2.89	0.22	
14749	11/14/02	80	3	F	2000	0.70773	0.94	W	TUO	372.0	50.9	42.3	60.9	F	F	P	45	2.86	0.17	
14753	11/14/02	84	3	M	2000	0.70774	0.95	W	TUO	393.0	54.4	45.9	64.5	F	F	P	64	3.10	0.20	
14769	11/14/02	81	3	F	2000	0.70757	0.85	W	TUO	378.0	51.9	43.3	61.9	F	F	P	51	3.19	0.27	
14783	11/14/02	89	3	M	2000	0.70793	0.98	W	TUO	496.0	72.1	63.5	82.1	P	P	S	77	3.43	0.22	
14785	11/14/02	95	3	M	2000	0.70766	0.91	W	TUO	447.0	63.7	55.1	73.7	P	P	P	.			
14786	11/14/02	76	3	F	2000	0.70781	0.96	W	TUO	421.0	59.2	50.6	69.3	P	F	P	51	3.57	0.20	
14813	11/14/02	86	3	M	2000	0.70799	0.97	W	TUO	430.0	60.8	52.2	70.8	P	F	P	65	3.08	0.24	
14815	11/15/02	82	3	F	2000	0.70761	0.89	W	TUO	438.0	62.1	53.6	72.2	P	F	P	.			
14858	11/18/02	104	3	M	2000	0.70740	0.61	W	TUO	464.2	66.6	58.0	76.7	P	P	S	73	3.23	0.29	
14880	11/18/02	80	3	M	2000	0.70727	0.31	W	TUO*	409.0	57.2	48.6	67.2	P	F	P	48	3.57	0.28	
14907	11/18/02	74	3	F	2000	0.70773	0.95	W	TUO	475.0	68.5	59.9	78.5	P	P	S	71	3.08	0.22	
14921	11/18/02	93	3.5	F	2000	0.70780	0.96	W	TUO	377.0	51.7	43.1	61.8	F	F	P	28	3.08	0.21	
14929	11/18/02	91	3	M	2000	0.70764	0.90	W	TUO	454.0	64.9	56.3	74.9	P	P	P	67	3.37	0.27	
14975	11/19/02	102	3	M	2000	0.70743	0.67	W	TUO	392.0	54.3	45.7	64.3	F	F	P	.			
15091	11/21/02	100	3	F	2000	0.70792	0.98	W	TUO	497.0	72.2	63.6	82.3	P	P	S	60	3.52	0.23	
15113	11/21/02	100	3	M	2000	0.70763	0.90	W	TUO	407.0	56.8	48.2	66.9	P	F	P	.			
15133	11/24/02	103	3	M	2000	0.70754	0.83	W	TUO	428.0	60.4	51.8	70.5	P	F	P	67	3.06	0.25	
15193	11/24/02	101	3	M	2000	0.70773	0.94	W	TUO	508.0	74.1	65.5	84.2	P	P	S	79	3.11	0.25	
15243	12/02/02	91	3	M	2000	0.70777	0.95	W	TUO	414.0	58.0	49.4	68.1	P	F	P	71	3.02	0.27	
19681	11/15/01	65	2	M	2000	0.70759	0.87	W	TUO	383.0	52.7	44.1	62.8	F	F	P	.			
19695	11/19/01	59.5	2	M	2000	0.70759	0.88	W	TUO	488.0	70.7	62.1	80.8	P	P	S	74	3.09	0.26	
19813	12/03/01	48	2	M	2000	0.70789	0.97	W	TUO	503.0	73.3	64.7	83.3	P	P	S	133	3.11	0.26	
19831	12/03/01	57	2	F	2000	0.70779	0.96	W	TUO	386.0	53.2	44.7	63.3	F	F	P	48	3.29	0.24	
19853	12/04/01	60	2	F	2000	0.70781	0.96	W	TUO	517.0	75.6	67.1	85.7	S	P	S	90	3.14	0.29	
19858	12/04/01	58	2	F	2000	0.70761	0.89	W	TUO	437.0	62.0	53.4	72.0	P	F	P	.			
17628	11/14/05	91	3	M	2003	0.70730	0.37	W	TUO*	459.8	65.9	57.3	75.9	P	P	S	70	3.67	0.26	
17631	11/14/05	84	3	F	2003	0.70751	0.80	W	TUO	554.2	82.0	73.4	92.1	S	P	S	94	3.80	0.25	

Appendix 1A Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the Tuolumne River (natal exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive ("INC"), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable. The life stage at natal river exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

17634	11/14/05	81	3	F	2003	0.70772	0.94	W	TUO	475.1	68.5	59.9	78.6	P	P	S	94	2.57	0.22	
17637	11/16/05	92	3	M	2003	0.70726	0.27	W	TUO*	381.2	52.4	43.8	62.5	F	F	P	*Inconclusive natal assignment*			
17638	11/16/05	76	3	F	2003	0.70731	0.41	W	TUO*	536.5	79.0	70.4	89.0	S	P	S	81	3.60	0.24	
17645	11/21/05	75	3	F	2003	0.70747	0.74	W	TUO	557.4	82.6	74.0	92.6	S	P	S	.			
17651	11/21/05	88	3	M	2003	0.70745	0.71	W	TUO	538.8	79.4	70.8	89.4	S	P	S	76	3.98	0.22	
17654	11/21/05	73	3	F	2003	0.70757	0.86	W	TUO	309.6	40.2	31.6	50.3	F	F	F	57	2.79	0.26	
17666	11/28/05	73	3	F	2003	0.70753	0.82	W	TUO	485.8	70.3	61.7	80.4	P	P	S	88	3.09	0.20	
17667	11/28/05	75	3	F	2003	0.70744	0.69	W	TUO	493.7	71.7	63.1	81.7	P	P	S	97	3.34	0.27	
17669	11/28/05	72	3	F	2003	0.70743	0.66	W	TUO	504.9	73.6	65.0	83.6	P	P	S	.			
17672	11/28/05	79	3	F	2003	0.70756	0.85	INC	TUO*	n/a (vaterite)	n/a	n/a	n/a	n/a	n/a	n/a	.			Otolith was vateritic during natal rearing (so no HvW assignment or exit age/distance)
17673	11/28/05	71	3	F	2003	0.70745	0.70	W	TUO	450.5	64.3	55.7	74.3	P	P	P	.			
17679	11/28/05	85	3	M	2003	0.70729	0.34	W	TUO*	452.8	64.7	56.1	74.7	P	P	P	53	3.86	0.22	
17680	11/28/05	75	3	F	2003	0.70777	0.96	W	TUO	507.7	74.1	65.5	84.1	P	P	S	85	2.92	0.26	Microstructure ran out 54um before last natal spot (inferred 18 increments)
17681	11/28/05	72	3	F	2003	0.70763	0.90	W	TUO	441.7	62.8	54.2	72.8	P	F	P	.			
17685	11/28/05	61	3	M	2003	0.70727	0.30	W	TUO*	419.8	59.0	50.4	69.1	P	F	P	*Inconclusive natal assignment*			
17690	11/28/05	83	3	M	2003	0.70754	0.83	W	TUO	565.8	84.0	75.4	94.1	S	S	S	102	3.61	0.28	
17692	11/29/05	85	3	F	2003	0.70759	0.87	W	TUO	432.4	61.2	52.6	71.2	P	F	P	46	4.20	0.19	
17703	12/06/05	75	3	F	2003	0.70751	0.79	W	TUO	599.2	89.7	81.1	99.8	S	S	S	108	3.33	0.19	
17712	12/06/05	90	3	M	2003	0.70734	0.46	W	TUO*	456.5	65.3	56.7	75.4	P	P	S	*Inconclusive natal assignment*			
17713	12/06/05	76	3	F	2003	0.70755	0.84	W	TUO	446.3	63.6	55.0	73.6	P	F	P	66	3.63	0.20	
17716	12/06/05	82	3	F	2003	0.70744	0.69	W	TUO	514.6	75.2	66.7	85.3	S	P	S	.			
17718	12/07/05	79	3	F	2003	0.70751	0.79	W	TUO	530.9	78.0	69.4	88.1	S	P	S	.			
17729	12/12/05	92	3	M	2003	0.70754	0.82	W	TUO	481.6	69.6	61.0	79.7	P	P	S	.			
17740	12/12/05	79	3	F	2003	0.70738	0.56	W	TUO	453.7	64.8	56.2	74.9	P	P	P	.			
17742	12/12/05	75	3	F	2003	0.70743	0.66	W	TUO	416.6	58.5	49.9	68.5	P	F	P	65	3.09	0.21	
17746	12/12/05	72	3	F	2003	0.70762	0.89	W	TUO	599.7	89.8	81.2	99.9	S	S	S	.			
17751	12/12/05	85	3	F	2003	0.70755	0.84	W	TUO	504.9	73.6	65.0	83.6	P	P	S	93	3.49	0.21	
17753	12/12/05	81	3	M	2003	0.70750	0.79	W	TUO	478.8	69.1	60.5	79.2	P	P	S	65	3.50	0.26	
17758	12/12/05	84	3	F	2003	0.70718	0.14	W	TUO*	501.2	72.9	64.4	83.0	P	P	S	76	3.59	0.21	

Appendix 1A Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the Tuolumne River (natal exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive (“INC”), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable. The life stage at natal river exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

17759	12/12/05	70	3	F	2003	0.70765	0.91	W	TUO	487.2	70.6	62.0	80.6	P	P	S	.			
17763	12/12/05	79	3	F	2003	0.70744	0.70	W	TUO	461.6	66.2	57.6	76.2	P	P	S	74	3.59	0.19	
18144	12/05/06	86	4	F	2003	0.70726	0.29	W	TUO*	502.1	73.1	64.5	83.2	P	P	S	78	3.37	0.22	
18150	12/11/06	84	4	F	2003	0.70741	0.62	W	TUO	444.9	63.3	54.7	73.4	P	F	P	65	3.30	0.17	
24120	11/07/11	76	3	F	2009	0.70777	0.73	W	TUO	451.3	64.4	55.8	74.5	P	P	P	66	3.29	0.23	
24176	11/14/11	81	3	F	2009	0.70781	0.77	W	TUO	542.0	79.9	71.3	90.0	S	P	S	76	3.78	0.24	
24178	11/14/11	67	3	M	2009	0.70778	0.74	W	TUO	559.0	81.0	72.4	91.0	S	P	S	109	3.19	0.23	
24238	11/21/11	70	3	F	2009	0.70773	0.69	W	TUO	508.2	74.1	65.5	84.2	P	P	S	.			
24283	11/23/11	83	3	M	2009	0.70734	0.16	W	TUO*	479.7	69.3	60.7	79.3	P	P	S	*Inconclusive natal assignment*			
24292	11/28/11	95	3	M	2009	0.70730	0.12	W	TUO*	555.9	82.3	73.7	92.4	S	P	S	*Inconclusive natal assignment*			
26012	11/13/12	84	4	F	2009	0.70780	0.76	W	TUO	546.1	80.6	72.0	90.7	S	P	S	101	3.16	0.23	

[1] Assignments using isotope-based discriminant function analysis and reference samples from existing or ongoing projects ([1], [2], P. Weber, A. Sturrock, unpub)
[2] Hatchery vs. wild assignment using microstructure-based discriminant function analysis and existing reference samples, after [3].
[3] Size-defined life stage designations (fry: <55mm, parr: >55mm to <75mm, smolt: >75mm), after [4].

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive (“INC”), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

						Natal Sr ratio				FW EXIT	Predicted FL at natal exit (mm)			Predicted life stage at natal exit [3]				Increment width (um)		
Sample ID	Capture date	Capture FL (cm)	Scale age	Sex	Outmi-gration year	Mean natal value	Prob to TUO [1]	H vs. W [2]	Natal location	Otolith distance (um)	FL	Lower 95% CI	Upper 95% CI	Life stage	Lower 95% CI	Upper 95% CI	Increment number (days)	Mean	CV	Notes
4175	10/10/00	98	3	M	1998	0.70799	0.97	W	TUO	603.6	90.4	81.9	100.5	S	S	S	4	3.1	0.2	
4176	10/10/00	91	3	M	1998	0.70774	0.95	W	TUO	604.3	90.6	82.0	100.6	S	S	S	22	3.1	0.2	
4182	10/17/00	76	3	M	1998	0.70803	0.96	W	TUO	578.3	86.1	77.5	96.2	S	S	S	11	2.8	0.3	
4183	10/17/00	90	3	M	1998	0.70797	0.97	W	TUO	514.7	75.3	66.7	85.3	S	P	S	16	3.7	0.2	
4185	10/17/00	84	3	F	1998	0.70728	0.64	W	TUO	585.4	87.3	78.7	97.4	S	S	S	30	2.6	0.2	
4189	10/24/00	90	3	F	1998	0.70806	0.94	W	TUO	496.4	72.1	63.5	82.2	P	P	S	11	2.9	0.3	
4192	10/24/00	87.5	3	F	1998	0.70807	0.93	W	TUO	517.3	75.7	67.1	85.8	S	P	S	5	5.3	0.3	
4196	10/24/00	67.9	3	F	1998	0.70800	0.97	W	TUO	524.7	77.0	68.4	87.0	S	P	S	n/a	n/a	n/a	
4197	10/24/00	78.6	3	F	1998	0.70740	0.61	W	TUO	531.8	78.2	69.6	88.2	S	P	S	23	3.8	0.2	
4200	10/24/00	68.6	3	F	1998	0.70760	0.88	W	TUO	611.4	91.8	83.2	101.9	S	S	S	9	3.4	0.2	
4210	10/24/00	88.3	3	M	1998	0.70764	0.91	W	TUO	511.3	74.7	66.1	84.7	P	P	S	8	3.9	0.2	
4211	10/24/00	72	3	F	1998	0.70783	0.97	W	TUO	625.4	94.2	85.6	104.2	S	S	S	.			
4212	10/24/00	78.1	3	M	1998	0.70765	0.91	W	TUO	568.9	84.5	75.9	94.6	S	S	S	13	2.8	0.3	
4215	10/25/00	79	3	F	1998	0.70802	0.96	W	TUO	620.1	93.3	84.7	103.3	S	S	S	18	3.5	0.2	
4226	10/25/00	80	3	F	1998	0.70770	0.93	W	TUO	479.9	69.3	60.7	79.4	P	P	S	6	4.1	0.2	
4232	10/25/00	88.5	3	M	1998	0.70821	0.53	W	TUO	540.3	79.6	71.0	89.7	S	P	S	.			
4233	10/25/00	72	3	F	1998	0.70795	0.98	W	TUO	504.7	73.5	64.9	83.6	P	P	S	18	2.5	0.2	
4234	10/25/00	77	3	F	1998	0.70823	0.45	W	TUO*	607.6	91.1	82.6	101.2	S	S	S	*Inconclusive natal assignment*			
4240	10/26/00	80	3	F	1998	0.70726	0.28	W	TUO*	484.4	70.1	61.5	80.1	P	P	S	*Inconclusive natal assignment*			
4249	10/30/00	80	3	F	1998	0.70737	0.54	W	TUO	520.5	76.2	67.6	86.3	S	P	S	.			
4253	10/30/00	80	3	M	1998	0.70810	0.90	W	TUO	595.9	89.1	80.6	99.2	S	S	S	16	2.8	0.3	
4266	10/30/00	77	3	F	1998	0.70740	0.60	W	TUO	508.6	74.2	65.6	84.3	P	P	S	19	2.7	0.2	
4267	10/30/00	75	3	F	1998	0.70812	0.86	W	TUO	534.2	78.6	70.0	88.7	S	P	S	.			
4269	10/30/00	80	3	F	1998	0.70732	0.43	W	TUO*	662.8	100.6	92.0	110.6	S	S	S	*Inconclusive natal assignment*			
4275	10/31/00	79	3	F	1998	0.70721	0.18	W	TUO*	444.6	63.3	54.7	73.3	P	F	P	*Inconclusive natal assignment*			
4278	10/31/00	83	3	F	1998	0.70802	0.96	W	TUO	515.7	75.4	66.8	85.5	S	P	S	.			
4279	10/31/00	87.5	3	F	1998	0.70798	0.97	W	TUO	596.6	89.3	80.7	99.3	S	S	S	7	3.0	0.2	
4281	10/31/00	91	3	M	1998	0.70728	0.31	W	TUO*	523.6	76.8	68.2	86.8	S	P	S	*Inconclusive natal assignment*			
4292	10/31/00	74	3	F	1998	0.70733	0.44	W	TUO*	608.5	91.3	82.7	101.4	S	S	S	*Inconclusive natal assignment*			
4294	10/31/00	86	3	F	1998	0.70800	0.97	W	TUO	586.2	87.5	78.9	97.6	S	S	S	.			

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive (“INC”), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

4295	10/31/00	72	3	F	1998	0.70816	0.77	W	TUO	518.5	75.9	67.3	86.0	S	P	S	10	2.8	0.2	
4297	11/01/00	74	3	F	1998	0.70805	0.95	W	TUO	644.1	97.4	88.8	107.4	S	S	S	13	3.3	0.2	
4299	11/06/00	81	3	F	1998	0.70801	0.97	W	TUO	555.3	82.2	73.6	92.3	S	P	S	.			
4300	11/06/00	96	3	M	1998	0.70735	0.50	W	TUO*	520.0	76.2	67.6	86.2	S	P	S	*Inconclusive natal assignment*			
4306	11/06/00	85	3	F	1998	0.70801	0.97	W	TUO	576.1	85.7	77.2	95.8	S	S	S	18	3.1	0.2	
4309	11/06/00	84	3	F	1998	0.70807	0.93	W	TUO	453.7	64.8	56.2	74.9	P	P	P	.			
4311	11/06/00	74	3	F	1998	0.70752	0.81	W	TUO	503.0	73.3	64.7	83.3	P	P	S	18	3.2	0.2	
4316	11/06/00	81	3	F	1998	0.70738	0.55	W	TUO	428.0	60.4	51.8	70.5	P	F	P	.			
4317	11/06/00	79	3	F	1998	0.70786	0.97	W	TUO	520.8	76.3	67.7	86.4	S	P	S	n/a	n/a	n/a	Microstructure ran out before fish left natal river
4321	11/06/00	70	3	F	1998	0.70742	0.65	W	TUO	592.5	88.6	80.0	98.6	S	S	S	29	3.9	0.3	
4331	11/07/00	86	3	M	1998	0.70798	0.97	W	TUO	604.8	90.7	82.1	100.7	S	S	S	10	2.3	0.2	
4334	11/07/00	85	3	F	1998	0.70739	0.59	W	TUO	439.7	62.4	53.8	72.5	P	F	P	11	3.4	0.1	
4337	11/07/00	74	3	F	1998	0.70733	0.45	W	TUO*	601.7	90.1	81.5	100.2	S	S	S	*Inconclusive natal assignment*			
4340	11/07/00	75.5	3	F	1998	0.70783	0.97	W	TUO	531.7	78.2	69.6	88.2	S	P	S	.			
4343	11/07/00	81	3	F	1998	0.70768	0.92	W	TUO	545.2	80.5	71.9	90.5	S	P	S	11	3.5	0.2	
4352	11/07/00	73	3	F	1998	0.70788	0.97	W	TUO	588.8	87.9	79.3	98.0	S	S	S	26	2.5	0.3	
4360	11/08/00	76.5	3	F	1998	0.70818	0.67	W	TUO	596.3	89.2	80.6	99.3	S	S	S	.			
4376	11/09/00	85	3	F	1998	0.70733	0.46	W	TUO*	621.8	93.6	85.0	103.6	S	S	S	*Inconclusive natal assignment*			
4378	11/09/00	88	3	M	1998	0.70728	0.33	W	TUO*	647.5	98.0	89.4	108.0	S	S	S	*Inconclusive natal assignment*			
4381	11/13/00	90	3	M	1998	0.70816	0.75	W	TUO	483.0	69.8	61.2	79.9	P	P	S	10	3.1	0.2	
4383	11/13/00	79	3	M	1998	0.70756	0.85	W	TUO	567.9	84.3	75.8	94.4	S	S	S	.			
4384	11/13/00	80	3	F	1998	0.70786	0.97	W	TUO	563.9	83.7	75.1	93.7	S	S	S	20	3.5	0.3	
4397	11/13/00	67	3	F	1998	0.70819	0.66	W	TUO	515.4	75.4	66.8	85.4	S	P	S	14	2.9	0.3	
4403	11/14/00	77	3	F	1998	0.70808	0.92	W	TUO	538.8	79.4	70.8	89.4	S	P	S	10	3.3	0.2	
4414	11/14/00	81	3	F	1998	0.70749	0.77	W	TUO	507.4	74.0	65.4	84.1	P	P	S	.			
4418	11/14/00	86	3	F	1998	0.70742	0.66	W	TUO	520.4	76.2	67.6	86.3	S	P	S	17	4.7	0.2	
4424	11/14/00	77	3	F	1998	0.70783	0.97	W	TUO	591.3	88.3	79.8	98.4	S	S	S	10	3.2	0.2	
4441	11/20/00	72	3	F	1998	0.70823	0.45	W	TUO*	531.0	78.0	69.5	88.1	S	P	S	*Inconclusive natal assignment*			
4442	11/20/00	95	3	M	1998	0.70771	0.94	W	TUO	631.7	95.3	86.7	105.3	S	S	S	26	3.1	0.4	
4443	11/20/00	100	3	M	1998	0.70735	0.50	W	TUO*	541.5	79.8	71.3	89.9	S	P	S	*Inconclusive natal assignment*			
4450	11/20/00	82	3	F	1998	0.70817	0.73	W	TUO	447.6	63.8	55.2	73.8	P	P	P	0	n/a	n/a	Strange profile (used same distance for natal and FW exit)

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive (“INC”), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

4451	11/20/00	92	3	M	1998	0.70817	0.72	W	TUO	507.3	74.0	65.4	84.1	P	P	S	25	2.7	0.2	
4455	11/20/00	74	3	F	1998	0.70769	0.93	W	TUO	533.3	78.4	69.9	88.5	S	P	S	12	3.6	0.3	
4458	11/21/00	80	3	F	1998	0.70792	0.98	W	TUO	591.4	88.4	79.8	98.4	S	S	S	16	3.7	0.2	
4476	11/22/00	100	3	M	1998	0.70804	0.95	W	TUO	556.0	82.3	73.7	92.4	S	P	S	15	3.1	0.3	
4484	11/27/00	77	3	F	1998	0.70788	0.97	W	TUO	557.1	82.5	73.9	92.6	S	P	S	12	3.5	0.1	
4487	11/27/00	84	3	F	1998	0.70800	0.97	W	TUO	533.6	78.5	69.9	88.6	S	P	S	.			
4504	12/04/00	100	3	M	1998	0.70826	0.30	W	TUO*	517.5	75.7	67.1	85.8	S	P	S	*Inconclusive natal assignment*			
4506	12/04/00	80	3	F	1998	0.70756	0.85	W	TUO	458.0	65.6	57.0	75.6	P	P	S	15	3.7	0.2	
4508	12/04/00	89	3	F	1998	0.70806	0.94	W	TUO	500.1	72.8	64.2	82.8	P	P	S	25	2.7	0.2	
4509	12/04/00	70.5	3	F	1998	0.70812	0.86	W	TUO	520.7	76.3	67.7	86.4	S	P	S	14	4.0	0.2	
4510	12/05/00	77	3	F	1998	0.70776	0.95	W	TUO	538.9	79.4	70.8	89.5	S	P	S	27	4.3	0.2	
4514	12/05/00	78	3	F	1998	0.70794	0.98	W	TUO	488.2	70.7	62.1	80.8	P	P	S	.			
4515	12/05/00	77	3	F	1998	0.70815	0.80	W	TUO	545.4	80.5	71.9	90.6	S	P	S	9	3.1	0.1	
4516	12/05/00	82	3	F	1998	0.70818	0.69	W	TUO	497.1	72.2	63.7	82.3	P	P	S	9	3.7	0.2	
4517	12/05/00	88.5	3	F	1998	0.70798	0.97	W	TUO	555.9	82.3	73.7	92.4	S	P	S	16	3.0	0.2	
4518	12/05/00	83	3	F	1998	0.70789	0.97	W	TUO	563.3	83.6	75.0	93.6	S	P	S	15	3.0	0.2	
4521	12/06/00	78.5	3	F	1998	0.70788	0.97	W	TUO	563.3	83.6	75.0	93.6	S	P	S	14	3.2	0.2	
4527	12/11/00	83	3	M	1998	0.70819	0.66	W	TUO	604.6	90.6	82.0	100.7	S	S	S	30	2.9	0.2	
4535	12/19/00	78	3	F	1998	0.70814	0.82	W	TUO	541.6	79.9	71.3	89.9	S	P	S	11	3.5	0.1	
9536	07/07/00	75	3	F	1998	0.70775	0.95	W	TUO	752.4	115.9	107.3	126.0	S	S	S	.			
11015	11/16/01	86.5	4	F	1998	0.70789	0.97	W	TUO	548.6	81.0	72.5	91.1	S	P	S	10	4.3	0.2	
11036	12/11/01	86	4	F	1998	0.70772	0.94	W	TUO	617.6	92.8	84.3	102.9	S	S	S	17	2.6	0.2	
11037	12/11/01	110	4	M	1998	0.70792	0.98	W	TUO	592.2	88.5	79.9	98.6	S	S	S	18	3.6	0.2	
11038	12/11/01	78	4	F	1998	0.70821	0.53	W	TUO	504.6	73.5	64.9	83.6	P	P	S	.			
11040	12/11/01	98	4	F	1998	0.70812	0.86	W	TUO	595.5	89.1	80.5	99.1	S	S	S	18	3.0	0.2	
11056	11/20/01	78	4	F	1998	0.70779	0.96	W	TUO	571.4	85.0	76.4	95.0	S	S	S	19	2.9	0.3	
11064	11/20/01	95	4	M	1998	0.70745	0.71	W	TUO	586.3	87.5	78.9	97.6	S	S	S	10	4.0	0.4	
11072	11/20/01	112	4	M	1998	0.70816	0.75	W	TUO	500.3	72.8	64.2	82.9	P	P	S	9	3.5	0.1	
11085	11/20/01	87	4	F	1998	0.70737	0.55	W	TUO	448.5	63.9	55.4	74.0	P	P	P	.			
11089	11/20/01	104	4	M	1998	0.70816	0.76	W	TUO	509.0	74.3	65.7	84.3	P	P	S	17	2.5	0.3	
11097	11/30/01	82	4	M	1998	0.70743	0.67	W	TUO	573.9	85.4	76.8	95.4	S	S	S	29	2.8	0.3	
11098	11/30/01	87	4	F	1998	0.70807	0.93	W	TUO	553.7	81.9	73.3	92.0	S	P	S	10	3.4	0.1	
11140	11/26/01	88	4	F	1998	0.70769	0.93	W	TUO	526.7	77.3	68.7	87.4	S	P	S	18	3.1	0.2	
11154	11/26/01	87	4	F	1998	0.70794	0.98	W	TUO	568.6	84.5	75.9	94.5	S	S	S	18	2.8	0.1	

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11176	12/07/01	92.5	4	F	1998	0.70821	0.54	W	TUO	605.9	90.8	82.3	100.9	S	S	S	.			
11177	12/07/01	90	4	F	1998	0.70781	0.96	W	TUO	546.6	80.7	72.1	90.8	S	P	S	.			
11181	12/18/01	87	3	F	1998	0.70819	0.63	W	TUO	730.2	112.1	103.5	122.2	S	S	S	42	2.5	0.2	
11182	12/17/01	99	4	M	1998	0.70798	0.97	W	TUO	417.2	58.6	50.0	68.7	P	F	P	3	3.56	0.2 4	
11190	11/23/01	90	3	M	1998	0.70821	0.53	W	TUO	540.6	79.7	71.1	89.8	S	P	S	18	2.6	0.2	
11216	11/21/01	94	4	F	1998	0.70821	0.54	W	TUO	552.9	81.8	73.2	91.9	S	P	S	14	2.6	0.2	
19680	11/15/01	103	4	M	1998	0.70766	0.92	W	TUO	661.5	100.4	91.8	110.4	S	S	S	.			
19684	11/15/01	92	3.5	M	1998	0.70776	0.95	W	TUO	578.3	86.1	77.5	96.2	S	S	S	.			
19685	11/15/01	87	4	F	1998	0.70811	0.89	W	TUO	545.7	80.6	72.0	90.6	S	P	S	.			
19687	11/15/01	82	3.5	M	1998	0.70806	0.95	W	TUO	557.0	82.5	73.9	92.5	S	P	S	16	3.5	0.3	
19691	11/15/01	91	4	M	1998	0.70721	0.19	W	TUO*	488.7	70.8	62.2	80.9	P	P	S	*Inconclusive natal assignment*			
19719	11/19/01	94.5	3.5	F	1998	0.70806	0.94	W	TUO	547.9	80.9	72.3	91.0	S	P	S	18	3.0	0.2	
19772	11/28/01	97	4	F	1998	0.70769	0.93	W	TUO	506.5	73.8	65.3	83.9	P	P	S	13	2.9	0.2	
19776	11/28/01	90	4	F	1998	0.70821	0.53	W	TUO	542.0	79.9	71.3	90.0	S	P	S	9	2.5	0.4	
19777	11/28/01	91	4	F	1998	0.70816	0.76	W	TUO	519.7	76.1	67.5	86.2	S	P	S	8	3.7	0.1	
19781	11/28/01	86	4	F	1998	0.70824	0.37	W	TUO*	532.5	78.3	69.7	88.4	S	P	S	*Inconclusive natal assignment*			
19783	11/28/01	89	4	F	1998	0.70793	0.98	W	TUO	480.4	69.4	60.8	79.5	P	P	S	16	3.0	0.2	
19785	11/28/01	88	4	F	1998	0.70765	0.91	W	TUO	540.6	79.7	71.1	89.8	S	P	S	34	3.2	0.3	
19790	11/28/01	94	4	F	1998	0.70818	0.68	W	TUO	583.5	87.0	78.4	97.1	S	S	S	32	2.9	0.2	
19796	12/03/01	81	4	F	1998	0.70811	0.88	W	TUO	566.3	84.1	75.5	94.1	S	S	S	17	3.8	0.1	
19798	12/03/01	93	4	M	1998	0.70814	0.83	W	TUO	525.6	77.1	68.5	87.2	S	P	S	17	4.0	0.2	
19800	12/03/01	114	4	M	1998	0.70776	0.95	W	TUO	595.1	89.0	80.4	99.1	S	S	S	.			
19802	12/03/01	97	4	F	1998	0.70824	0.40	W	TUO*	556.7	82.4	73.8	92.5	S	P	S	*Inconclusive natal assignment*			
19805	12/03/01	88	4	F	1998	0.70821	0.56	W	TUO	524.7	77.0	68.4	87.0	S	P	S	10	3.1	0.2	
19806	12/03/01	89	4	F	1998	0.70769	0.93	W	TUO	573.4	85.3	76.7	95.4	S	S	S	6	3.6	0.2	
19810	12/03/01	85	4	F	1998	0.70765	0.91	W	TUO	516.6	75.6	67.0	85.6	S	P	S	15	3.5	0.1	
19820	12/03/01	105	4	M	1998	0.70779	0.96	W	TUO	536.5	79.0	70.4	89.0	S	P	S	23	3.0	0.2	
19821	12/03/01	94	4	F	1998	0.70812	0.86	W	TUO	549.4	81.2	72.6	91.2	S	P	S	14	3.1	0.2	
19838	12/03/01	73	4	F	1998	0.70765	0.91	W	TUO	501.6	73.0	64.4	83.1	P	P	S	19	3.4	0.2	
19840	12/03/01	81	4	F	1998	0.70813	0.84	W	TUO	484.3	70.1	61.5	80.1	P	P	S	14	3.8	0.2	
19857	12/04/01	97	4	M	1998	0.70776	0.95	W	TUO	574.8	85.5	76.9	95.6	S	S	S	10	3.1	0.3	
19864	12/04/01	99	4	M	1998	0.70813	0.84	W	TUO	564.5	83.8	75.2	93.8	S	S	S	17	2.5	0.3	
19867	12/04/01	86	4	F	1998	0.70808	0.93	W	TUO	502.5	73.2	64.6	83.2	P	P	S	6	3.1	0.2	

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive ("INC"), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

19872	12/10/01	84	4	F	1998	0.70815	0.78	W	TUO	508.7	74.2	65.6	84.3	P	P	S	16	3.1	0.2	
19875	12/10/01	83	4	F	1998	0.70823	0.42	W	TUO*	526.6	77.3	68.7	87.4	S	P	S	*Inconclusive natal assignment*			
19879	12/10/01	76	4	F	1998	0.70766	0.91	W	TUO	530.5	78.0	69.4	88.0	S	P	S	15	2.5	0.1	
19880	12/10/01	89	4	F	1998	0.70765	0.91	W	TUO	506.0	73.8	65.2	83.8	P	P	S	32	3.3	0.3	
19881	12/10/01	99	4	F	1998	0.70813	0.85	W	TUO	586.0	87.4	78.9	97.5	S	S	S	23	2.8	0.4	
20183	11/28/01	101	4	F	1998	0.70773	0.94	W	TUO	577.9	86.1	77.5	96.1	S	S	S	11	4.5	0.2	
4492	11/28/00	57	2	M	1999	0.70804	0.95	W	TUO	603.8	90.5	81.9	100.6	S	S	S	n/a	n/a	n/a	Microstructure ran out before fish left natal river
4526	12/11/00	67	2	F	1999	0.70800	0.97	W	TUO	871.9	136.3	127.7	146.4	S	S	S	.			
11009	11/16/01	.	3	F	1999	0.70757	0.86	W	TUO	517.8	75.8	67.2	85.8	S	P	S	.			
11016	11/16/01	79.5	3	F	1999	0.70731	0.40	W	TUO*	465.7	66.9	58.3	76.9	P	P	S	24	3.1	0.2	
11019	11/16/01	60	3	F	1999	0.70743	0.67	INC	TUO*	548.1	81.0	72.4	91.0	S	P	S		.		Unreadable, so cannot assign natal location or do ageing
11021	11/16/01	73	3	F	1999	0.70731	0.39	W	TUO*	525.1	77.0	68.4	87.1	S	P	S	17	2.8	0.3	
11041	12/11/01	77	3	F	1999	0.70805	0.95	W	TUO	556.9	82.5	73.9	92.5	S	P	S	13	3.0	0.2	
11094	11/30/01	80	3	F	1999	0.70756	0.85	W	TUO	516.3	75.5	66.9	85.6	S	P	S	15	3.8	0.3	
11096	11/30/01	77	3	F	1999	0.70764	0.91	W	TUO	568.8	84.5	75.9	94.6	S	S	S	12	3.5	0.2	
11099	11/30/01	73	3	F	1999	0.70733	0.44	W	TUO*	491.3	71.3	62.7	81.3	P	P	S	*Inconclusive natal assignment*			
11100	11/30/01	83	3	F	1999	0.70748	0.75	W	TUO	572.6	85.2	76.6	95.2	S	S	S	.			
11132	11/26/01	76	3	F	1999	0.70734	0.46	W	TUO*	521.5	76.4	67.8	86.5	S	P	S	15	3.0	0.3	
11141	11/26/01	77	3	F	1999	0.70741	0.63	W	TUO	485.0	70.2	61.6	80.2	P	P	S	.			
11146	11/26/01	81	3	F	1999	0.70722	0.20	W	TUO*	487.0	70.5	61.9	80.6	P	P	S	*Inconclusive natal assignment*			
11157	11/26/01	80	3	M	1999	0.70740	0.61	W	TUO	467.5	67.2	58.6	77.3	P	P	S	8	5.6	0.1	
11161	11/26/01	74	3	F	1999	0.70792	0.98	W	TUO	519.2	76.0	67.4	86.1	S	P	S	.			
11162	11/26/01	78	3	F	1999	0.70724	0.25	W	TUO*	534.0	78.6	70.0	88.6	S	P	S	7	4.7	0.3	
11174	12/07/01	80	3	F	1999	0.70754	0.83	W	TUO	488.2	70.7	62.1	80.8	P	P	S	1	2.7	n/a	
11192	11/23/01	74	3	F	1999	0.70772	0.94	W	TUO	550.0	81.3	72.7	91.4	S	P	S	29	3.1	0.3	
11209	11/21/01	97	3	M	1999	0.70771	0.94	W	TUO	602.1	90.2	81.6	100.3	S	S	S	15	3.8	0.2	
11213	11/21/01	83	3	F	1999	0.70771	0.94	W	TUO	521.3	76.4	67.8	86.4	S	P	S	.			
11217	11/21/01	40.5	3	M	1999	0.70764	0.90	W	TUO	474.1	68.3	59.7	78.4	P	P	S	10	2.8	0.2	
14499	11/04/02	93	4	F	1999	0.70814	0.83	W	TUO	610.2	91.6	83.0	101.6	S	S	S	33	2.8	0.3	
14568	11/05/02	107	4	M	1999	0.70761	0.89	W	TUO	631.3	95.2	86.6	105.3	S	S	S	30	2.69	0.36	

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive (“INC”), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

14621	11/12/02	104	4	M	1999	0.70776	0.95	W	TUO	642.0	97.0	88.4	107.1	S	S	S	31	3.1	0.2	
14623	11/12/02	85	4	F	1999	0.70782	0.97	W	TUO	531.8	78.2	69.6	88.2	S	P	S	12	3.0	0.2	
14627	11/12/02	97	4	F	1999	0.70754	0.83	W	TUO	522.3	76.6	68.0	86.6	S	P	S	.			
14635	11/12/02	101	4	M	1999	0.70777	0.96	W	TUO	548.5	81.0	72.4	91.1	S	P	S	17	2.9	0.3	
14647	11/12/02	96	4	F	1999	0.70805	0.95	W	TUO	503.9	73.4	64.8	83.5	P	P	S	.			
14669	11/12/02	104	4	M	1999	0.70761	0.89	W	TUO	541.0	79.7	71.2	89.8	S	P	S	15	3.8	0.2	
14687	11/12/02	91	4	F	1999	0.70738	0.56	W	TUO	580.1	86.4	77.8	96.5	S	S	S	20	3.7	0.2	
14693	11/12/02	99	4	M	1999	0.70751	0.80	W	TUO	570.7	84.8	76.2	94.9	S	S	S	27	3.2	0.2	
14716	11/13/02	97	4	M	1999	0.70757	0.85	W	TUO	597.6	89.4	80.8	99.5	S	S	S	28	3.2	0.3	
14729	11/13/02	96	4	M	1999	0.70726	0.28	W	TUO*	533.1	78.4	69.8	88.5	S	P	S	20	3.7	0.3	
14759	11/14/02	101	4	M	1999	0.70766	0.91	W	TUO	563.5	83.6	75.0	93.7	S	S	S	22	2.3	0.2	
14774	11/14/02	86	4	F	1999	0.70786	0.97	W	TUO	528.7	77.6	69.1	87.7	S	P	S	.			
14804	11/14/02	93	4	F	1999	0.70768	0.93	W	TUO	543.8	80.2	71.6	90.3	S	P	S	18	3.9	0.2	
14824	11/15/02	98	4	M	1999	0.70733	0.44	W	TUO*	551.6	81.6	73.0	91.6	S	P	S	*Inconclusive natal assignment*			
14850	11/18/02	92	4	F	1999	0.70722	0.19	W	TUO*	513.4	75.0	66.4	85.1	S	P	S	*Inconclusive natal assignment*			
14884	11/18/02	89	4	F	1999	0.70749	0.77	W	TUO	545.5	80.5	71.9	90.6	S	P	S	.			
14889	11/18/02	88	4	M	1999	0.70754	0.82	W	TUO	576.1	85.8	77.2	95.8	S	S	S	22	3.7	0.2	
14892	11/18/02	100	4	M	1999	0.70725	0.26	W	TUO*	534.3	78.6	70.0	88.7	S	P	S	*Inconclusive natal assignment*			
14904	11/18/02	100	4	M	1999	0.70745	0.70	W	TUO	553.8	81.9	73.3	92.0	S	P	S	28	3.4	0.2	
14919	11/18/02	88	4	F	1999	0.70729	0.35	W	TUO*	458.5	65.6	57.1	75.7	P	P	S	*Inconclusive natal assignment*			
14953	11/19/02	103	4	M	1999	0.70787	0.97	W	TUO	534.2	78.6	70.0	88.6	S	P	S	16	2.7	0.3	
14955	11/19/02	94	4	F	1999	0.70813	0.84	W	TUO	562.1	83.4	74.8	93.4	S	P	S	8	3.4	0.3	
14976	11/19/02	102	4	M	1999	0.70765	0.91	W	TUO	524.7	77.0	68.4	87.0	S	P	S	5	3.9	0.1	
14999	11/20/02	104	4	M	1999	0.70726	0.27	W	TUO*	523.4	76.7	68.1	86.8	S	P	S	1	4.9		
15001	11/20/02	101	4	M	1999	0.70787	0.97	W	TUO	487.7	70.6	62.0	80.7	P	P	S	13	3.7	0.3	
15052	11/20/02	105	4	M	1999	0.70776	0.95	W	TUO	590.3	88.2	79.6	98.2	S	S	S	.			
15064	11/20/02	98	4	M	1999	0.70775	0.95	W	TUO	475.5	68.5	60.0	78.6	P	P	S	11	3.2	0.4	
15097	11/21/02	104	4	M	1999	0.70774	0.95	W	TUO	563.5	83.6	75.0	93.7	S	S	S	11	3.3	0.1	
15146	11/24/02	107	4	M	1999	0.70721	0.19	W	TUO*	513.8	75.1	66.5	85.2	S	P	S	*Inconclusive natal assignment*			
15150	11/24/02	108	4	M	1999	0.70761	0.89	W	TUO	505.1	73.6	65.0	83.7	P	P	S	22	3.6	0.3	
15165	11/24/02	100	4	M	1999	0.70726	0.27	W	TUO*	447.6	63.8	55.2	73.9	P	P	P	*Inconclusive natal assignment*			
19679	11/15/01	78	3	F	1999	0.70754	0.83	W	TUO	559.9	83.0	74.4	93.1	S	P	S	11	3.0	0.1	
19686	11/15/01	81	3	F	1999	0.70780	0.96	W	TUO	567.8	84.3	75.7	94.4	S	S	S	6	4.2	0.3	
19688	11/15/01	72.5	3	F	1999	0.70772	0.94	W	TUO	578.5	86.2	77.6	96.2	S	S	S	.			

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19705	11/15/01	76	3	F	1999	0.70729	0.35	W	TUO*	440.8	62.6	54.0	72.7	P	F	P	*Inconclusive natal assignment*			
19722	11/19/01	87	3	F	1999	0.70733	0.44	W	TUO*	582.6	86.9	78.3	96.9	S	S	S	*Inconclusive natal assignment*			
19775	11/28/01	83	3	F	1999	0.70736	0.52	W	TUO	592.7	88.6	80.0	98.7	S	S	S	31	3.7	0.2	
19779	11/28/01	70	3	F	1999	0.70760	0.88	W	TUO	522.2	76.5	67.9	86.6	S	P	S	10	3.5	0.2	
19782	11/28/01	76	3	M	1999	0.70779	0.96	W	TUO	555.0	82.1	73.6	92.2	S	P	S	18	3.1	0.2	
19786	11/28/01	85	3	M	1999	0.70746	0.73	W	TUO	580.0	86.4	77.8	96.5	S	S	S	9	3.5	0.3	
19791	11/28/01	79	3	F	1999	0.70735	0.49	W	TUO*	508.6	74.2	65.6	84.3	P	P	S	*Inconclusive natal assignment*			
19792	11/28/01	76	3	F	1999	0.70814	0.83	W	TUO	520.8	76.3	67.7	86.4	S	P	S	5	4.1	0.1	
19797	12/03/01	84	3	F	1999	0.70735	0.48	W	TUO*	523.0	76.7	68.1	86.7	S	P	S	*Inconclusive natal assignment*			
19816	12/03/01	81	3	M	1999	0.70770	0.93	W	TUO	736.1	113.1	104.5	123.2	S	S	S	.			
19836	12/03/01	88	3	M	1999	0.70726	0.29	W	TUO*	486.4	70.4	61.8	80.5	P	P	S	*Inconclusive natal assignment*			
19841	12/03/01	74	3	F	1999	0.70724	0.23	W	TUO*	491.7	71.3	62.7	81.4	P	P	S	*Inconclusive natal assignment*			
19845	12/04/01	87	3	M	1999	0.70788	0.97	W	TUO	549.3	81.2	72.6	91.2	S	P	S	20	3.2	0.2	
19855	12/04/01	85	3	M	1999	0.70768	0.92	W	TUO	523.0	76.7	68.1	86.7	S	P	S	33	2.8	0.2	
19861	12/04/01	74	3	F	1999	0.70775	0.95	W	TUO	544.2	80.3	71.7	90.4	S	P	S	8	3.4	0.2	
19866	12/04/01	86	3	M	1999	0.70724	0.23	W	TUO*	487.4	70.6	62.0	80.6	P	P	S	9	3.1	0.2	
19868	12/04/01	74	3	F	1999	0.70736	0.51	W	TUO	645.4	97.6	89.0	107.7	S	S	S	9	3.7	0.2	
19874	12/10/01	75	3	F	1999	0.70756	0.84	W	TUO	409.6	57.3	48.7	67.4	P	F	P	8	2.73	0.14	
19876	12/10/01	71	3	M	1999	0.70765	0.91	W	TUO	538.8	79.4	70.8	89.4	S	P	S	16	3.2	0.2	
11055	11/20/01	56	2	M	2000	0.70770	0.93	W	TUO	433.6	61.4	52.8	71.5	P	F	P	.			
11063	11/20/01	58	2	M	2000	0.70763	0.90	W	TUO	614.4	92.3	83.7	102.4	S	S	S	53	2.8	0.2	
11076	11/20/01	81	2	F	2000	0.70807	0.93	W	TUO	557.2	82.5	73.9	92.6	S	P	S	5	3.1	0.1	
11083	11/20/01	59	2	M	2000	0.70742	0.65	W	TUO	529.8	77.8	69.2	87.9	S	P	S	35	3.2	0.2	
11111	11/08/01	54.5	2	F	2000	0.70775	0.95	W	TUO	563.7	83.6	75.0	93.7	S	S	S	24	4.0	0.3	
11133	11/26/01	59	2	F	2000	0.70797	0.97	W	TUO	472.4	68.0	59.4	78.1	P	P	S	.			
11167	11/26/01	60	2	F	2000	0.70752	0.81	W	TUO	512.3	74.8	66.3	84.9	P	P	S	33	3.4	0.3	
11212	11/21/01	65.5	2	F	2000	0.70760	0.88	W	TUO	559.7	82.9	74.4	93.0	S	P	S	32	3.8	0.2	
11215	11/21/01	60	2	F	2000	0.70795	0.98	W	TUO	577.4	86.0	77.4	96.0	S	S	S	20	4.3	0.3	
11220	10/31/01	62	2	F	2000	0.70789	0.97	W	TUO	601.9	90.2	81.6	100.2	S	S	S	30	2.7	0.3	
11223	10/31/01	54	2	M	2000	0.70784	0.97	W	TUO	571.0	84.9	76.3	94.9	S	S	S	33	3.4	0.3	
11228	10/31/01	60	2	M	2000	0.70778	0.96	W	TUO	519.3	76.0	67.4	86.1	S	P	S	30	3.7	0.3	
14528	11/04/02	95	3	M	2000	0.70813	0.85	W	TUO	558.3	82.7	74.1	92.8	S	P	S	24	3.3	0.2	
14539	11/04/02	72	3	F	2000	0.70789	0.97	W	TUO	519.7	76.1	67.5	86.2	S	P	S	28	3.2	0.1	

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14540	11/04/02	69	3	F	2000	0.70777	0.96	INC	TUO*	466.3	67.0	58.4	77.0	P	P	S		.		Unreadable, so cannot assign natal location or do ageing
14544	11/05/02	78	3	F	2000	0.70782	0.96	W	TUO	523.5	76.8	68.2	86.8	S	P	S	39	3.0	0.2	
14545	11/05/02	92	3	M	2000	0.70792	0.98	W	TUO	482.3	69.7	61.1	79.8	P	P	S	.			
14548	11/05/02	72	3	F	2000	0.70801	0.97	W	TUO	615.8	92.5	84.0	102.6	S	S	S	.			
14550	11/05/02	80	3	M	2000	0.70789	0.97	W	TUO	487.8	70.7	62.1	80.7	P	P	S	29	3.1	0.3	
14556	11/05/02	73	3	F	2000	0.70742	0.64	W	TUO	552.0	81.6	73.0	91.7	S	P	S	29	4.0	0.3	
14559	11/05/02	89	3	M	2000	0.70768	0.92	W	TUO	430.9	60.9	52.3	71.0	P	F	P	.			
14560	11/05/02	78	3	F	2000	0.70756	0.85	W	TUO	537.9	79.2	70.6	89.3	S	P	S	28	3.8	0.2	
14566	11/05/02	79	3	F	2000	0.70786	0.97	W	TUO	504.0	73.4	64.8	83.5	P	P	S	.			
14571	11/05/02	97	3	M	2000	0.70763	0.90	W	TUO	590.4	88.2	79.6	98.3	S	S	S	38	3.4	0.3	
14575	11/05/02	73	3	F	2000	0.70795	0.98	W	TUO	500.4	72.8	64.2	82.9	P	P	S	21	3.1	0.3	
14578	11/05/02	73	3	F	2000	0.70745	0.71	W	TUO	511.4	74.7	66.1	84.8	P	P	S	.			
14579	11/05/02	93	3	M	2000	0.70742	0.65	W	TUO	521.3	76.4	67.8	86.4	S	P	S	31	3.8	0.2	
14584	11/05/02	81	.	M	2000	0.70772	0.94	W	TUO	520.2	76.2	67.6	86.3	S	P	S	.			
14587	11/05/02	80	3	F	2000	0.70780	0.96	W	TUO	584.3	87.2	78.6	97.2	S	S	S	.			
14596	11/05/02	80	3	F	2000	0.70800	0.97	W	TUO	568.9	84.5	75.9	94.6	S	S	S	19	2.9	0.3	
14597	11/05/02	91	3	M	2000	0.70756	0.85	W	TUO	528.1	77.5	69.0	87.6	S	P	S	35	3.4	0.3	
14600	11/05/02	75	3	F	2000	0.70774	0.95	W	TUO	460.7	66.0	57.4	76.1	P	P	S	.			
14616	11/12/02	94	3	M	2000	0.70768	0.92	W	TUO	494.1	71.7	63.1	81.8	P	P	S	61	3.5	0.2	
14626	11/12/02	91	3	M	2000	0.70735	0.50	W	TUO	545.9	80.6	72.0	90.7	S	P	S	.			
14629	11/12/02	74	3	F	2000	0.70772	0.94	W	TUO	555.0	82.1	73.6	92.2	S	P	S	.			
14661	11/12/02	94	3	M	2000	0.70761	0.89	W	TUO	556.0	82.3	73.7	92.4	S	P	S	42	3.8	0.3	
14668	11/12/02	90	3	M	2000	0.70785	0.97	W	TUO	530.4	77.9	69.3	88.0	S	P	S	23	3.3	0.2	
14673	11/12/02	90	3	M	2000	0.70770	0.93	W	TUO	532.9	78.4	69.8	88.4	S	P	S	26	3.8	0.2	
14689	11/12/02	93	3	M	2000	0.70803	0.96	W	TUO	521.2	76.4	67.8	86.4	S	P	S	n/a	n/a	n/a	Microstructure ran out before fish left natal river
14701	11/13/02	93	3	M	2000	0.70803	0.96	W	TUO	456.0	65.2	56.6	75.3	P	P	S	0	n/a	n/a	Strange profile (used same distance for natal and FW exit)
14721	11/13/02	76	3	F	2000	0.70804	0.95	W	TUO	512.1	74.8	66.2	84.9	P	P	S	18	3.7	0.2	
14735	11/13/02	92	3	M	2000	0.70763	0.90	W	TUO	514.7	75.2	66.7	85.3	S	P	S	38	3.9	0.3	
14743	11/13/02	76	3	F	2000	0.70802	0.96	W	TUO	535.2	78.8	70.2	88.8	S	P	S	12	4.2	0.2	

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive ("INC"), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

14749	11/14/02	80	3	F	2000	0.70773	0.94	W	TUO	473.3	68.2	59.6	78.2	P	P	S	34	2.6	0.2	
14753	11/14/02	84	3	M	2000	0.70774	0.95	W	TUO	525.1	77.0	68.4	87.1	S	P	S	31	4.1	0.3	
14769	11/14/02	81	3	F	2000	0.70757	0.85	W	TUO	503.2	73.3	64.7	83.4	P	P	S	31	3.7	0.3	
14783	11/14/02	89	3	M	2000	0.70793	0.98	W	TUO	564.4	83.8	75.2	93.8	S	S	S	12	4.6	0.2	
14785	11/14/02	95	3	M	2000	0.70766	0.91	W	TUO	535.2	78.8	70.2	88.8	S	P	S	.			
14786	11/14/02	76	3	F	2000	0.70781	0.96	W	TUO	505.4	73.7	65.1	83.7	P	P	S	23	4.1	0.3	
14813	11/14/02	86	3	M	2000	0.70799	0.97	W	TUO	500.7	72.9	64.3	82.9	P	P	S	25	3.4	0.3	
14815	11/15/02	82	3	F	2000	0.70761	0.89	W	TUO	501.9	73.1	64.5	83.1	P	P	S	.			
14858	11/18/02	104	3	M	2000	0.70740	0.61	W	TUO	484.4	70.1	61.5	80.1	P	P	S	3	2.0	0.0	
14880	11/18/02	80	3	M	2000	0.70727	0.31	W	TUO*	480.4	69.4	60.8	79.5	P	P	S	12	5.1	0.2	
14907	11/18/02	74	3	F	2000	0.70773	0.95	W	TUO	497.3	72.3	63.7	82.3	P	P	S	14	3.9	0.2	
14921	11/18/02	93	3.5	F	2000	0.70780	0.96	W	TUO	547.1	80.8	72.2	90.9	S	P	S	47	3.3	0.2	
14929	11/18/02	91	3	M	2000	0.70764	0.90	W	TUO	529.8	77.8	69.3	87.9	S	P	S	30	3.2	0.3	
14975	11/19/02	102	3	M	2000	0.70743	0.67	W	TUO	565.7	84.0	75.4	94.0	S	S	S	.			
15091	11/21/02	100	3	F	2000	0.70792	0.98	W	TUO	557.5	82.6	74.0	92.6	S	P	S	26 †	3.90	0.1 5	† Microstructure ran out 52um before FW exit (inferred 13 increments at end)
15113	11/21/02	100	3	M	2000	0.70763	0.90	W	TUO	495.1	71.9	63.3	82.0	P	P	S	.			
15133	11/24/02	103	3	M	2000	0.70754	0.83	W	TUO	513.7	75.1	66.5	85.1	S	P	S	23	3.8	0.2	
15193	11/24/02	101	3	M	2000	0.70773	0.94	W	TUO	611.3	91.8	83.2	101.8	S	S	S	31	3.1	0.3	
15243	12/02/02	91	3	M	2000	0.70777	0.95	W	TUO	524.0	76.8	68.3	86.9	S	P	S	22	3.5	0.2	
19681	11/15/01	65	2	M	2000	0.70759	0.87	W	TUO	478.4	69.1	60.5	79.1	P	P	S	.			
19695	11/19/01	59.5	2	M	2000	0.70759	0.88	W	TUO	540.6	79.7	71.1	89.7	S	P	S	25	3.2	0.3	
19813	12/03/01	48	2	M	2000	0.70789	0.97	W	TUO	561.0	83.2	74.6	93.2	S	P	S	48	3.4	0.3	
19831	12/03/01	57	2	F	2000	0.70779	0.96	W	TUO	498.5	72.5	63.9	82.5	P	P	S	28	4.8	0.3	
19853	12/04/01	60	2	F	2000	0.70781	0.96	W	TUO	544.3	80.3	71.7	90.4	S	P	S	7	4.0	0.2	
19858	12/04/01	58	2	F	2000	0.70761	0.89	W	TUO	487.6	70.6	62.0	80.7	P	P	S	.			
17628	11/14/05	91	3	M	2003	0.70730	0.37	W	TUO*	551.7	81.6	73.0	91.6	S	P	S	19	3.2	0.3	
17631	11/14/05	84	3	F	2003	0.70751	0.80	W	TUO	594.7	88.9	80.4	99.0	S	S	S	12	4.6	0.2	
17634	11/14/05	81	3	F	2003	0.70772	0.94	W	TUO	511.9	74.8	66.2	84.8	P	P	S	9	2.9	0.1	
17637	11/16/05	92	3	M	2003	0.70726	0.27	W	TUO*	457.4	65.5	56.9	75.5	P	P	S	*Inconclusive natal assignment*			
17638	11/16/05	76	3	F	2003	0.70731	0.41	W	TUO*	558.9	82.8	74.2	92.9	S	P	S	11	3.1	0.2	
17645	11/21/05	75	3	F	2003	0.70747	0.74	W	TUO	628.3	94.7	86.1	104.7	S	S	S	.			

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive (“INC”), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

17651	11/21/05	88	3	M	2003	0.70745	0.71	W	TUO	582.0	86.8	78.2	96.8	S	S	S	8	4.4	0.2	
17654	11/21/05	73	3	F	2003	0.70757	0.86	W	TUO	380.8	52.4	43.8	62.4	F	F	P	16	3.6	0.1	
17666	11/28/05	73	3	F	2003	0.70753	0.82	W	TUO	529.0	77.7	69.1	87.8	S	P	S	5	2.9	0.3	
17667	11/28/05	75	3	F	2003	0.70744	0.69	W	TUO	531.9	78.2	69.6	88.3	S	P	S	18	2.9	0.3	
17669	11/28/05	72	3	F	2003	0.70743	0.66	W	TUO	597.8	89.5	80.9	99.5	S	S	S	.			
17672	11/28/05	79	3	F	2003	0.70756	0.85	INC	TUO*		n/a (vaterite)						.			Otolith vateritic during natal rearing (so no HvW assignment or exit age/dist)
17673	11/28/05	71	3	F	2003	0.70745	0.70	W	TUO		73.8	65.2	83.8	P	P	S	.			
17679	11/28/05	85	3	M	2003	0.70729	0.34	W	TUO*		82.3	73.7	92.4	S	P	S	21	4.6	0.3	
17680	11/28/05	75	3	F	2003	0.70777	0.96	W	TUO		86.6	78.0	96.6	S	S	S	n/a	n/a	n/a	Microstructure ran out before fish left natal river
17681	11/28/05	72	3	F	2003	0.70763	0.90	W	TUO		67.5	58.9	77.6	P	P	S	.			
17685	11/28/05	61	3	M	2003	0.70727	0.30	W	TUO*		74.7	66.1	84.8	P	P	S	*Inconclusive natal assignment*			
17690	11/28/05	83	3	M	2003	0.70754	0.83	W	TUO		91.5	82.9	101.5	S	S	S	8	3.1	0.3	
17692	11/29/05	85	3	F	2003	0.70759	0.87	W	TUO		73.9	65.4	84.0	P	P	S	2	4.3	0.1	
17703	12/06/05	75	3	F	2003	0.70751	0.79	W	TUO		96.9	88.3	106.9	S	S	S	14	3.1	0.2	
17712	12/06/05	90	3	M	2003	0.70734	0.46	W	TUO*		79.8	71.2	89.8	S	P	S	*Inconclusive natal assignment*			
17713	12/06/05	76	3	F	2003	0.70755	0.84	W	TUO		70.3	61.7	80.3	P	P	S	5	4.4	0.2	
17716	12/06/05	82	3	F	2003	0.70744	0.69	W	TUO		85.0	76.4	95.1	S	S	S	.			
17718	12/07/05	79	3	F	2003	0.70751	0.79	W	TUO		86.7	78.1	96.8	S	S	S	.			
17729	12/12/05	92	3	M	2003	0.70754	0.82	W	TUO		81.7	73.1	91.8	S	P	S	.			
17740	12/12/05	79	3	F	2003	0.70738	0.56	W	TUO		73.6	65.0	83.6	P	P	S	.			
17742	12/12/05	75	3	F	2003	0.70743	0.66	W	TUO		74.6	66.0	84.6	P	P	S	19	3.8	0.2	
17746	12/12/05	72	3	F	2003	0.70762	0.89	W	TUO		94.7	86.1	104.8	S	S	S	.			
17751	12/12/05	85	3	F	2003	0.70755	0.84	W	TUO		83.2	74.6	93.3	S	P	S	9	3.7	0.1	
17753	12/12/05	81	3	M	2003	0.70750	0.79	W	TUO		73.2	64.7	83.3	P	P	S	5	4.1	0.1	
17758	12/12/05	84	3	F	2003	0.70718	0.14	W	TUO*		78.1	69.5	88.2	S	P	S	8	3.6	0.3	
17759	12/12/05	70	3	F	2003	0.70765	0.91	W	TUO		78.3	69.8	88.4	S	P	S	.			
17763	12/12/05	79	3	F	2003	0.70744	0.70	W	TUO		75.9	67.3	86.0	S	P	S	13	3.9	0.2	
18144	12/05/06	86	4	F	2003	0.70726	0.29	W	TUO*		80.7	72.1	90.8	S	P	S	16	3.1	0.1	
18150	12/11/06	84	4	F	2003	0.70741	0.62	W	TUO		72.3	63.7	82.4	P	P	S	15	3.2	0.2	
24120	11/07/11	76	3	F	2009	0.70777	0.73	W	TUO		73.9	65.4	84.0	P	P	S	24	3.1	0.3	

Appendix 1B Table showing capture details of adult samples, their natal assignment and reconstructed fork length (FL) and age at exit from the freshwater delta (FW exit). The probability of the assignment to the Tuolumne (TUO) based on Sr isotopes is indicated, as well as the results of the otolith microstructure analyses to separate hatchery from wild fish (H vs. W). Where otoliths were unreadable, and microstructure analyses inconclusive ("INC"), or when the probability of assignment to TUO was <0.5 based on mean Sr isotopic values, the natal location is marked by an asterisk. Increment information is marked with (.) if otolith was unreadable.The life stage at FW exit was categorized as fry (F: FL<55mm), parr (P: FL >55mm to <75mm) or smolt (S: FL >75mm).

24176	11/14/11	81	3	F	2009	0.70781	0.77	W	TUO		91.3	82.7	101.4	S	S	S	20	2.9	0.4	
24178	11/14/11	67	3	M	2009	0.70778	0.74	W	TUO		88.0	79.4	98.1	S	S	S	13	3.5	0.3	
24238	11/21/11	70	3	F	2009	0.70773	0.69	W	TUO		80.1	71.5	90.2	S	P	S	.			
24283	11/23/11	83	3	M	2009	0.70734	0.16	W	TUO*		80.1	71.5	90.2	S	P	S	*Inconclusive natal assignment*			
24292	11/28/11	95	3	M	2009	0.70730	0.12	W	TUO*		91.4	82.8	101.4	S	S	S	*Inconclusive natal assignment*			
26012	11/13/12	84	4	F	2009	0.70780	0.76	W	TUO		83.7	75.1	93.8	S	S	S	7	2.6	0.1	

[1] Assignments using isotope-based discriminant function analysis and reference samples from existing or ongoing projects ([1], [2], P. Weber, A. Sturrock, unpub)
[2] Hatchery vs. wild assignment using microstructure-based discriminant function analysis and existing reference samples, after [3].
[3] Size-defined life stage designations (fry: <55mm, parr: >55mm to <75mm, smolt: >75mm), after [4].

1. Barnett-Johnson, R., et al., *Tracking natal origins of salmon using isotopes, otoliths, and landscape geology.* Limnology and Oceanography, 2008. **53**(4): p. 1633-1642.
2. Ingram, L.B. and P.K. Weber, *Salmon origin in California's Sacramento–San Joaquin river system as determined by otolith strontium isotopic composition.* Geology, 1999. **27**(9): p. 851-854.
3. Barnett-Johnson, R., et al., *Identifying the contribution of wild and hatchery Chinook salmon (Oncorhynchus tshawytscha) to the ocean fishery using otolith microstructure as natural tags.* Canadian Journal of Fisheries and Aquatic Sciences, 2007. **64**(12): p. 1683-1692.
4. Miller, J.A., A. Gray, and J. Merz, *Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon Oncorhynchus tshawytscha.* Marine Ecology Progress Series, 2010. **408**: p. 227-240.

Appendix 2 Capture details and natal assignments of strays to the Tuolumne River from outmigration years 1998, 1999, 2000, 2003 and 2009. The natal assignments were primarily based on otolith Sr isotopes, however where there was ambiguity in the assignment, otolith microstructure analyses were used to separate hatchery from wild fish (HvW). Site codes are provided in Table 2 of the main report.

ASN	Outmigration year	Date	Age	Length	Sex	Natal location	HvW
4184	1998	10/17/2000	3	84	F	X	H
4188	1998	10/19/2000	3	79.5	F	MOH	H
4190	1998	10/24/2000	3	91	M	MOH	H
4224	1998	10/25/2000	3	91	M	X	H
4227	1998	10/25/2000	3	87	M	X	H
4235	1998	10/25/2000	3	91	M	FEH	H
4236	1998	10/25/2000	3	72	F	MEH	n/a
4250	1998	10/30/2000	3	80	F	MOH	H
4260	1998	10/30/2000	3	78.5	M	X	H
4268	1998	10/30/2000	3	77	F	MOH	H
4273	1998	10/31/2000	3	78	F	MOK	W
4282	1998	10/31/2000	3	87	M	MEH	n/a
4285	1998	10/31/2000	3	77.5	F	MEH	n/a
4286	1998	10/31/2000	3	80	F	MEH	n/a
4289	1998	10/31/2000	3	83	F	MEH	n/a
4302	1998	11/6/2000	3	81.5	F	X	H
4313	1998	11/6/2000	3	92	F	MEH	H
4314	1998	11/6/2000	3	76	F	MEH	n/a
4324	1998	11/6/2000	3	77	F	MEH	H
4336	1998	11/7/2000	3	87	M	MEH	n/a
4338	1998	11/7/2000	3	84	F	MEH	n/a
4344	1998	11/7/2000	3	68	M	MEH	n/a
4349	1998	11/7/2000	3	75	F	MEH	n/a
4382	1998	11/13/2000	3	87	F	MEH	n/a
4396	1998	11/13/2000	3	92.5	M	MEH	n/a
4402	1998	11/14/2000	3	75	F	X	H
4406	1998	11/15/2000	3	88	M	MEH	n/a
4416	1998	11/15/2000	3	75	F	MEH	n/a
4422	1998	11/14/2000	3	80	F	MEH	n/a
4453	1998	11/20/2000	3	97	F	STA	W
4457	1998	11/20/2000	3	75	F	MEH	n/a
4467	1998	11/21/2000	3	92	F	STA	n/a
4479	1998	11/27/2000	3	63.5	F	MEH	n/a
4491	1998	11/28/2000	3	54	F	MEH	H
4495	1998	11/28/2000	3	86	F	X	H
4498	1998	11/29/2000	3	82	F	X	H
4503	1998	12/4/2000	3	83	F	X	H
4529	1998	12/12/2000	3	67	F	X	H
4530	1998	12/12/2000	3	61	F	X	H
9534	1998	7/7/2000	3	68	F	MOH	H
9551	1998	8/11/2000	3	74	F	MOH	H
11067	1998	11/20/2001	4	88	F	MEH	n/a
11095	1998	11/29/2001	4	86	F	MEH	n/a
11145	1998	11/26/2001	4	95	F	MEH	n/a
11147	1998	11/26/2001	4	93	F	MEH	n/a
11149	1998	11/26/2001	4	118	M	MEH	H
11150	1998	11/26/2001	4	84	M	MEH	n/a
11153	1998	11/26/2001	4	110	M	MEH	H
11156	1998	11/26/2001	4	92	F	MEH	n/a
11165	1998	11/26/2001	4	87	F	X	H
11170	1998	11/26/2001	4	95	F	MOH	H
11171	1998	11/26/2001	4	84	F	X	H
11172	1998	11/26/2001	4	83	F	MEH	H
11175	1998	12/7/2001	4	96	M	X	H
11178	1998	12/7/2001	4	88	F	MEH	H

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11180	1998	12/19/2001	4	90	F	MER	W
11208	1998	11/21/2001	4	84	F	MOH	H
19676	1998	11/15/2001	4	103	M	STA	W
19766	1998	11/27/2001	3.5	84	F	MEH	n/a
19804	1998	12/3/2001	4	98	M	MEH	n/a
19814	1998	12/3/2001	4	91	F	MOK	W
19825	1998	12/3/2001	4	96	M	MEH	n/a
19839	1998	12/3/2001	4	82	F	MEH	n/a
19843	1998	12/3/2001	4	87	F	X	H
19848	1998	12/4/2001	3.5	85	F	STA	W
19856	1998	12/4/2001	4	103	M	STA	W
4375	1999	11/8/2000	2	57.5	F	THE	n/a
4404	1999	11/15/2000	2	56	M	MEH	n/a
4405	1999	11/15/2000	2	57	M	MEH	n/a
4468	1999	11/21/2000	2	37	F	MOH	H
4536	1999	12/20/2000	2	52	M	NIH	n/a
9548	1999	7/28/2000	2	81	F	MOH	H
9549	1999	8/4/2000	2	78	F	MOH	H
11011	1999	11/16/2001	3	77	F	FEH	H
11075	1999	11/20/2001	3	92.5	M	MOH	H
11077	1999	11/20/2001	3	91	F	MEH	H
11091	1999	11/20/2001	3	81	F	MOH	H
11148	1999	11/26/2001	3	72	F	MOH	H
11159	1999	11/26/2001	3	77	F	MOH	H
11168	1999	11/26/2001	3	71	F	THE	n/a
11169	1999	11/26/2001	3	75	F	MOH	H
11179	1999	12/7/2001	3	93	M	NIH	n/a
11183	1999	12/17/2001	3	80	M	NIH	n/a
14525	1999	11/4/2002	4	99	M	MOH	H
14546	1999	11/5/2002	4	95	M	MOH	H
14639	1999	11/12/2002	4	99	M	FEH	H
14640	1999	11/12/2002	4	88	F	STA	n/a
14641	1999	11/12/2002	4	96	F	FEH	H
14644	1999	11/12/2002	4	103	M	MOH	H
14645	1999	11/12/2002	4	101	M	MEH	n/a
14651	1999	11/12/2002	4	101	M	STA	n/a
14692	1999	11/12/2002	4	90	F	MOH	H
14711	1999	11/13/2002	4	94	M	MOH	H
14736	1999	11/13/2002	4	95	M	X	H
14737	1999	11/13/2002	4	110	M	X	H
14800	1999	11/14/2002	4	104	M	MOH	H
14827	1999	11/16/2002	4	98	F	STA	n/a
14828	1999	11/16/2002	4	99	M	X	H
14839	1999	11/18/2002	4	103	M	X	H
14877	1999	11/18/2002	4	90	M	STA	n/a
14883	1999	11/18/2002	4	90	M	STA	n/a
14906	1999	11/18/2002	4	100	M	MOH	H
14908	1999	11/18/2002	4	101	M	MOH	H
14912	1999	11/18/2002	4	102	M	MOH	H
14931	1999	11/18/2002	4	92	F	X	H
14944	1999	11/19/2002	4	101	M	MOH	H
14997	1999	11/20/2002	4	103	M	STA	n/a
15015	1999	11/20/2002	4	103	M	MOH	H
15098	1999	11/21/2002	4	96	M	MOH	H
15112	1999	11/21/2002	4	95	F	NIH	n/a
15114	1999	11/21/2002	4	100	M	MOH	H

Appendix 2 Capture details and natal assignments of strays to the Tuolumne River from outmigration years 1998, 1999, 2000, 2003 and 2009. The natal assignments were primarily based on otolith Sr isotopes, however where there was ambiguity in the assignment, otolith microstructure analyses were used to separate hatchery from wild fish (HvW). Site codes are provided in Table 2 of the main report.

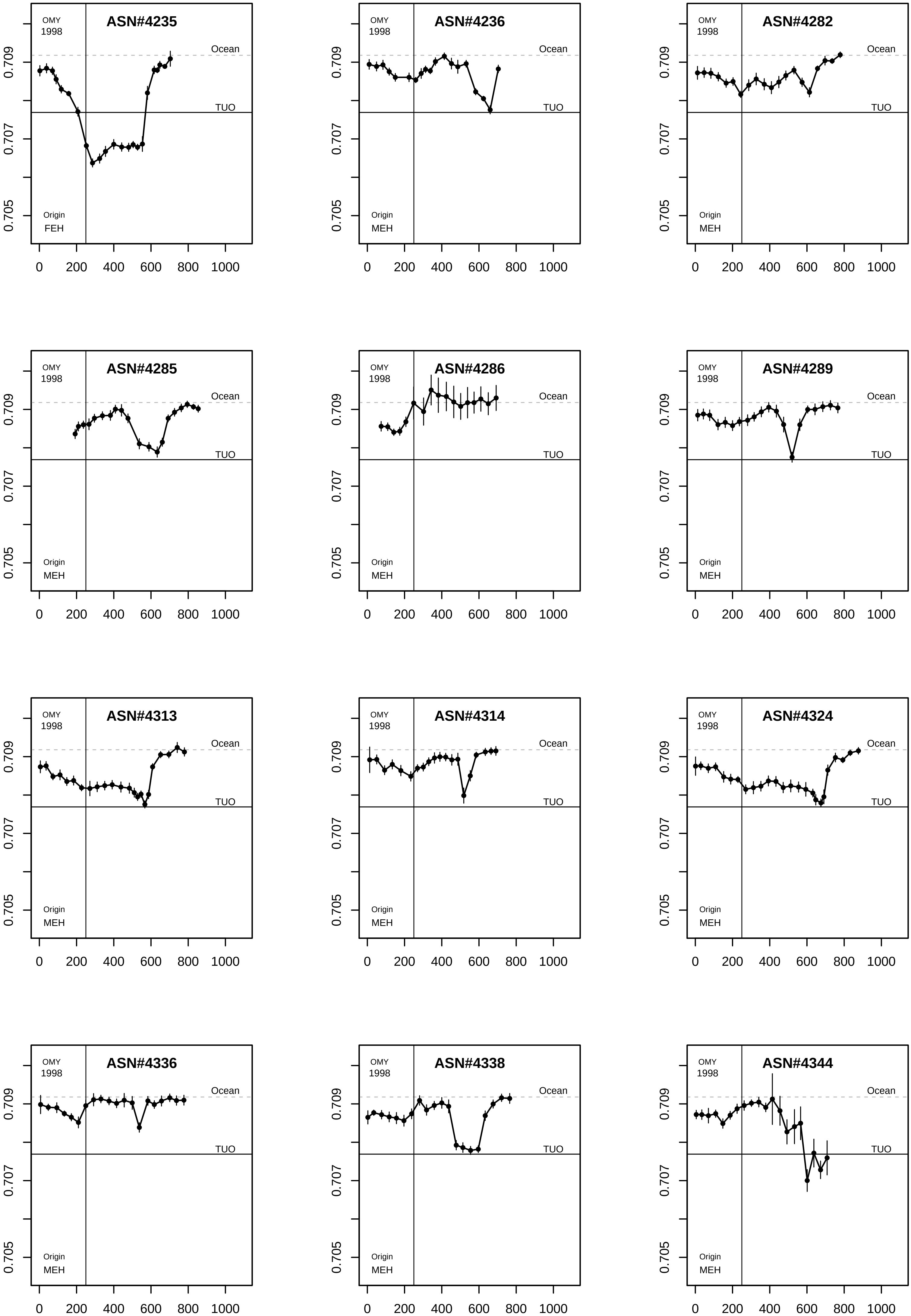
15124	1999	11/22/2002	4	95	F	STA	n/a
15127	1999	11/22/2002	4	102	M	STA	n/a
15131	1999	11/24/2002	4	100	M	MOK	n/a
15172	1999	11/24/2002	4	101	M	FEH	H
15178	1999	11/24/2002	4	104	F	MEH	H
15191	1999	11/24/2002	4	100	M	MOH	H
15216	1999	11/25/2002	4	98	M	FEH	H
15231	1999	11/26/2002	3.5	86	F	MOH	H
15236	1999	11/27/2002	4	100	M	NIH	n/a
15262	1999	12/3/2002	4	108	M	X	H
15269	1999	12/4/2002	4	102	M	X	H
15273	1999	12/5/2002	4	72	F	MOH	H
19678	1999	11/15/2001	3	82	F	MOH	H
19682	1999	11/15/2001	3	80	F	MEH	n/a
19689	1999	11/15/2001	3	88	F	X	H
19700	1999	11/15/2001	3	78	F	MEH	n/a
19778	1999	11/28/2001	3	77	F	MOH	H
19784	1999	11/28/2001	3	70	F	X	H
19787	1999	11/28/2001	3	89	F	X	H
19807	1999	12/3/2001	3	.		MEH	H
19832	1999	12/3/2001	3	69	F	MOH	H
19865	1999	12/4/2001	3	70	F	MOH	H
19870	1999	12/4/2001	3	75	M	X	H
19873	1999	12/10/2001	3	80	F	MEH	H
11012	2000	11/16/2001	2	58	F	X	H
11025	2000	11/9/2001	2	66	M	X	H
11062	2000	11/20/2001	2	86	M	FEH	H
11078	2000	11/20/2001	2	59	M	MEH	n/a
11079	2000	11/20/2001	2	55	M	MEH	n/a
11080	2000	11/20/2001	2	63	F	MOH	H
11103	2000	11/8/2001	2	57	M	MEH	n/a
11144	2000	11/26/2001	2	61	F	MEH	n/a
11184	2000	12/18/2001	2	54	M	NIH	n/a
11198	2000	11/21/2001	2	55.5	F	MOH	H
14486	2000	11/4/2002	3	110	M	MOH	H
14522	2000	11/4/2002	3	83	F	MOH	H
14524	2000	11/4/2002	3	77	F	MOH	H
14529	2000	11/4/2002	3	75	F	MOH	H
14547	2000	11/5/2002	3	79	M	MOH	H
14551	2000	11/5/2002	3	77	F	MOH	H
14569	2000	11/5/2002	3	81	M	MOH	H
14572	2000	11/5/2002	3	94	M	MOH	H
14577	2000	11/5/2002	3	99	M	FEH	H
14607	2000	11/6/2002	3	92	M	MOH	H
14612	2000	11/7/2002	3	98	M	MOH	H
14646	2000	11/12/2002	3	92	M	MOH	H
14657	2000	11/12/2002	3	76	F	MOH	H
14660	2000	11/12/2002	3	104	M	STA	W
14672	2000	11/12/2002	3	93	M	X	H
14744	2000	11/14/2002	3	84	M	X	H
14746	2000	11/14/2002	3	75	F	STA	W
14758	2000	11/14/2002	3	85	M	FEH	H
14763	2000	11/14/2002	3	79	F	X	H
14766	2000	11/14/2002	3	85	M	MOH	H
14890	2000	11/18/2002	3	87	M	MOH	H
14893	2000	11/18/2002	3	72	F	MOH	H

Appendix 2 Capture details and natal assignments of strays to the Tuolumne River from outmigration years 1998, 1999, 2000, 2003 and 2009. The natal assignments were primarily based on otolith Sr isotopes, however where there was ambiguity in the assignment, otolith microstructure analyses were used to separate hatchery from wild fish (HvW). Site codes are provided in Table 2 of the main report.

14895	2000	11/18/2002	3	75	F	MOH	H
14900	2000	11/18/2002	3	76	F	MOH	H
15025	2000	11/20/2002	3	100	M	STA	W
15067	2000	11/20/2002	3	99	M	MOH	H
15105	2000	11/21/2002	3	100	M	MOH	H
15128	2000	11/24/2002	3	107	M	STA	n/a
15159	2000	11/24/2002	3	105	M	FEH	H
19768	2000	11/27/2001	2	60	F	MOH	H
19789	2000	11/28/2001	2	64	F	MOH	H
19882	2000	12/10/2001	2	58	F	MEH	n/a
17621	2003	11/14/2005	3	75	F	MEH	n/a
17623	2003	11/14/2005	3	73	F	THE	n/a
17630	2003	11/14/2005	3	67	F	MOH	H
17632	2003	11/14/2005	3	65	F	THE	n/a
17641	2003	11/21/2005	3	70	F	MEH	n/a
17644	2003	11/21/2005	3	84	M	MOH	H
17647	2003	11/21/2005	3	85	F	MOH	H
17653	2003	11/21/2005	3	75	F	MOH	H
17658	2003	11/21/2005	3	74	F	MOH	H
17659	2003	11/21/2005	3	73	F	MOH	H
17661	2003	11/21/2005	3	75	F	MOH	H
17663	2003	11/21/2005	3	90	M	MEH	n/a
17674	2003	11/28/2005	3	74	F	NIH	n/a
17675	2003	11/28/2005	3	65	F	MOH	H
17676	2003	11/28/2005	3	79	F	MOH	H
17677	2003	11/28/2005	3	75	F	MOH	H
17686	2003	11/28/2005	3	70	M	NIH	n/a
17687	2003	11/28/2005	3	65	F	MOH	H
17688	2003	11/28/2005	3	76	F	MOH	H
17689	2003	11/28/2005	3	76	F	MEH	n/a
17694	2003	12/6/2005	3	77	F	MOH	H
17696	2003	12/6/2005	3	78	M	MOH	H
17697	2003	12/6/2005	3	81	F	NIH	n/a
17698	2003	12/6/2005	3	80	F	NIH	n/a
17704	2003	12/6/2005	3	81	F	MOH	H
17705	2003	12/6/2005	3	85	M	NIH	n/a
17707	2003	12/6/2005	3	84	M	MOH	H
17708	2003	12/6/2005	3	69	F	MOH	H
17709	2003	12/6/2005	3	79	F	NIH	n/a
17710	2003	12/6/2005	3	78	F	MOH	H
17719	2003	12/7/2005	3	80	M	MOH	H
17720	2003	12/7/2005	3	90	M	MOH	H
17721	2003	12/7/2005	3	79	F	NIH	n/a
17724	2003	12/12/2005	3	74	F	FEH	H
17726	2003	12/12/2005	3	80	F	NIH	n/a
17727	2003	12/12/2005	3	76	F	MOH	H
17730	2003	12/12/2005	3	79	M	MOH	H
17731	2003	12/12/2005	3	78	F	MOH	H
17732	2003	12/12/2005	3	69	F	MOH	H
17737	2003	12/12/2005	3	82	F	MOH	H
17739	2003	12/12/2005	3	77	F	THE	n/a
17741	2003	12/12/2005	3	77	F	FEH	H
17743	2003	12/12/2005	3	92	M	MOH	H
17744	2003	12/12/2005	3	75	F	FEH	H
17745	2003	12/12/2005	3	70	F	FEH	H
17747	2003	12/12/2005	3	78	F	MOH	H

Appendix 2 Capture details and natal assignments of strays to the Tuolumne River from outmigration years 1998, 1999, 2000, 2003 and 2009. The natal assignments were primarily based on otolith Sr isotopes, however where there was ambiguity in the assignment, otolith microstructure analyses were used to separate hatchery from wild fish (HvW). Site codes are provided in Table 2 of the main report.

17748	2003	12/12/2005	3	71	F	MOH	H
17749	2003	12/12/2005	3	78	F	MOH	H
17752	2003	12/12/2005	3	82	M	MOH	H
17754	2003	12/12/2005	3	73	F	FEH	H
17755	2003	12/12/2005	3	79	F	NIH	H
17760	2003	12/12/2005	3	74	F	MOH	H
17761	2003	12/12/2005	3	73	F	MOH	H
17762	2003	12/12/2005	3	83	F	MOH	H
18082	2003	11/14/2006	4	92	F	MOH	H
18095	2003	11/20/2006	4	78	F	MOH	H
18096	2003	11/20/2006	4	76	F	CNH	n/a
18101	2003	11/20/2006	4	88	F	MOH	H
18121	2003	11/21/2006	4	95	M	FEH	H
18129	2003	11/27/2006	4	88	F	MOH	H
18142	2003	12/4/2006	4	86	F	MOH	H
20197	2009	11/1/2010	2	63	M	CNH	n/a
20199	2009	11/1/2010	2	74	M	THE	H
20203	2009	11/1/2010	2	67	M	CNH	n/a
20204	2009	11/1/2010	2	63	M	CNH	n/a
20207	2009	11/8/2010	2	50	M	CNH	n/a
20218	2009	11/15/2010	2	59	M	MEH	n/a
20231	2009	11/15/2010	2	61	M	CNH	n/a
20239	2009	11/15/2010	2	60	M	CNH	n/a
20241	2009	11/15/2010	2	60	M	CNH	n/a
20242	2009	11/15/2010	2	62	M	CNH	n/a
20248	2009	11/17/2010	2	65	M	CNH	n/a
20249	2009	11/17/2010	2	68	M	CNH	n/a
20256	2009	11/22/2010	2	68	M	CNH	n/a
20264	2009	11/23/2010	2	63	M	MEH	n/a
24015	2009	10/3/2011	3	78	F	THE	n/a
24035	2009	10/10/2011	3	81	M	FEH	H
24038	2009	10/17/2011	3	77	F	FEA	W
24043	2009	10/17/2011	3	83	M	FEH	H
24052	2009	10/24/2011	3	81	F	FEH	H
24054	2009	10/24/2011	3	83	F	CNH	n/a
24056	2009	10/24/2011	3	82	F	CNH	n/a
24059	2009	10/24/2011	3	86	M	CNH	n/a
24065	2009	10/24/2011	3	82	F	CNH	n/a
24066	2009	10/24/2011	3	92	M	CNH	n/a
24112	2009	11/7/2011	3	77	M	FEH	H
24114	2009	11/7/2011	3	78	F	CNH	n/a
24117	2009	11/7/2011	3	86	M	CNH	n/a
24131	2009	11/7/2011	3	75	F	CNH	n/a
24141	2009	11/7/2011	3	77	F	CNH	n/a
24164	2009	11/9/2011	3	82	F	CNH	n/a
24168	2009	11/9/2011	3	87	M	CNH	n/a
24174	2009	11/14/2011	3	72	F	CNH	H
24177	2009	11/14/2011	3	78	F	CNH	n/a
24193	2009	11/14/2011	3	88	M	CNH	n/a
24214	2009	11/14/2011	3	85	F	CNH	n/a
24239	2009	11/21/2011	3	81	F	MOH	H
24290	2009	11/28/2011	3	75	F	NIH	n/a
24410	2009	12/12/2011	3	73	F	NIH	n/a
25886	2009	11/6/2012	4	81	F	THE	n/a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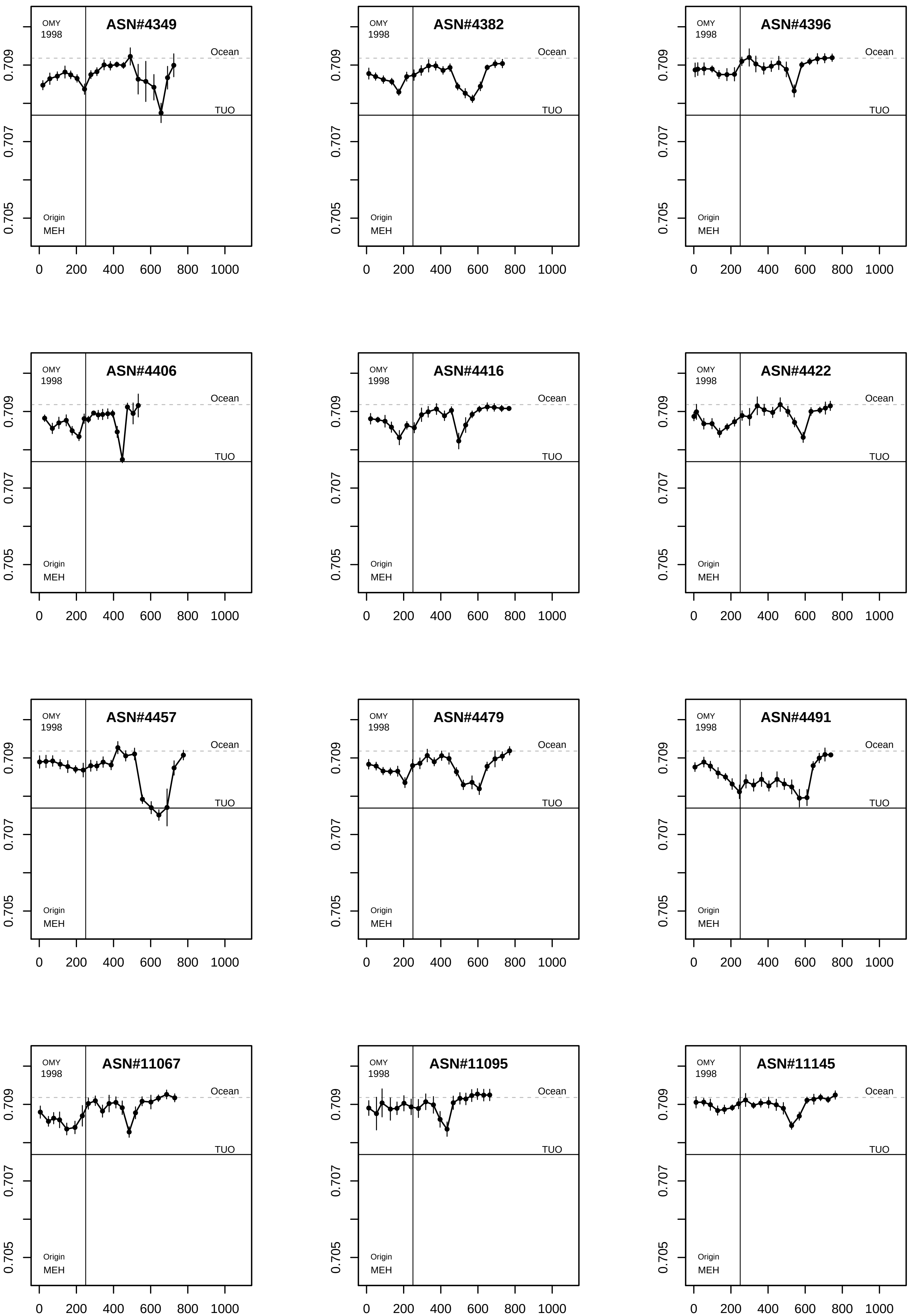

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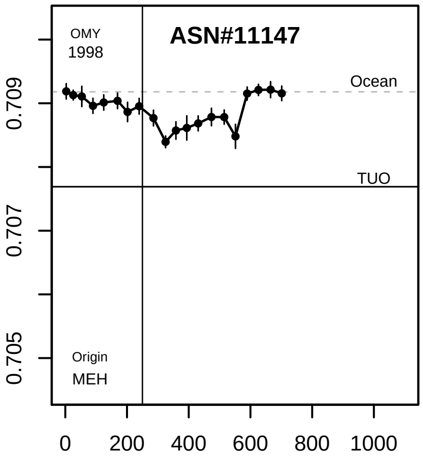
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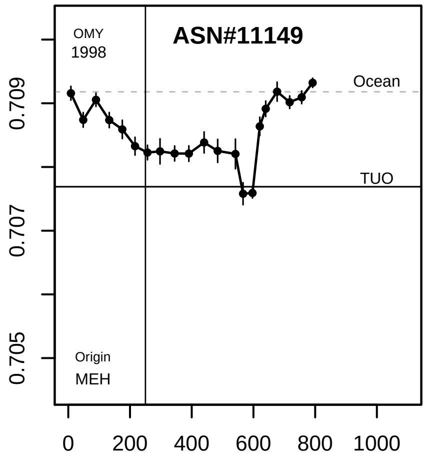
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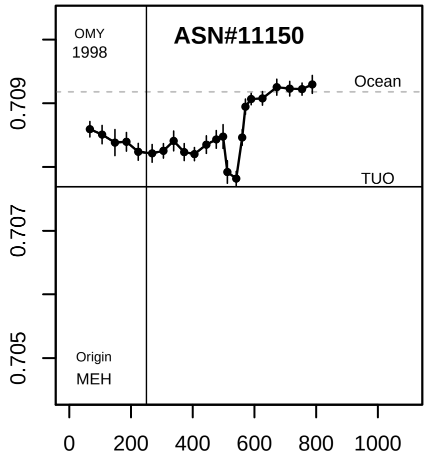
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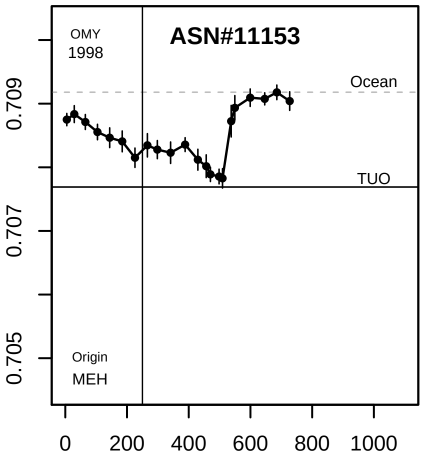
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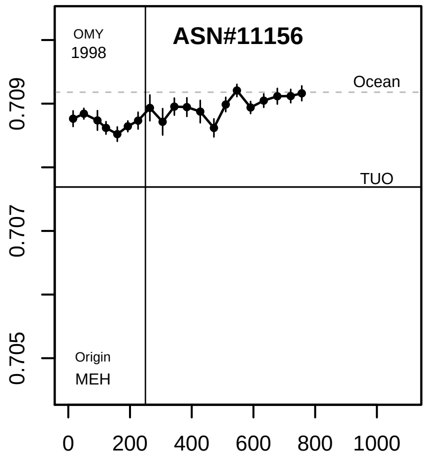
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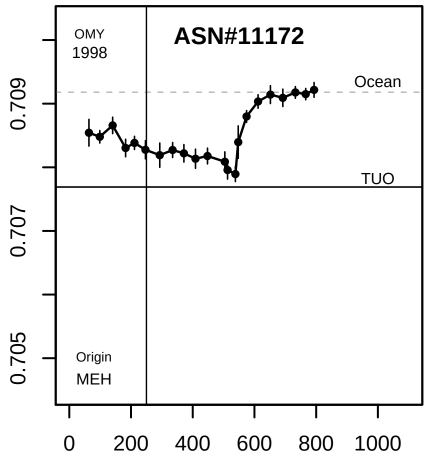
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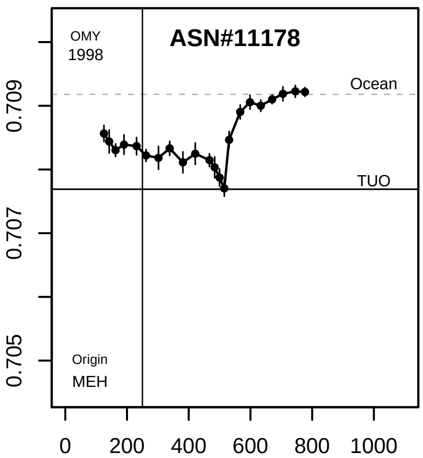
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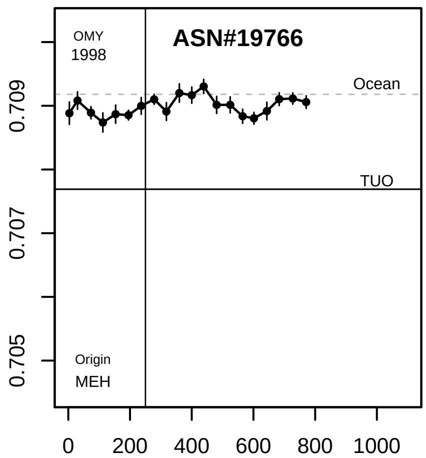
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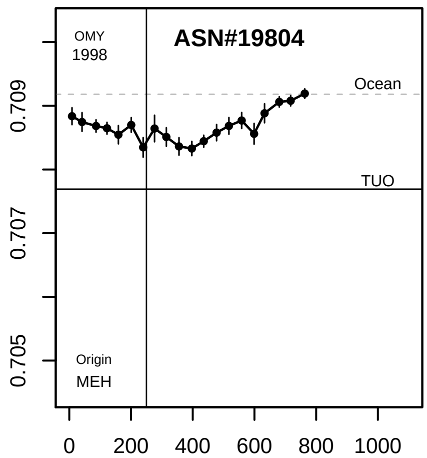
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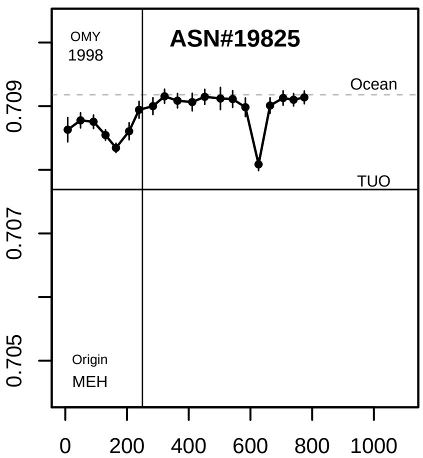
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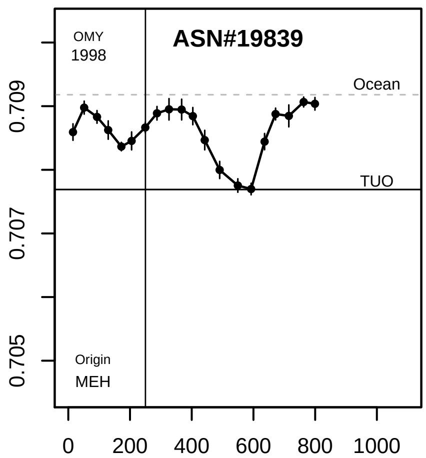
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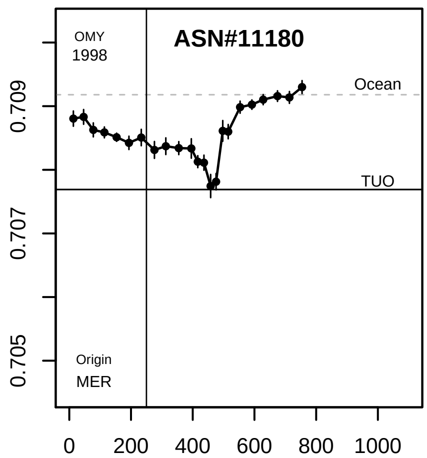
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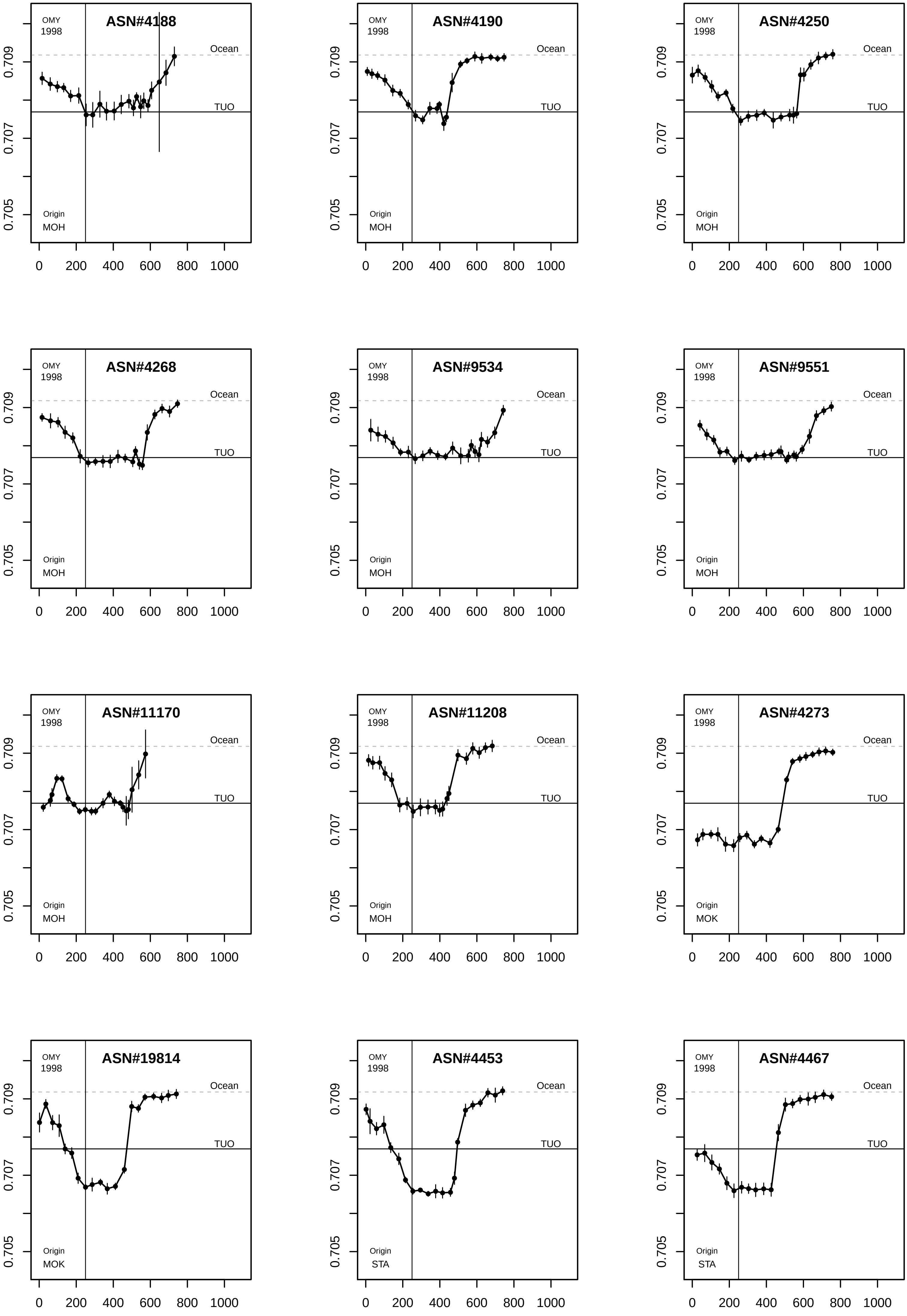

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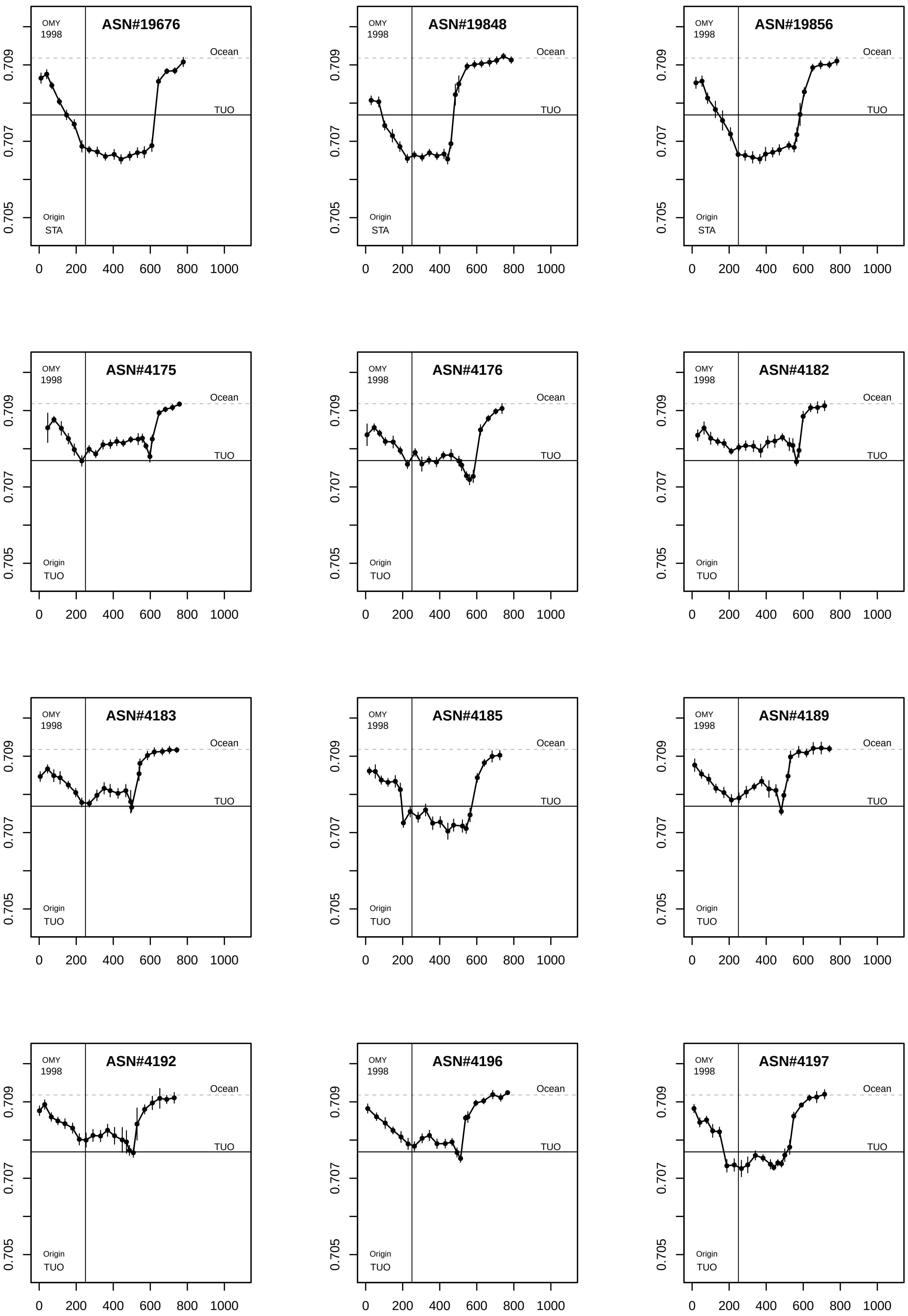
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OMY 1998
Origin TUO
ASN#4196
OMY 1998
Origin TUO
ASN#4197
OMY 1998
Origin TUO
Ocean
TUO
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0.709
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200
400
600
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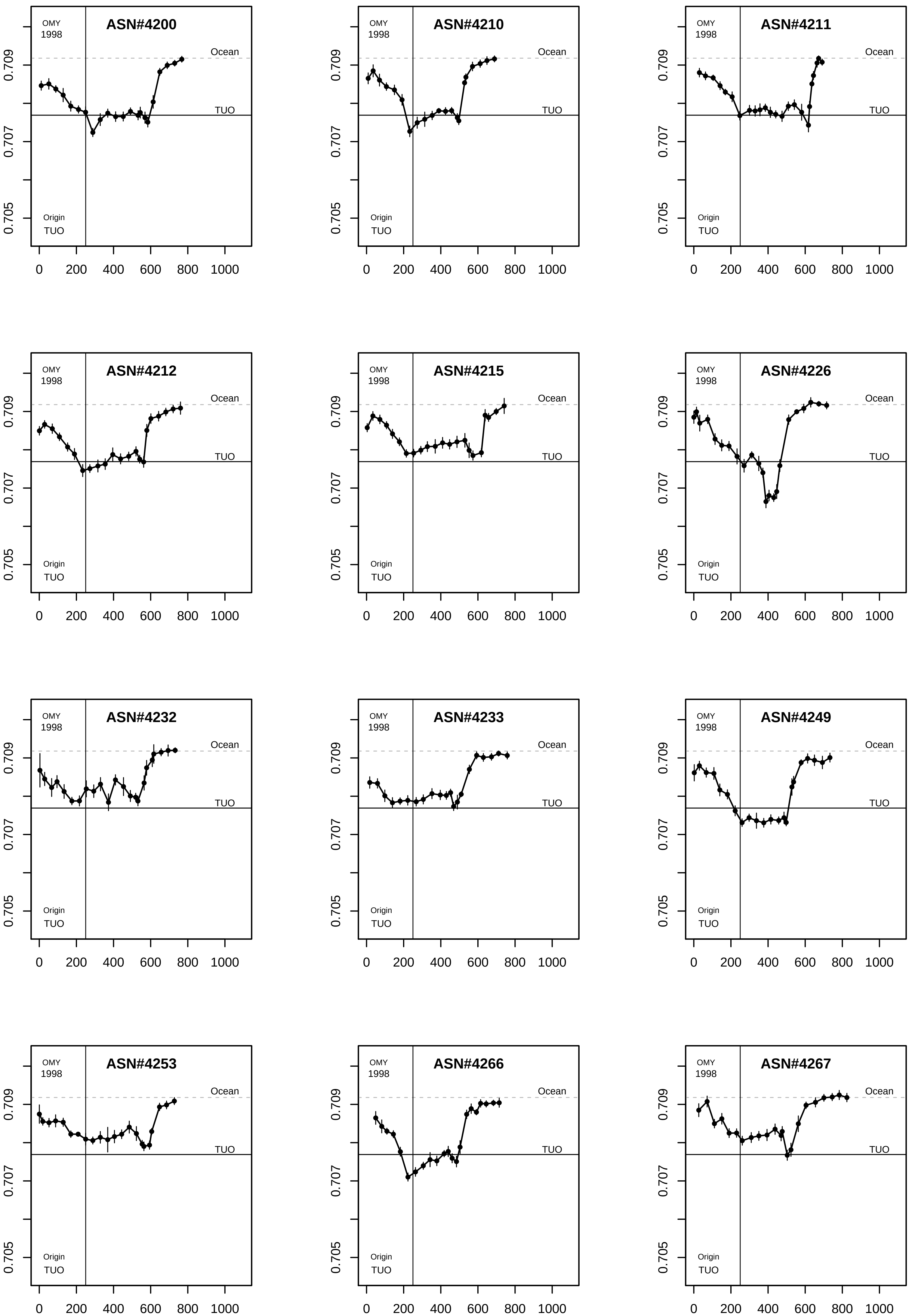

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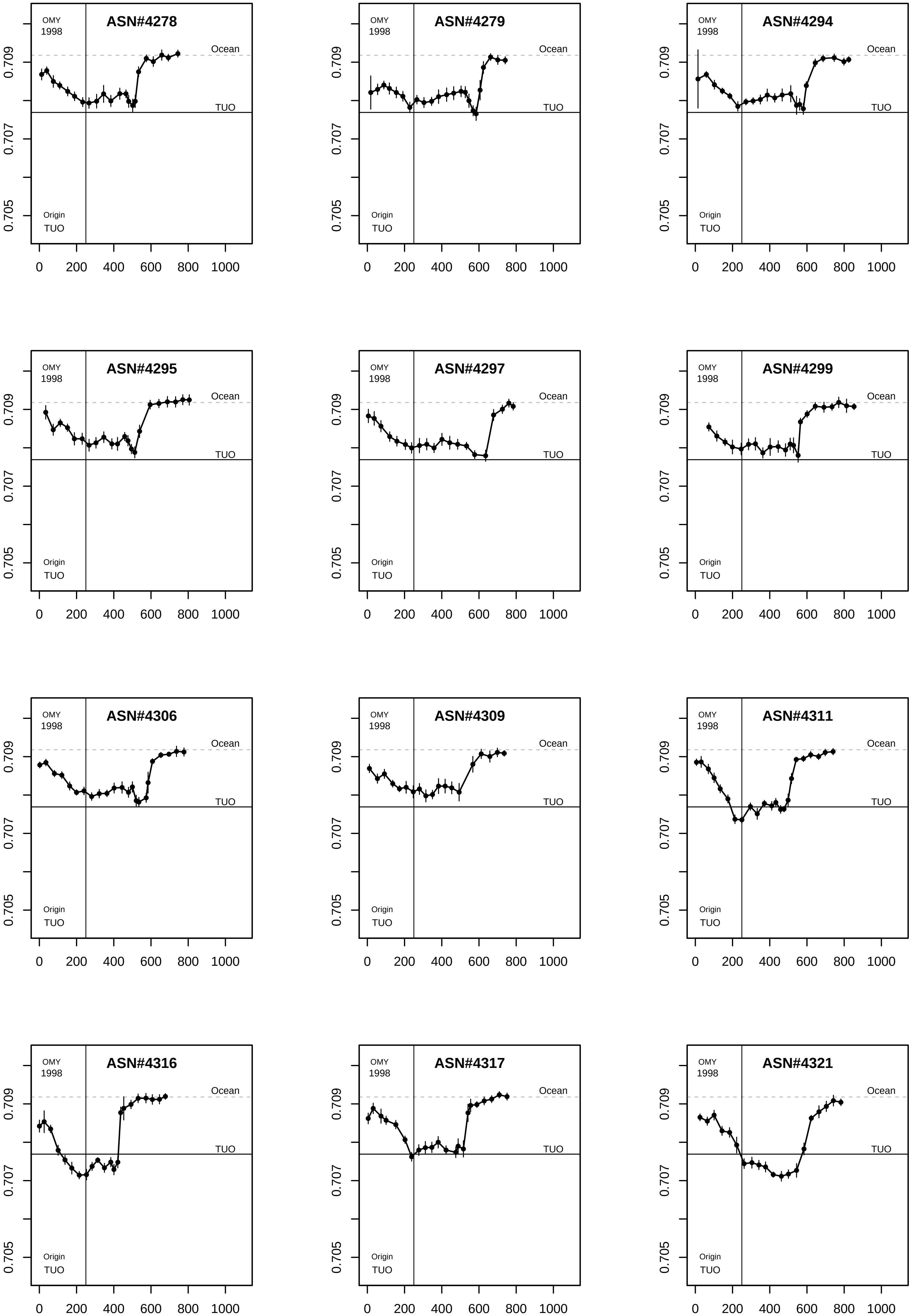
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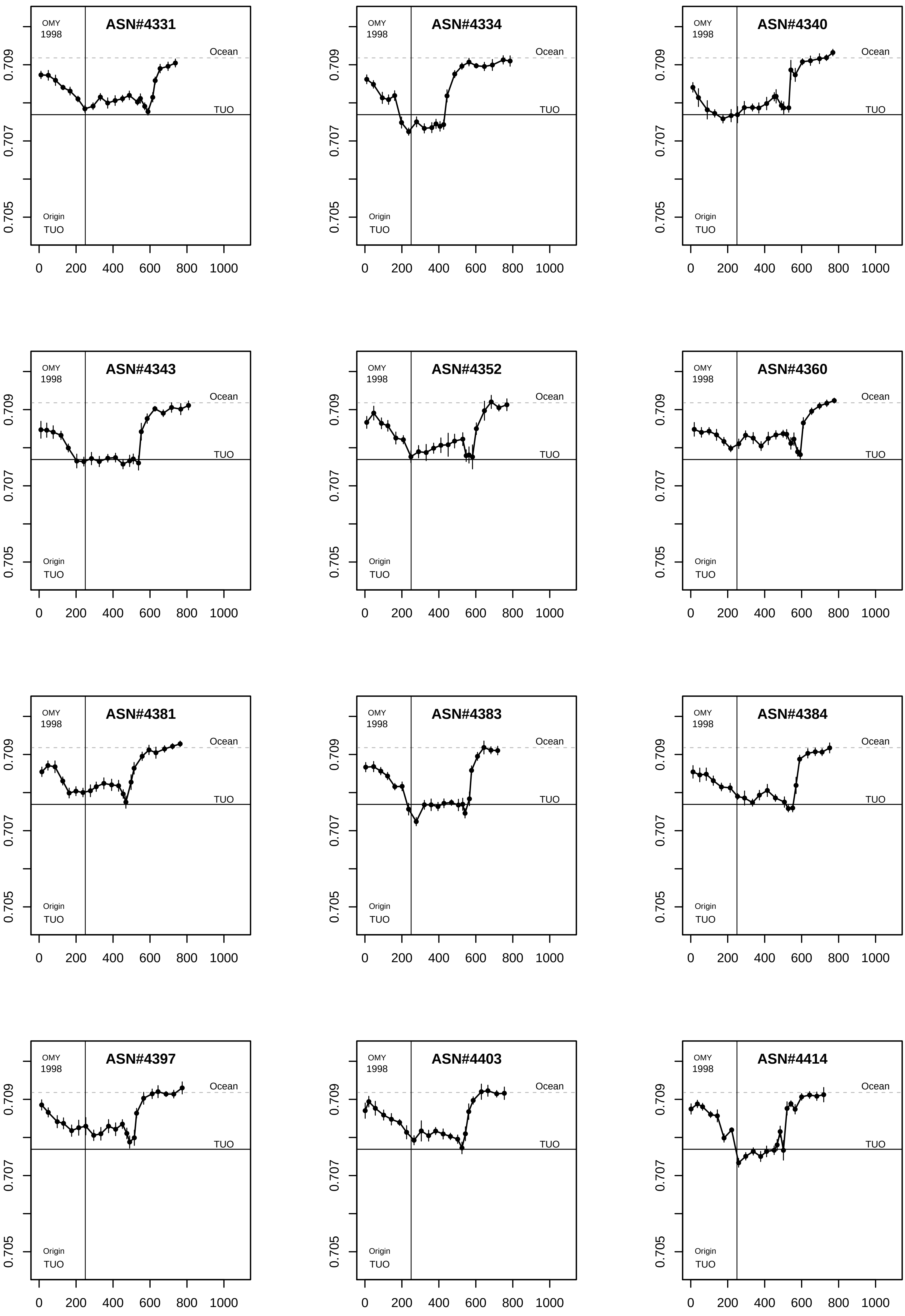
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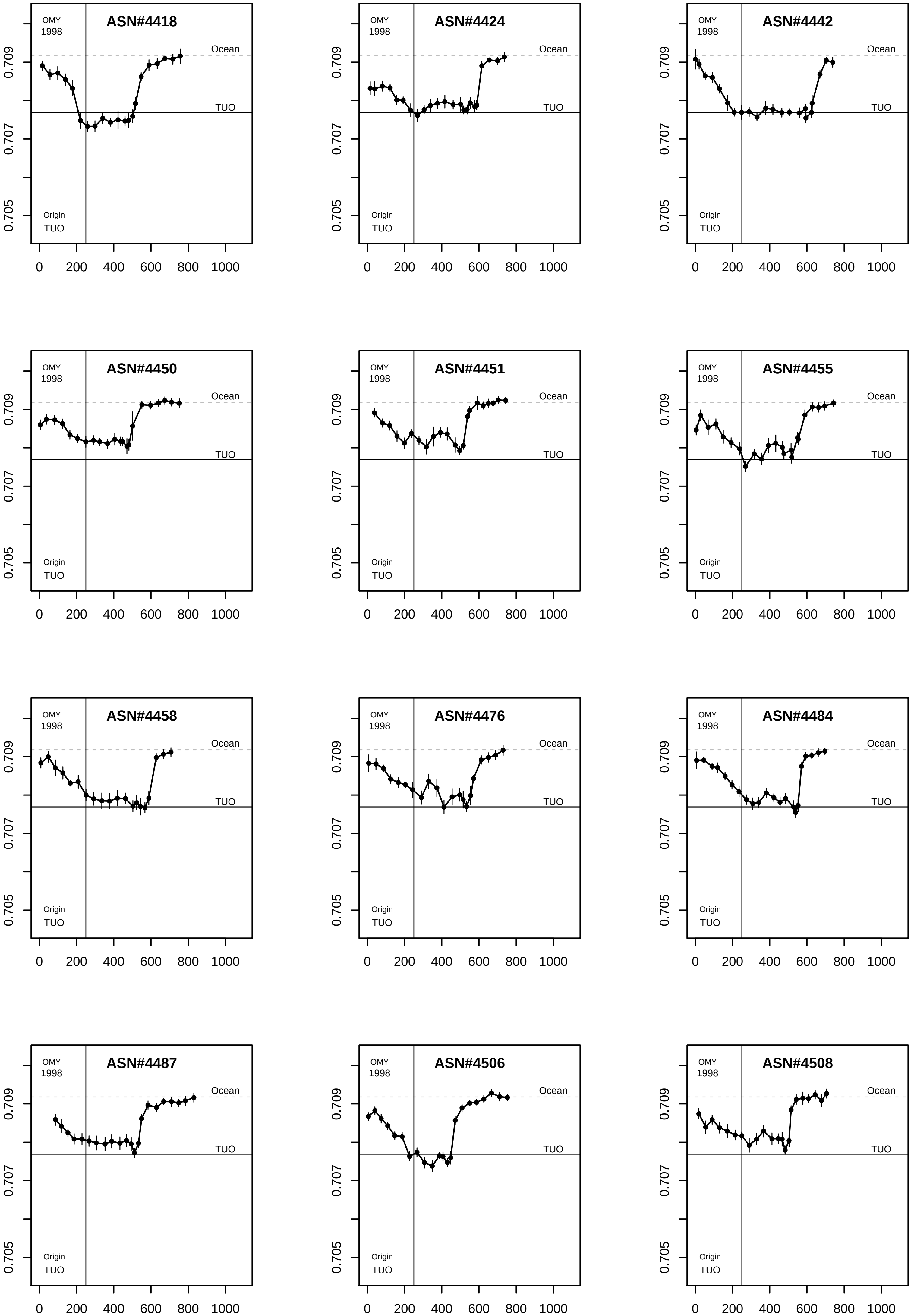

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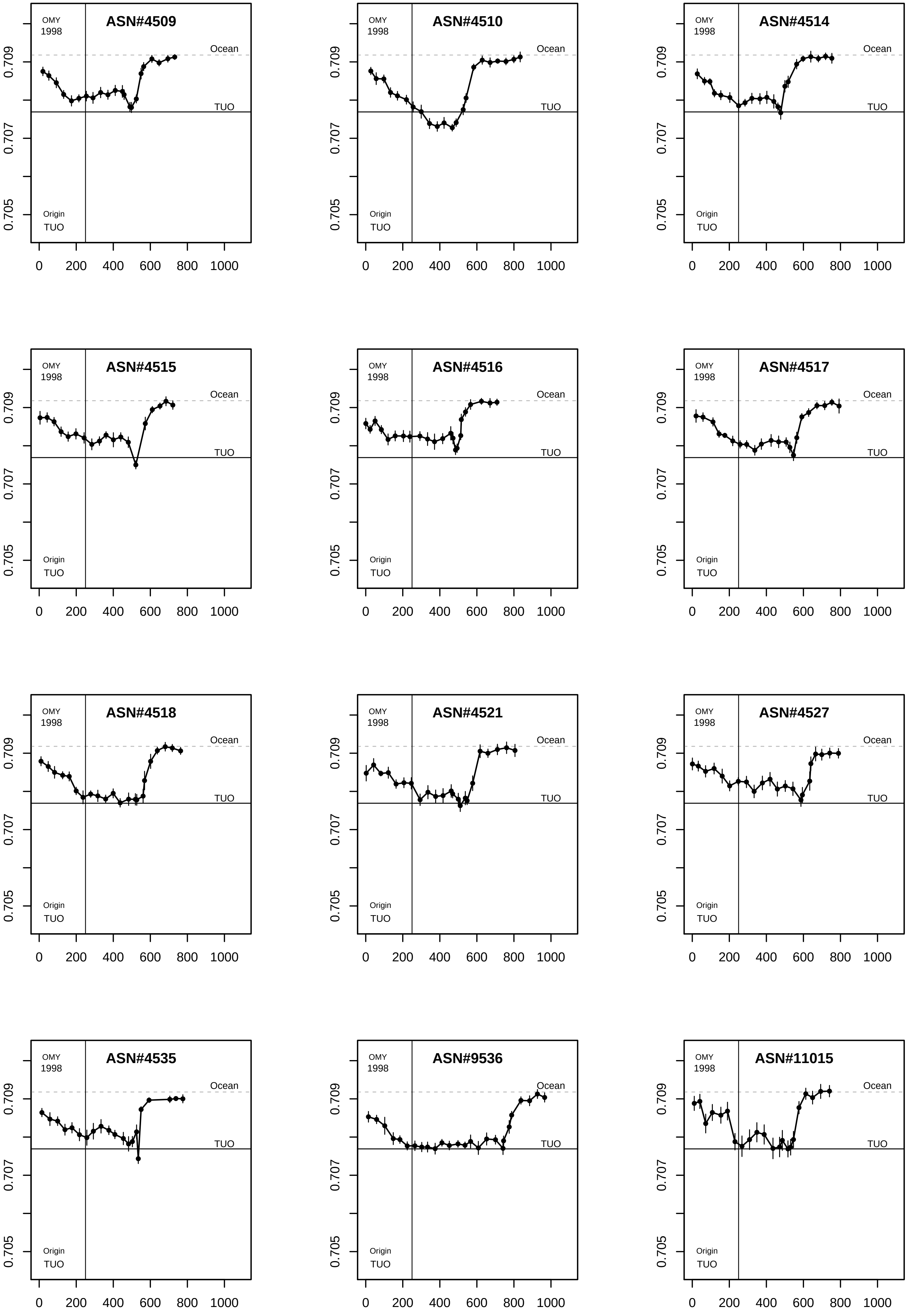
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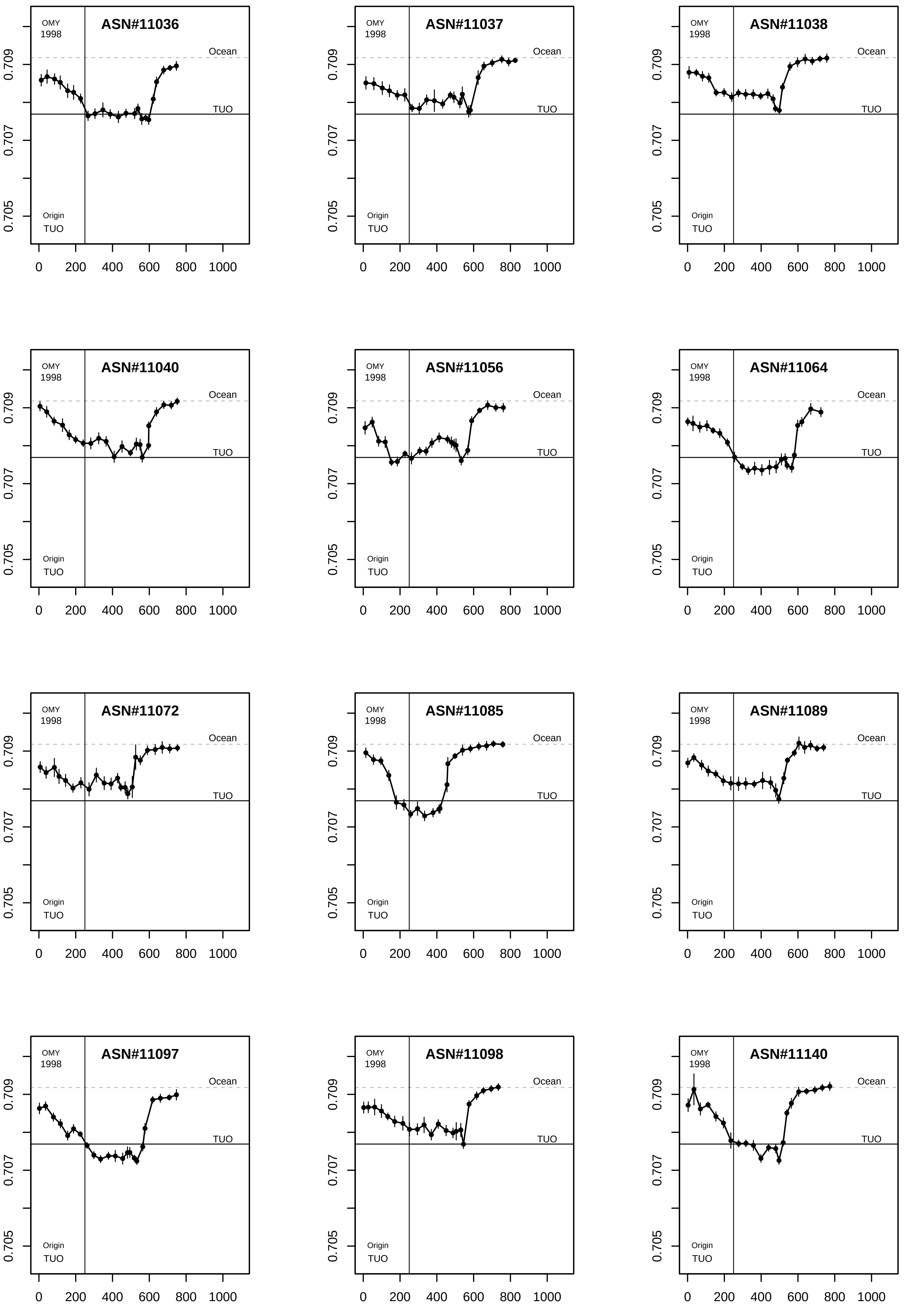
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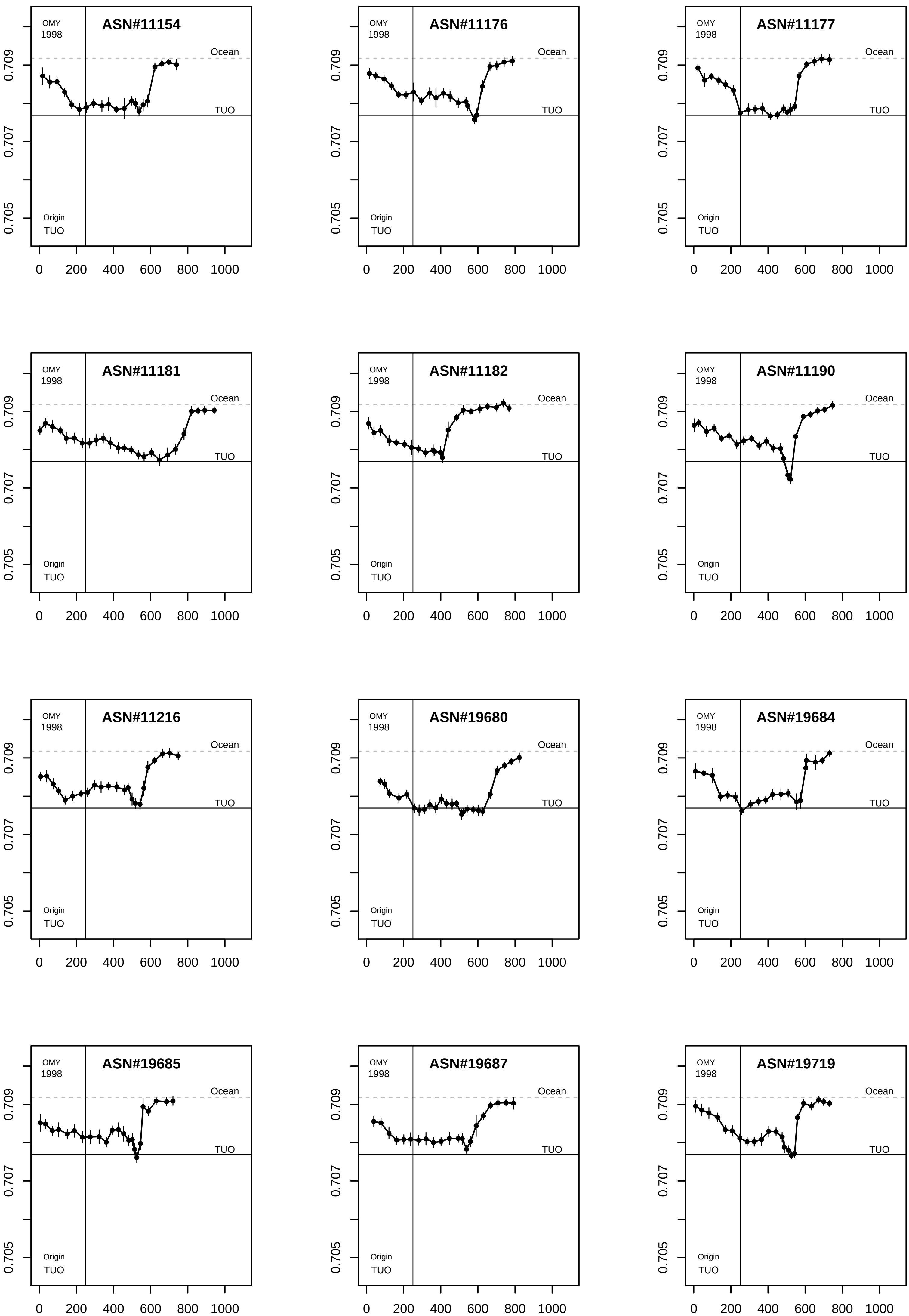
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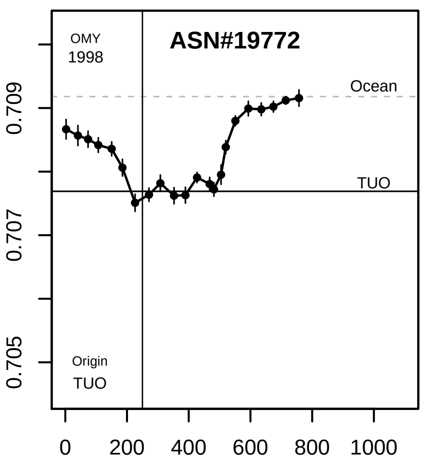
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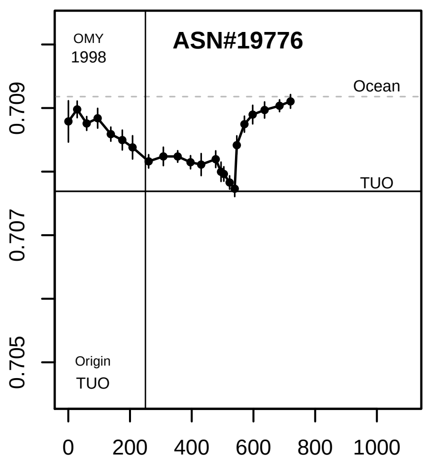
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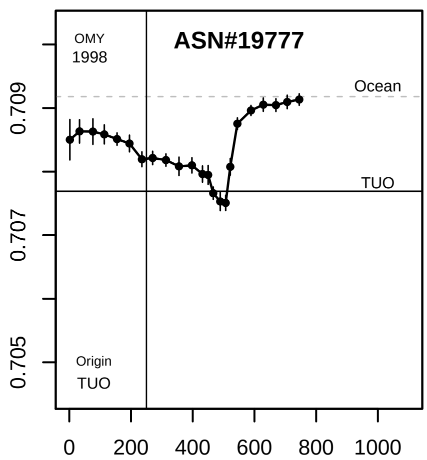
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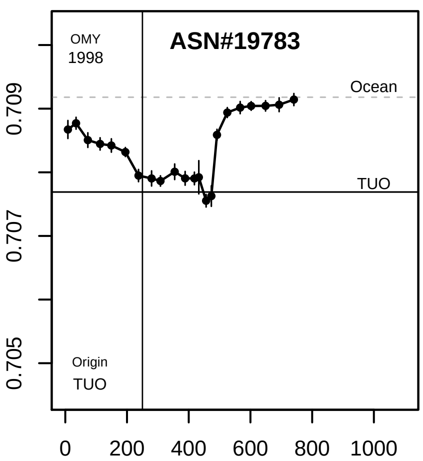
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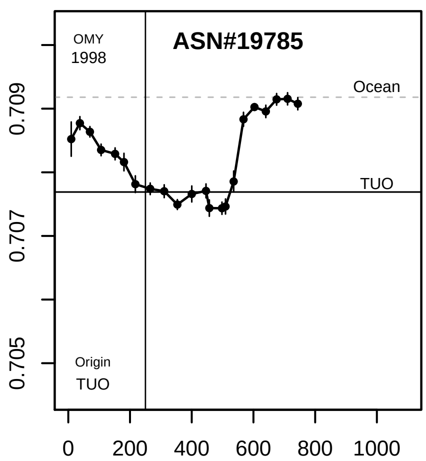
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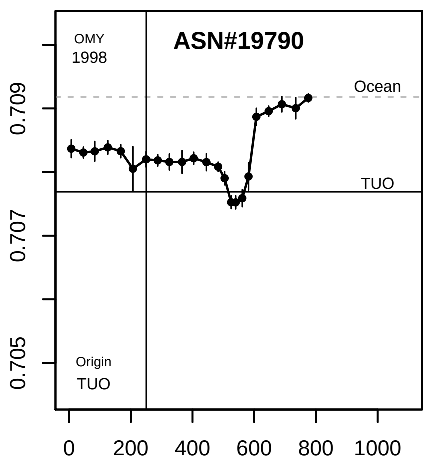
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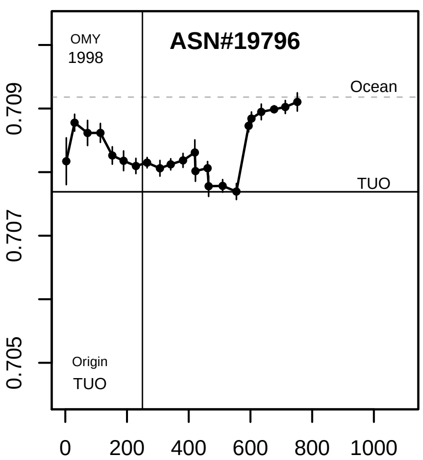
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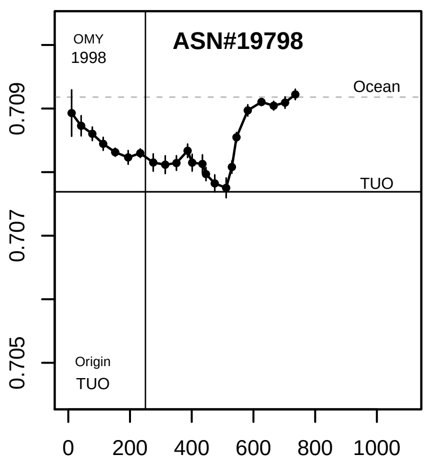
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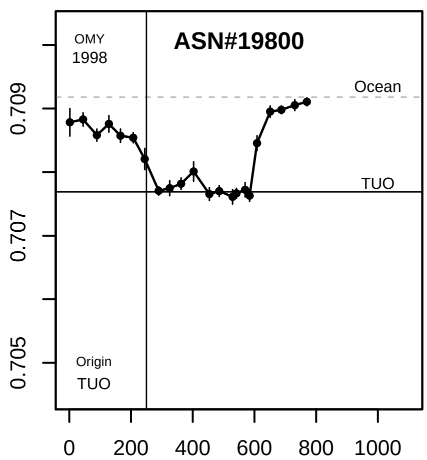
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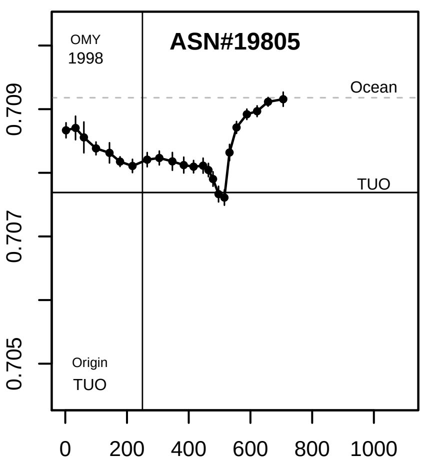
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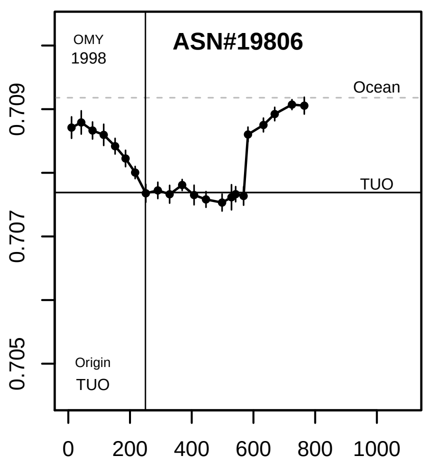
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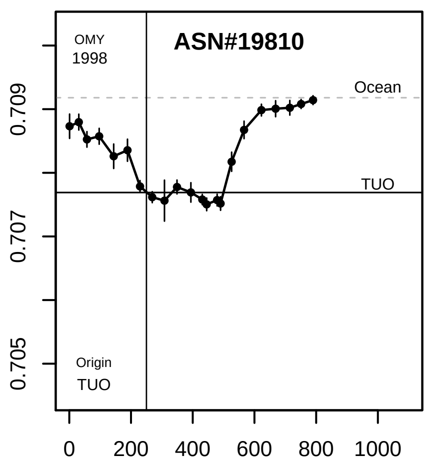
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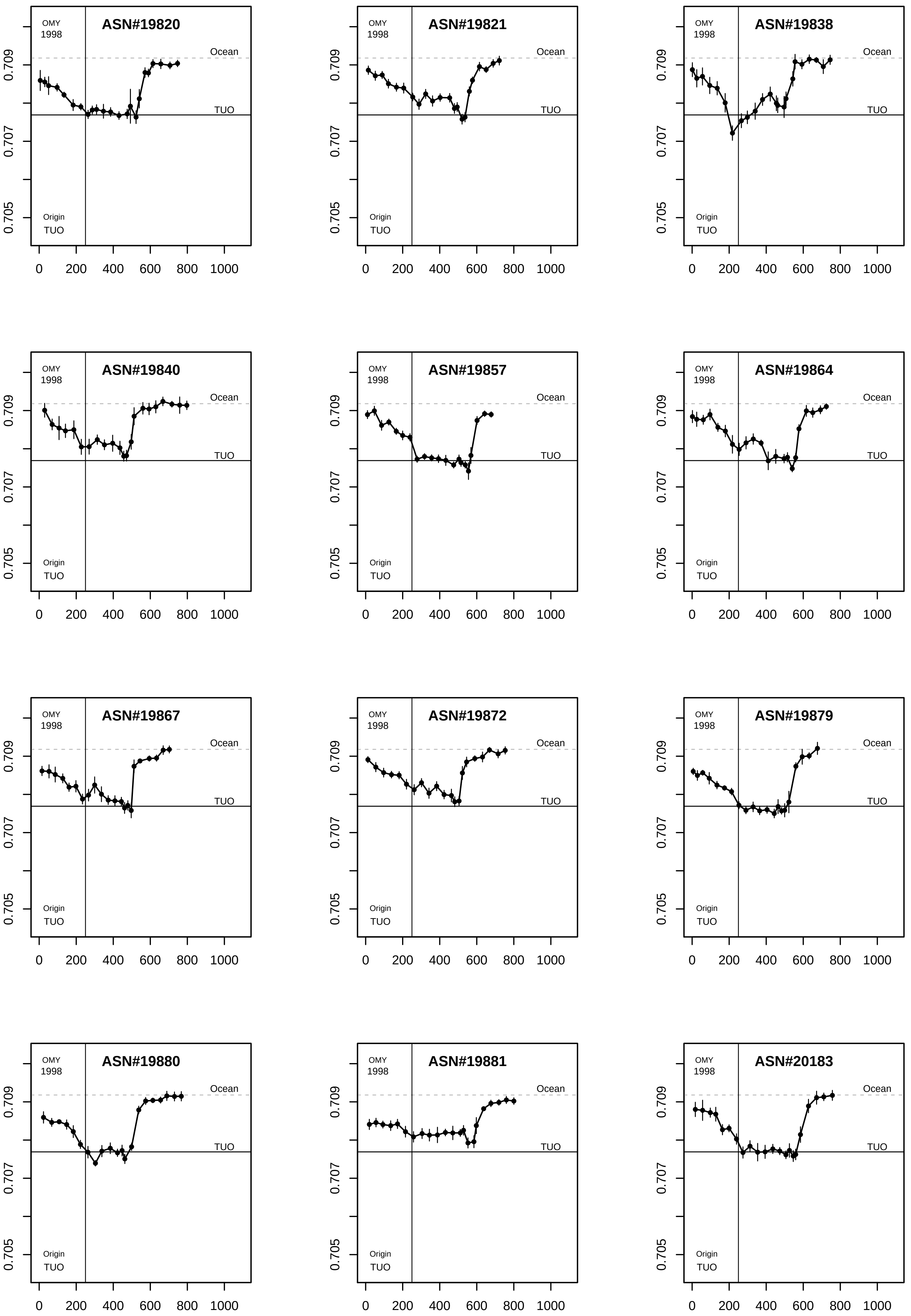
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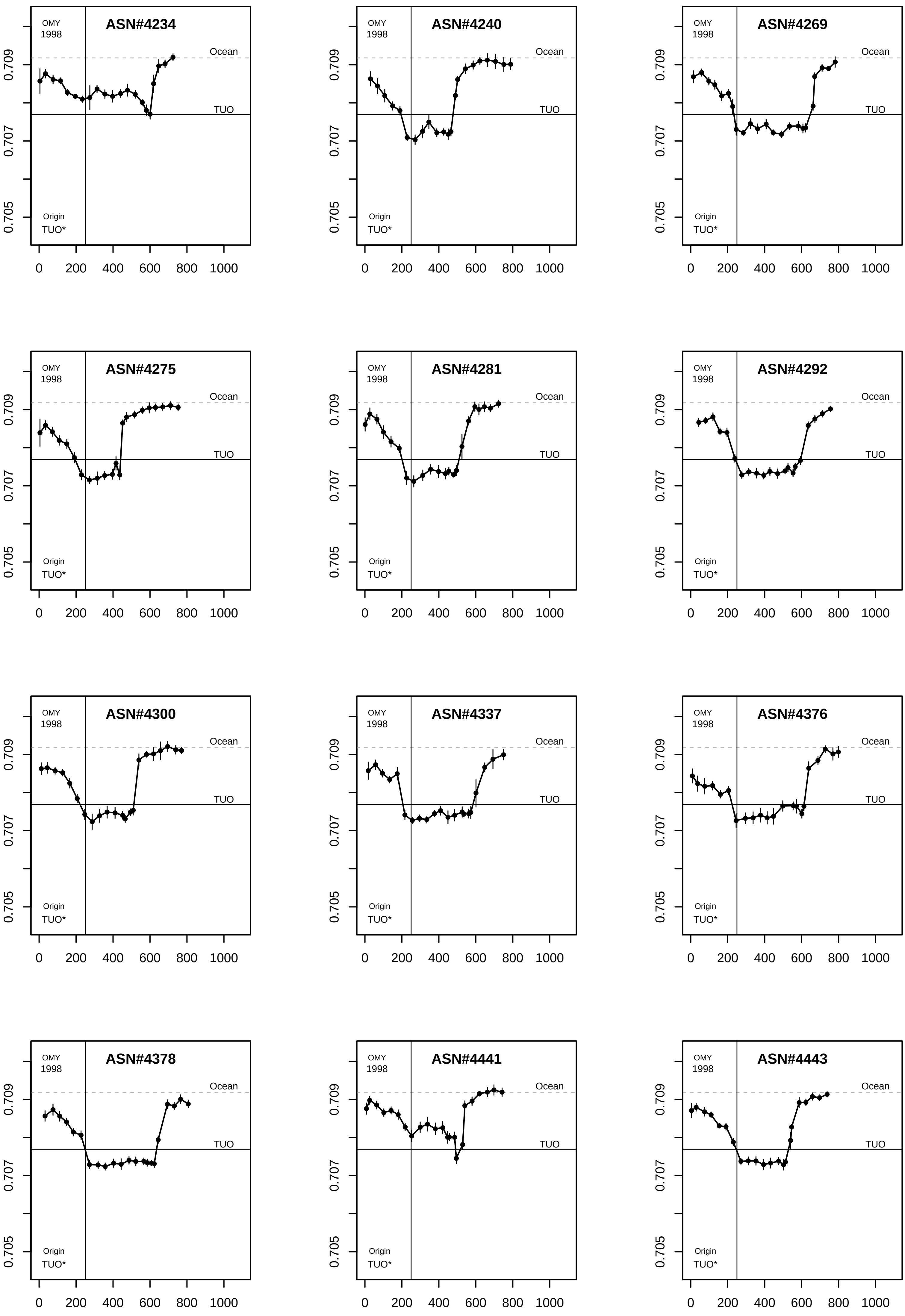

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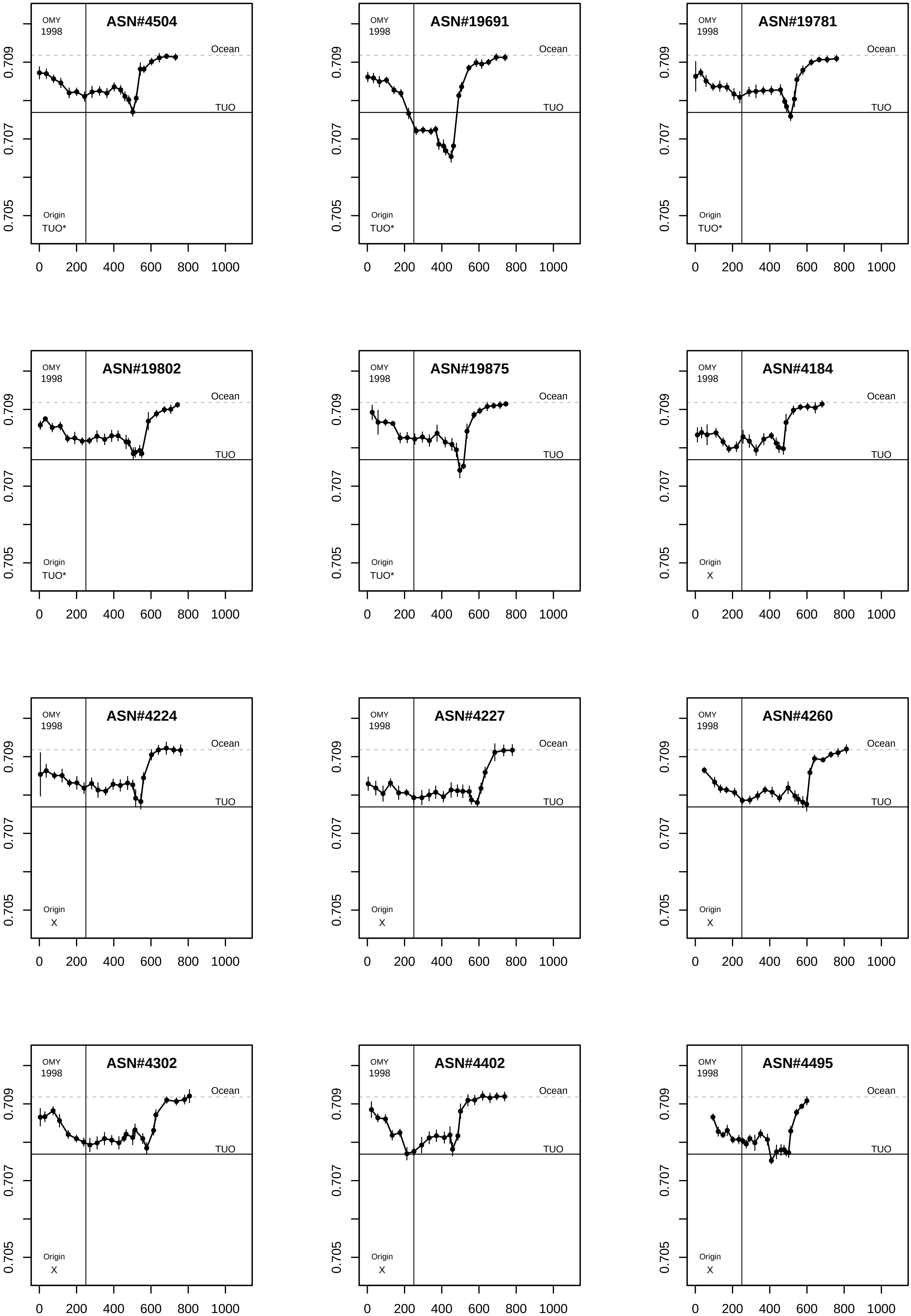
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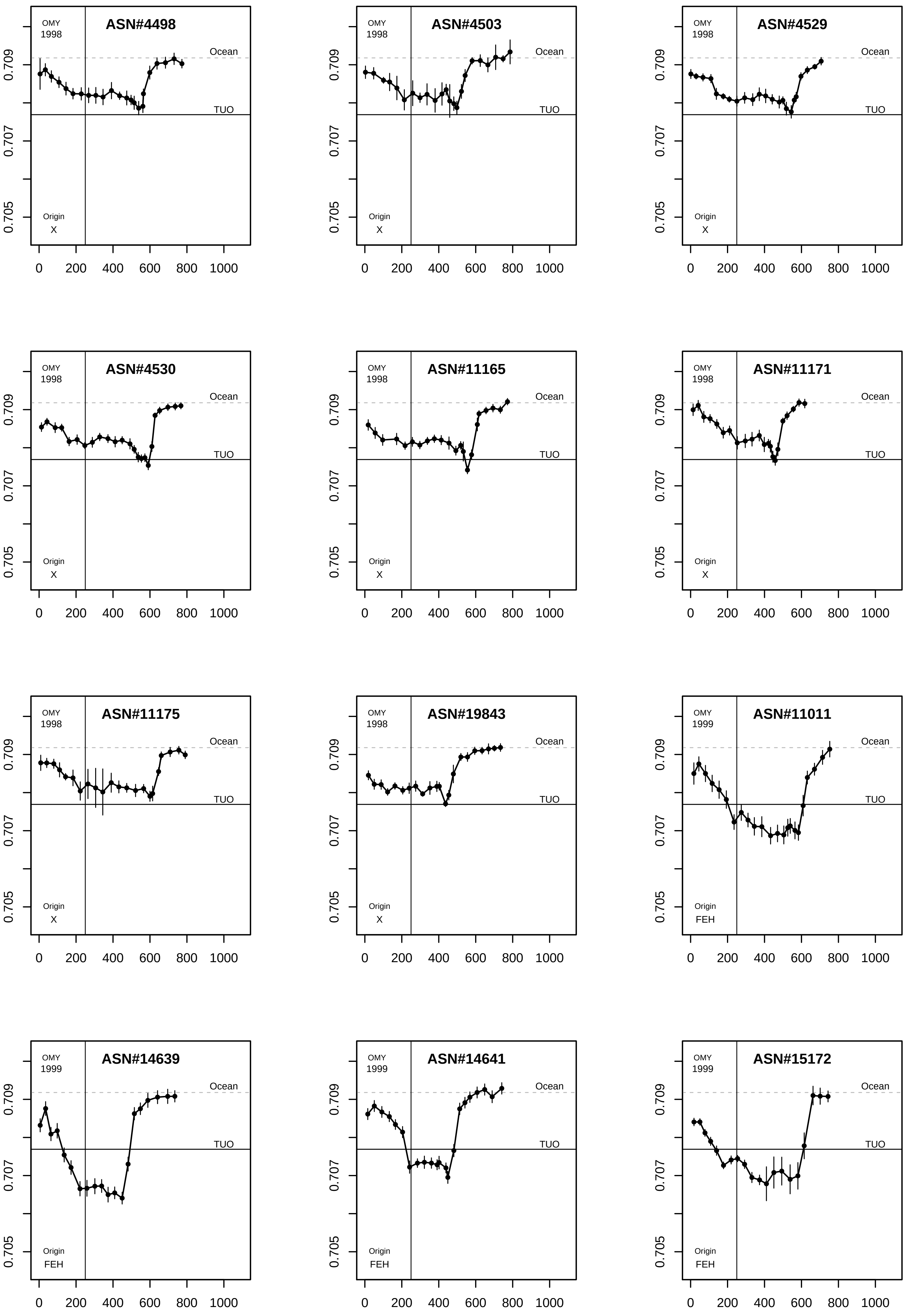
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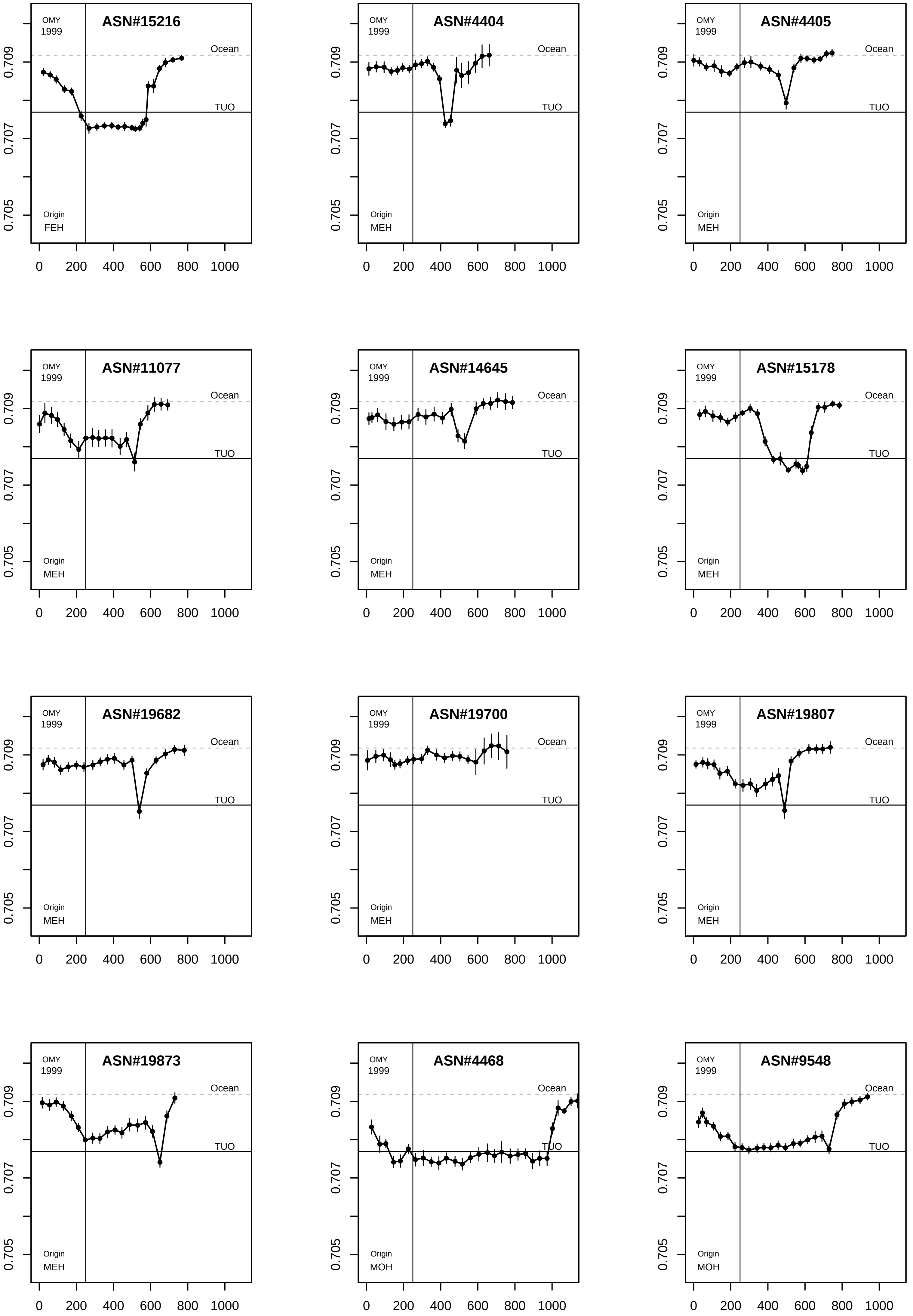

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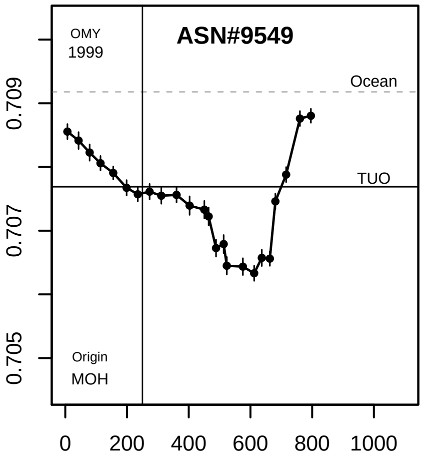
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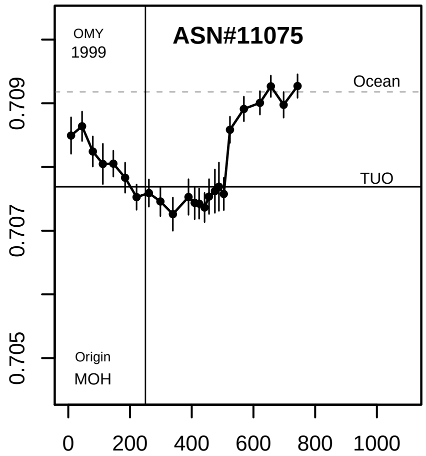
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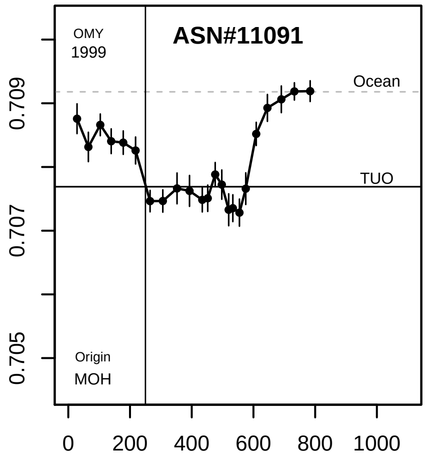
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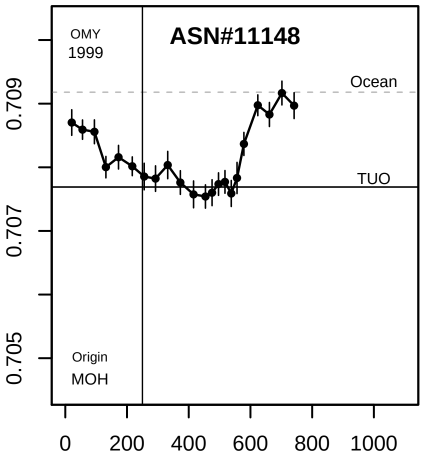
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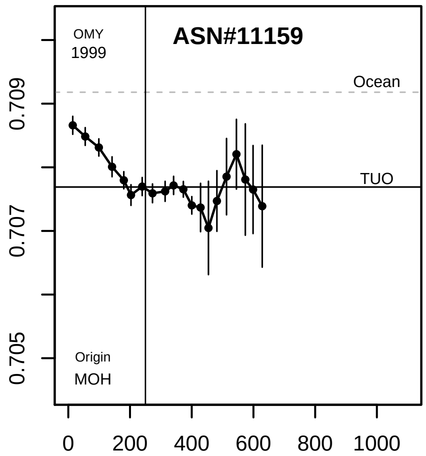
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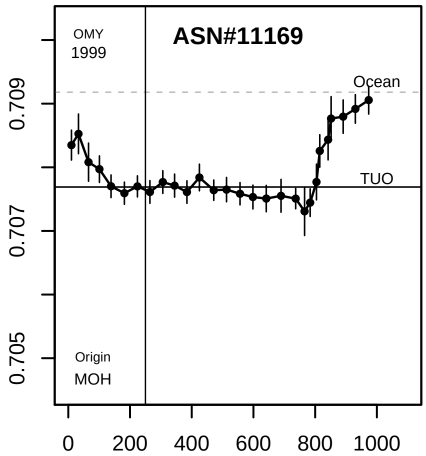
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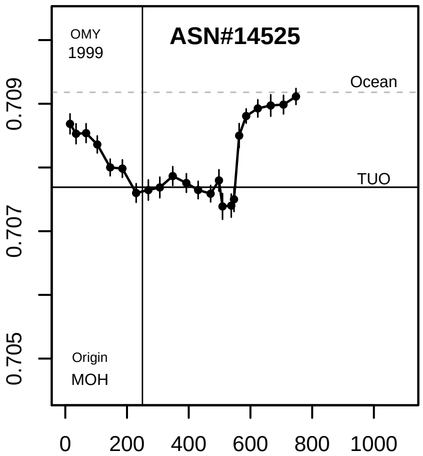
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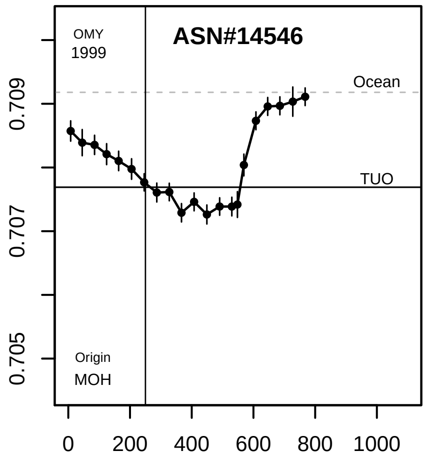
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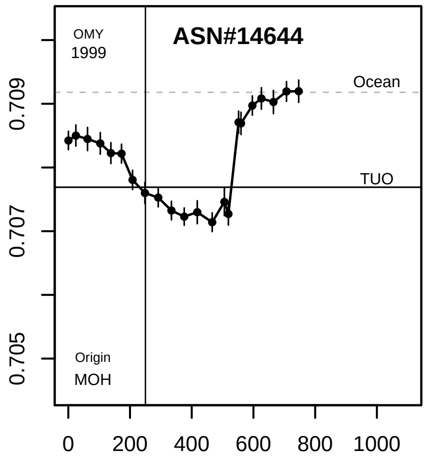
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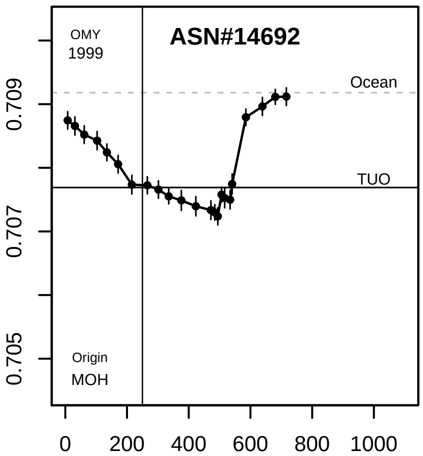
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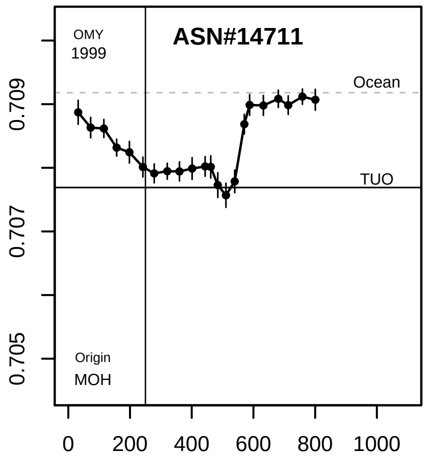
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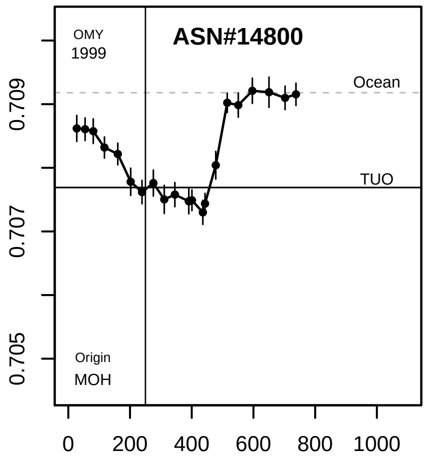
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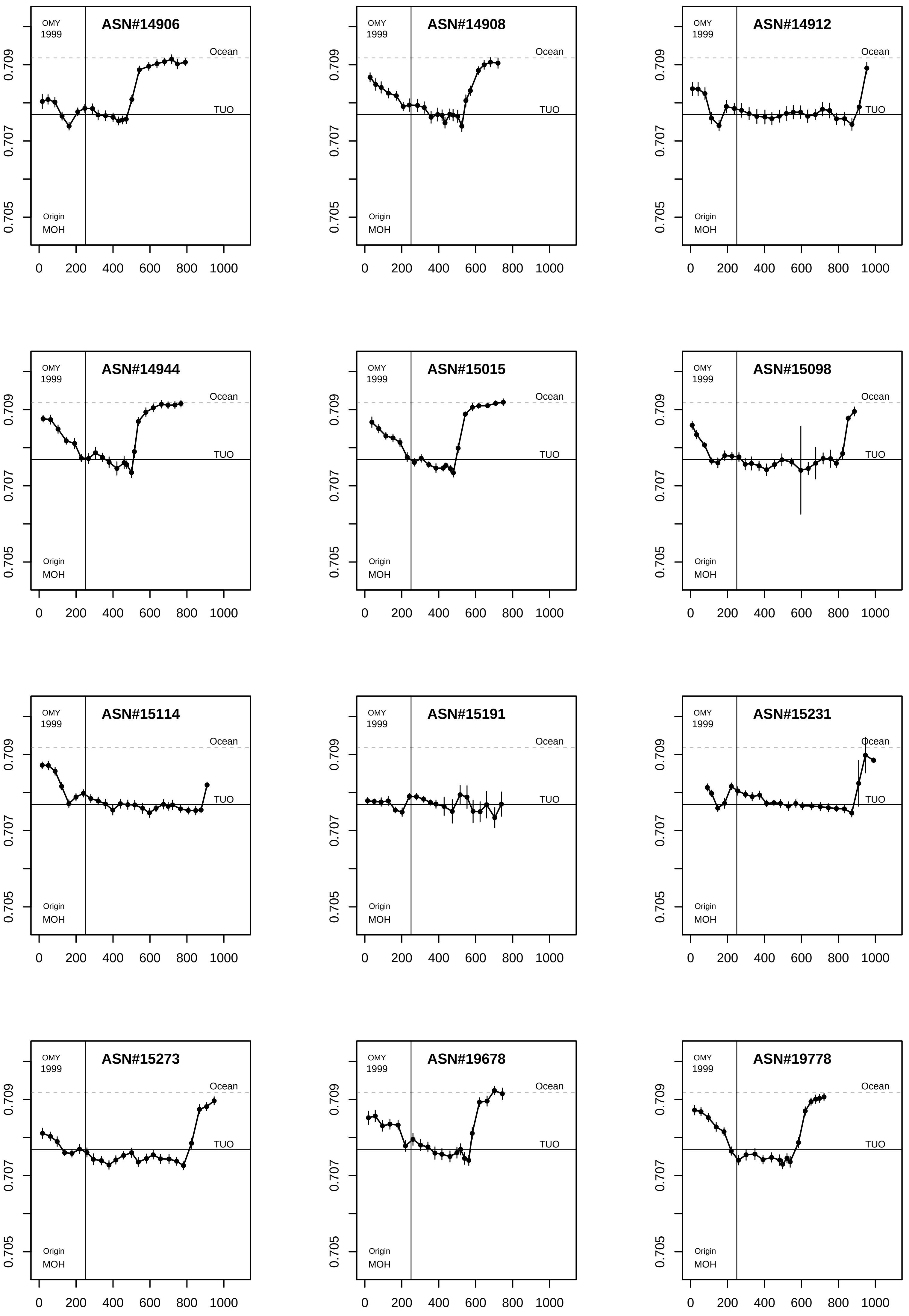
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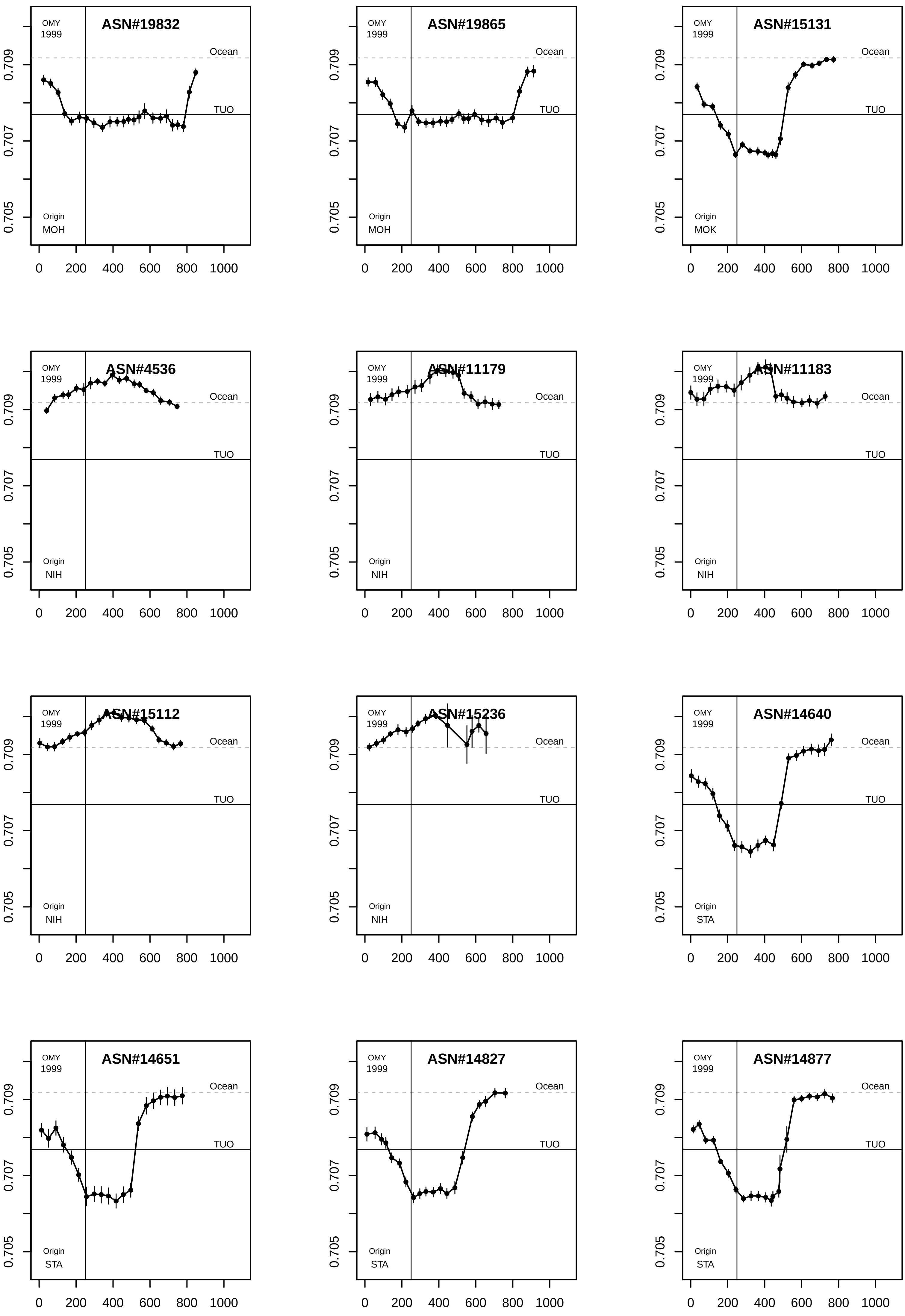
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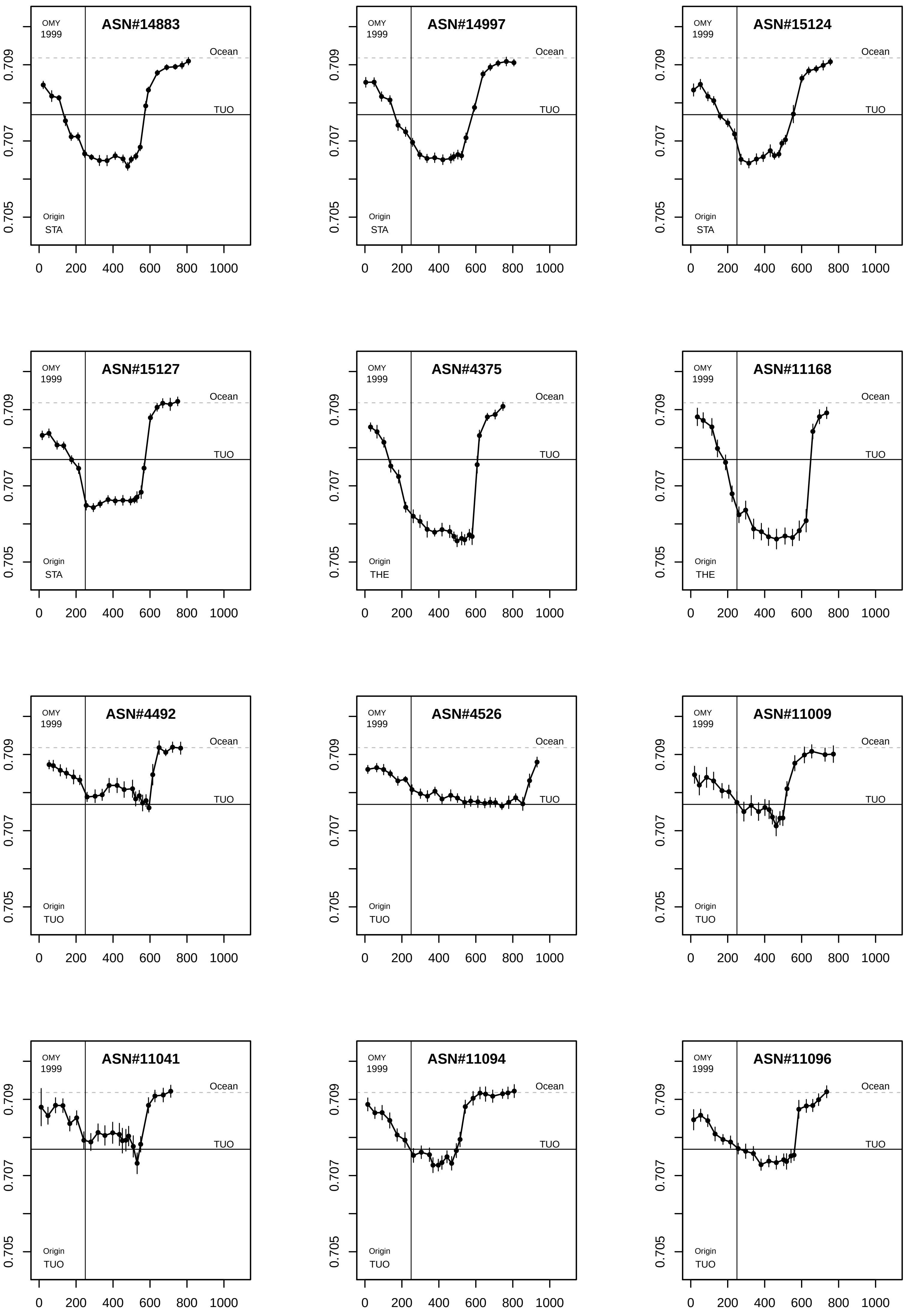

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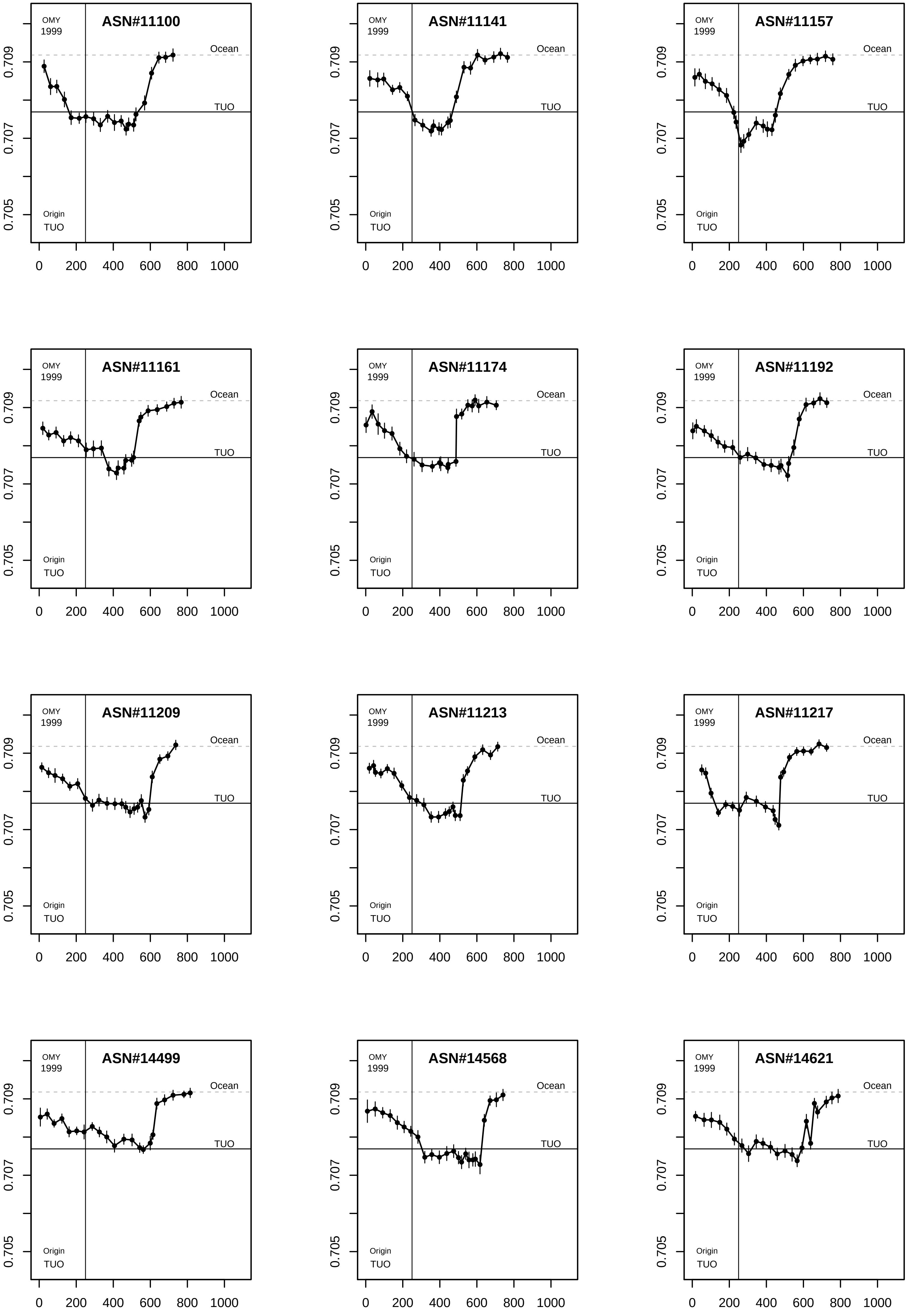

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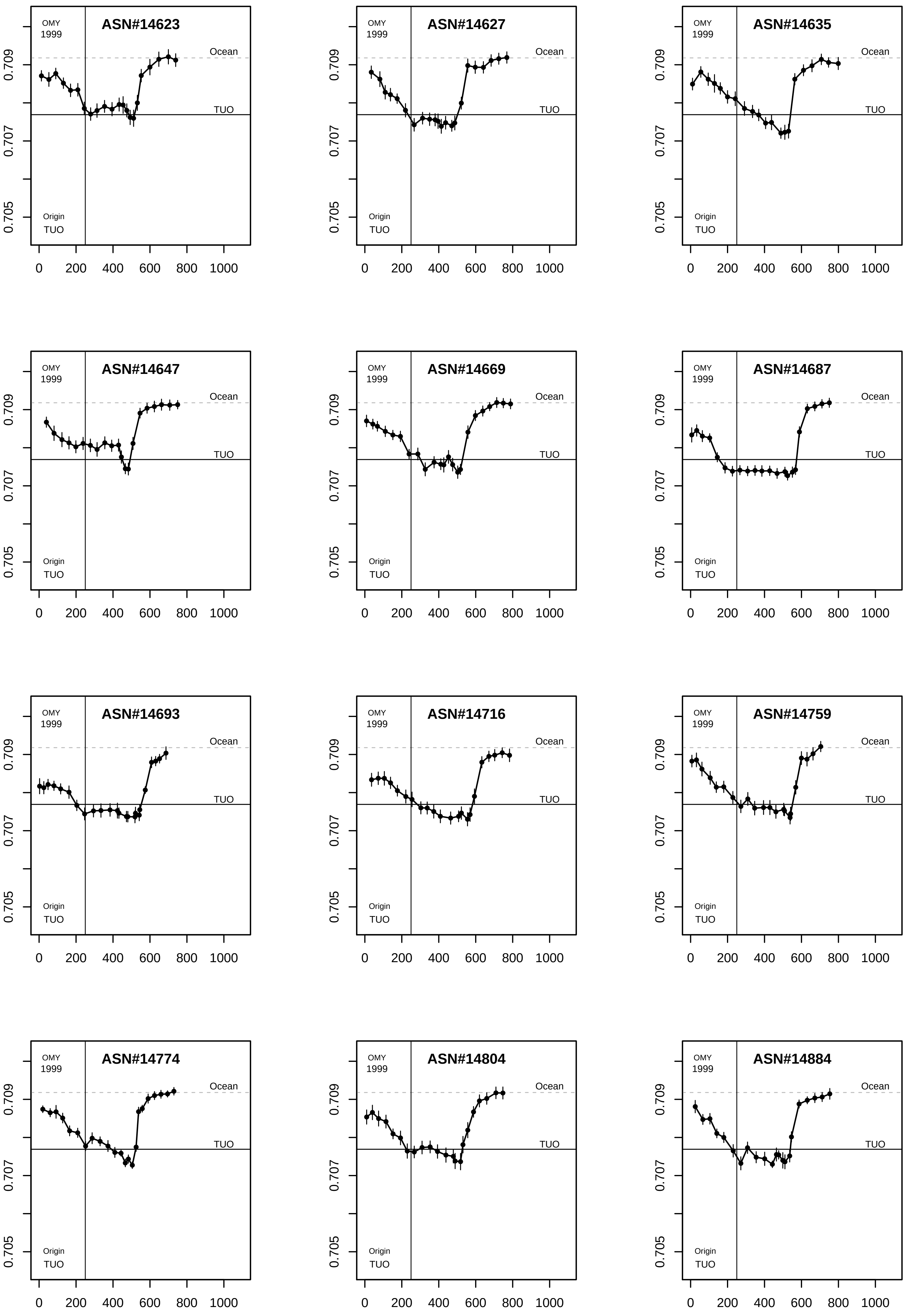
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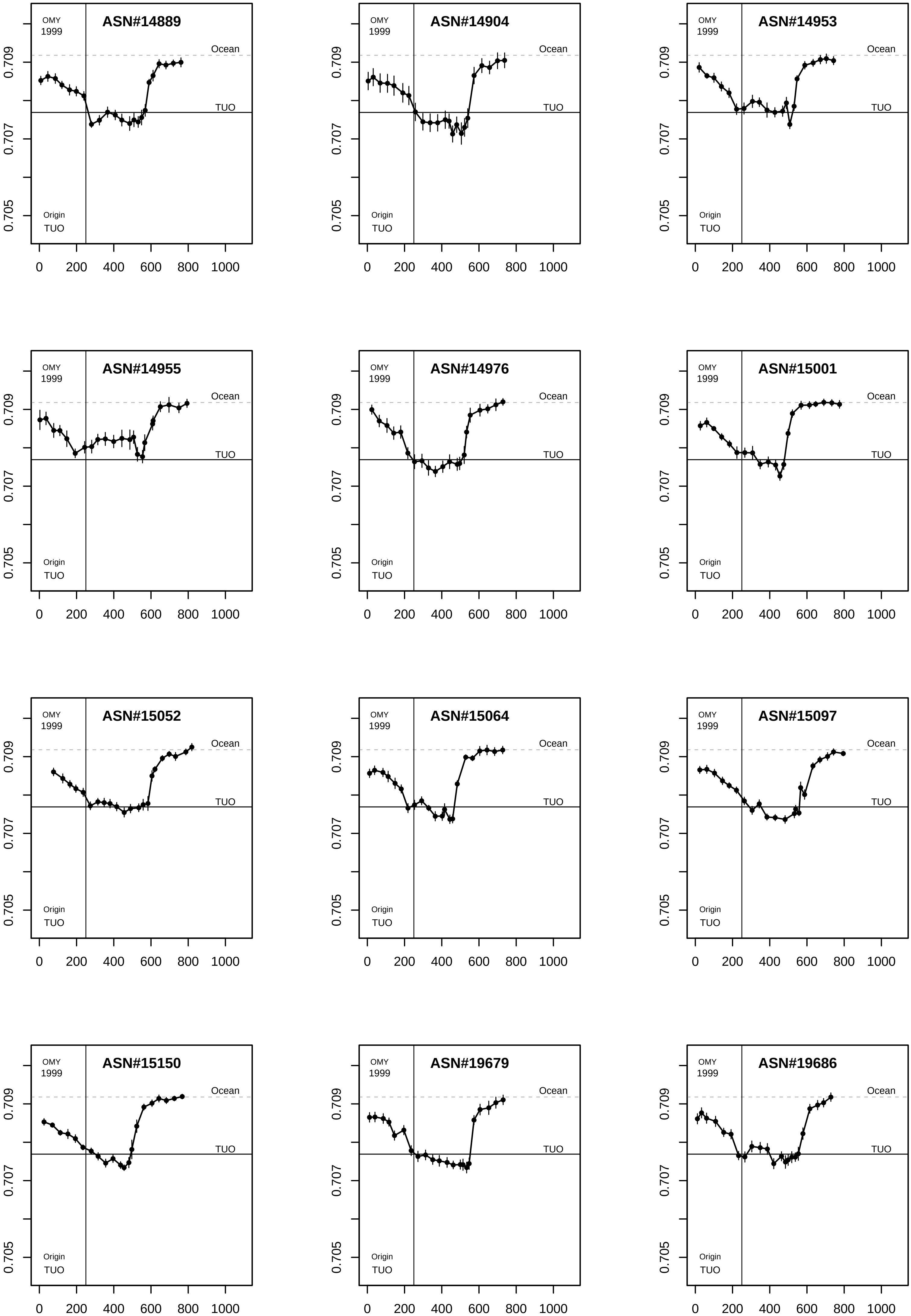
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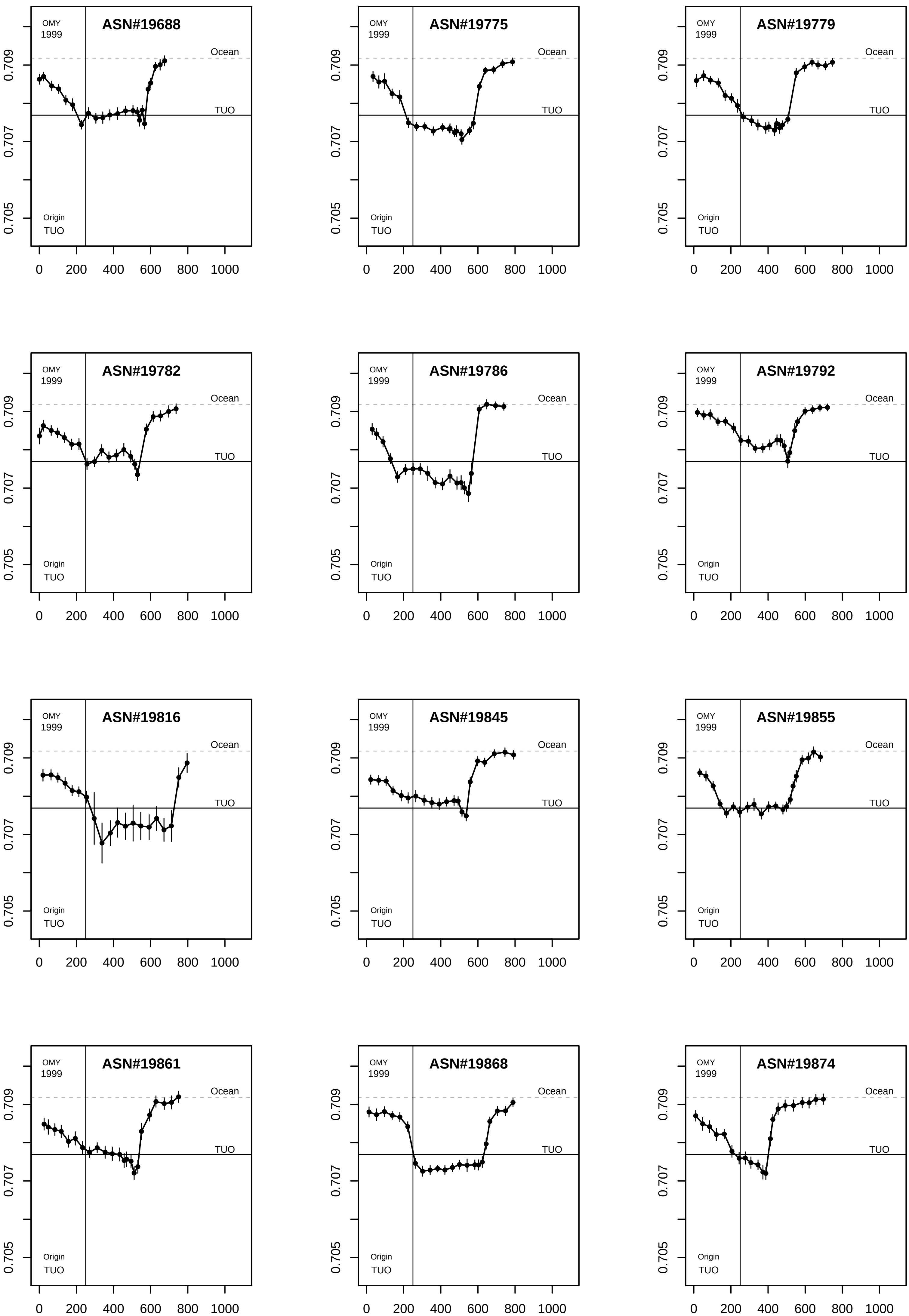

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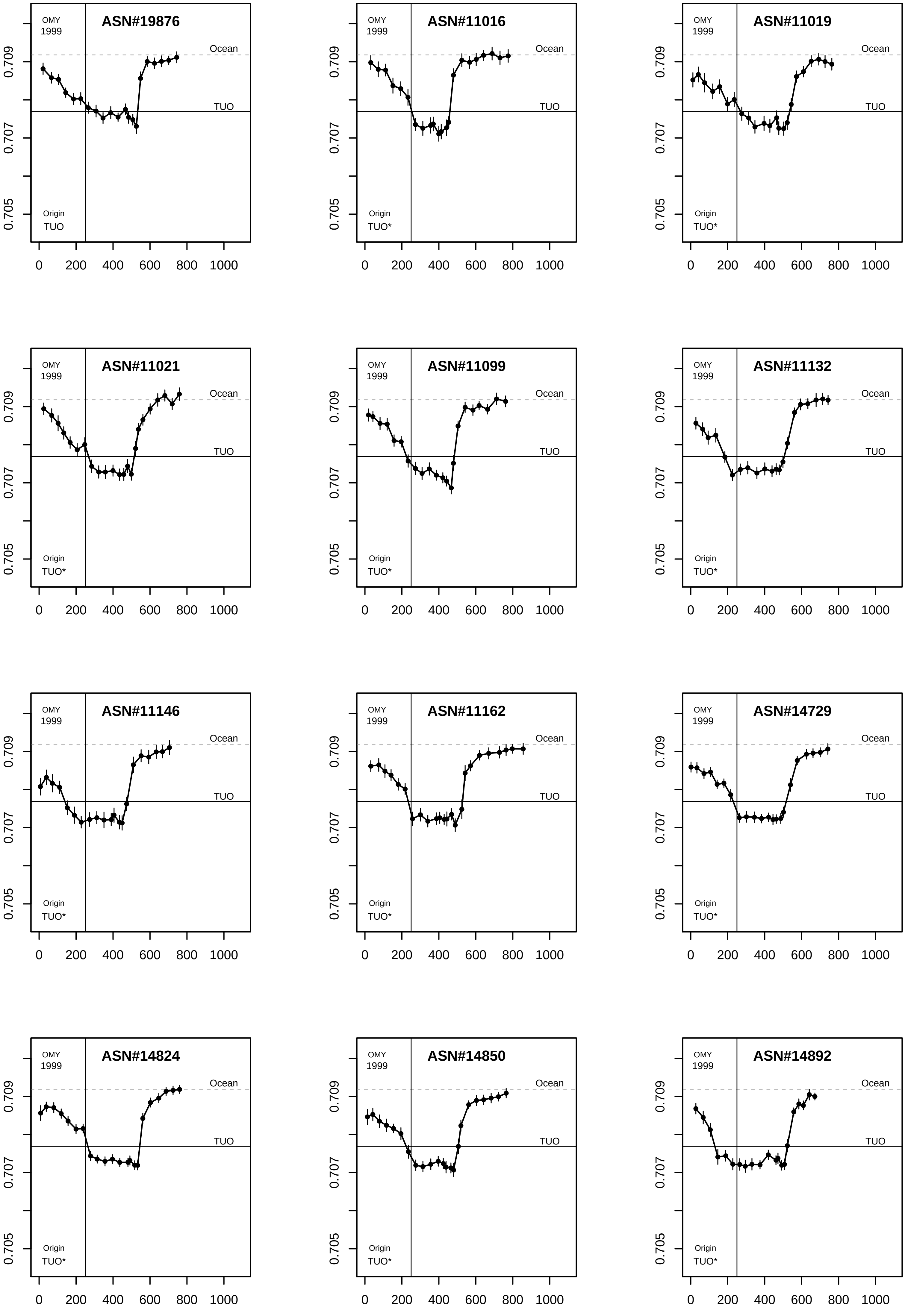

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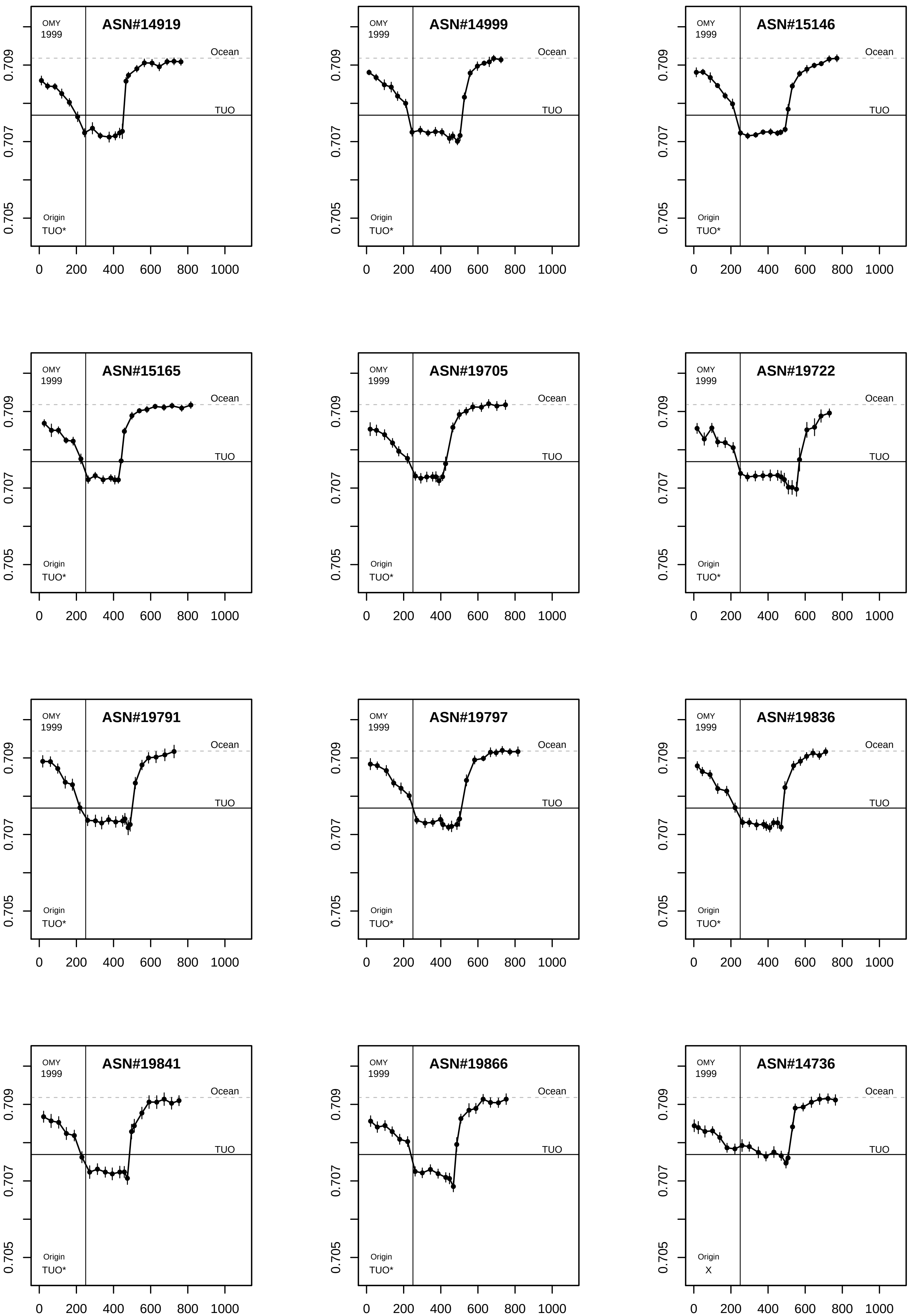

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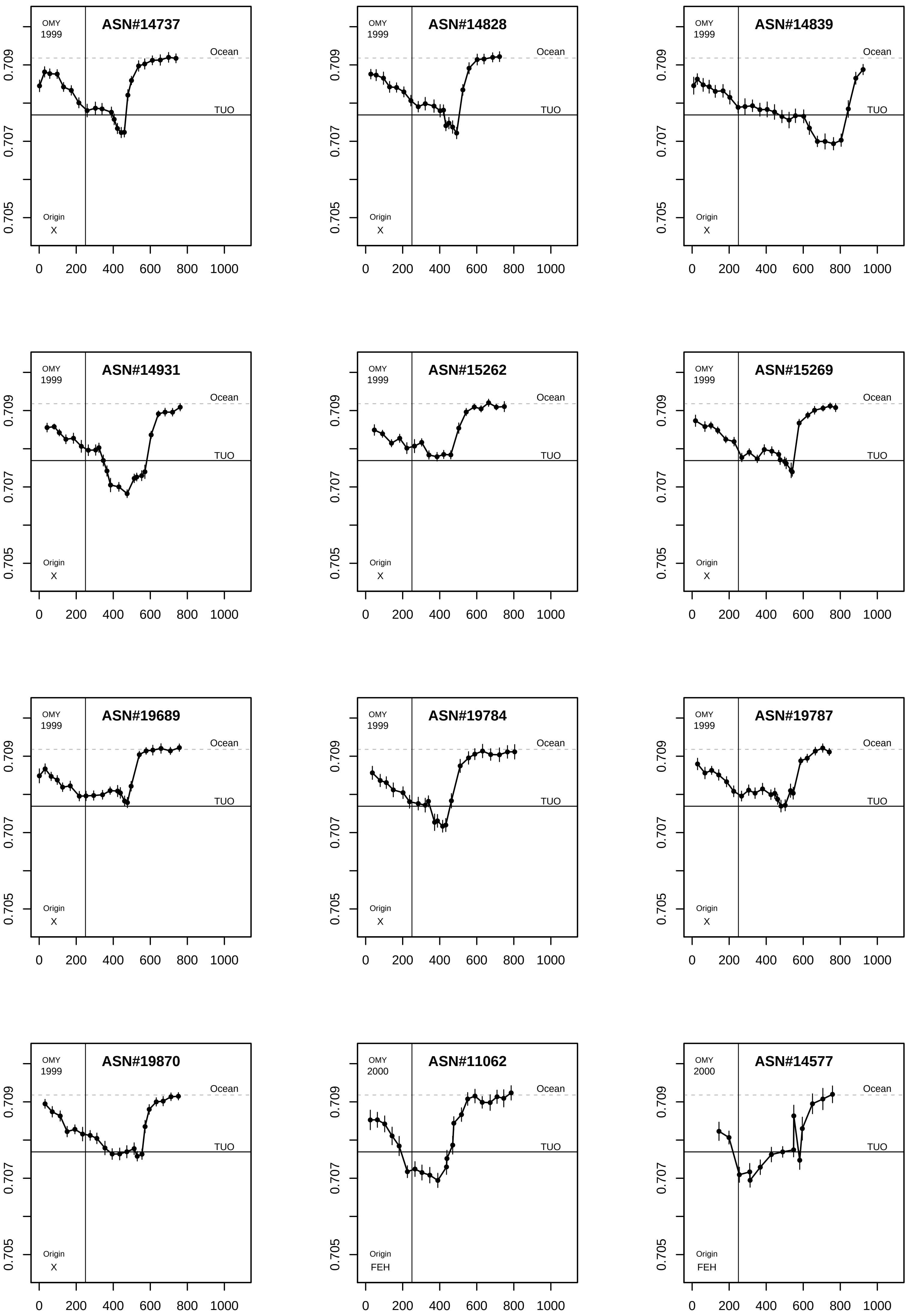

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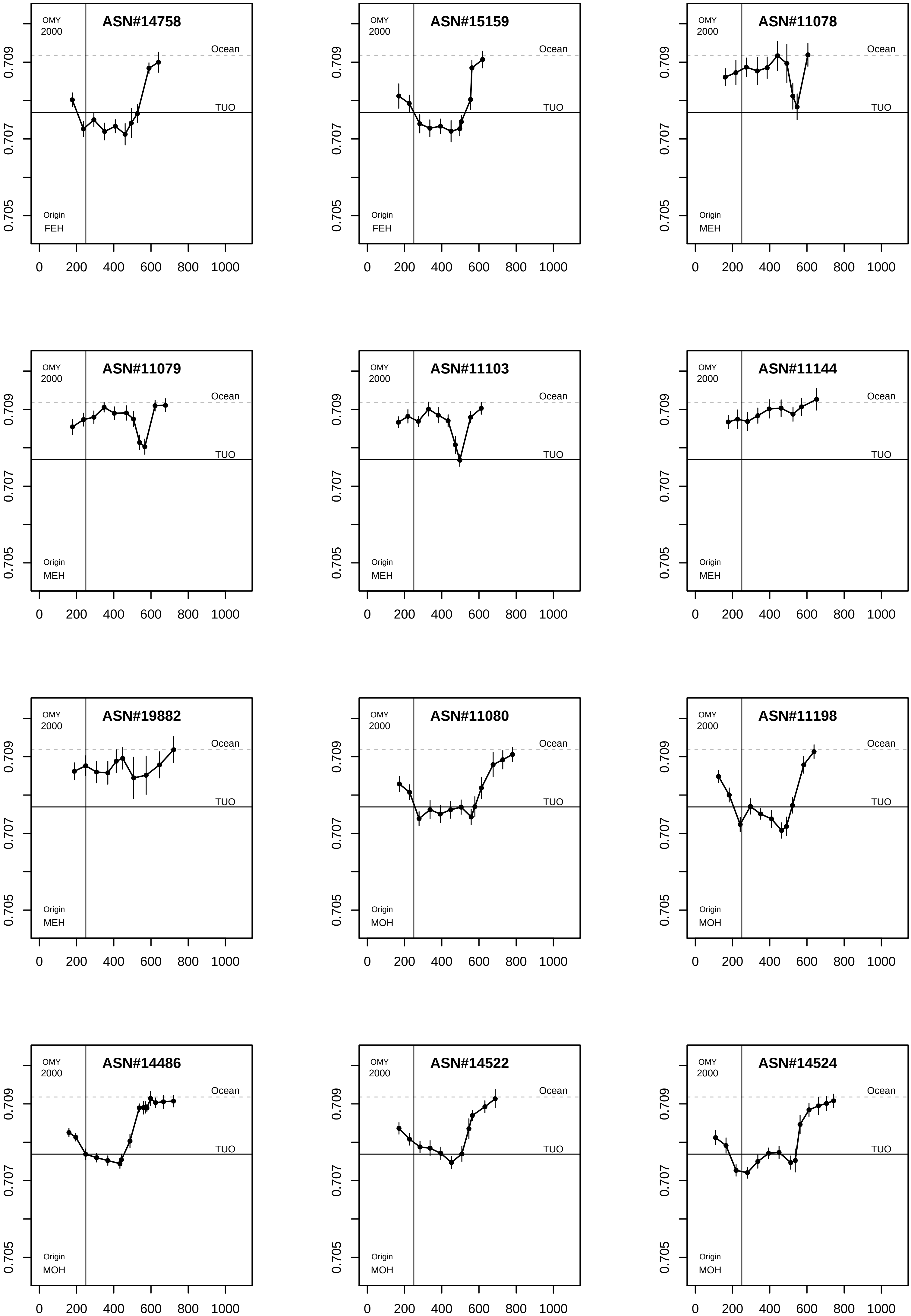
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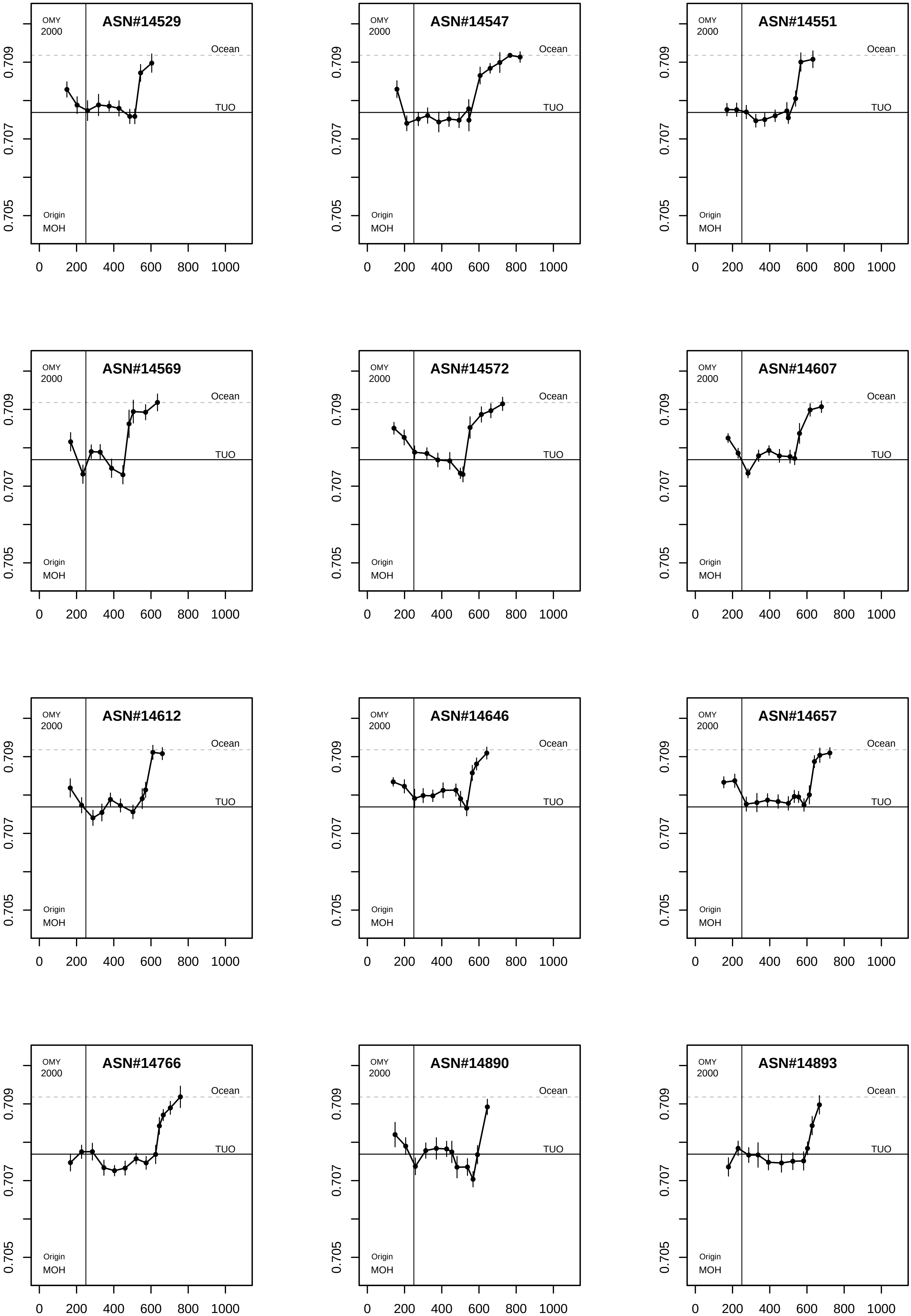
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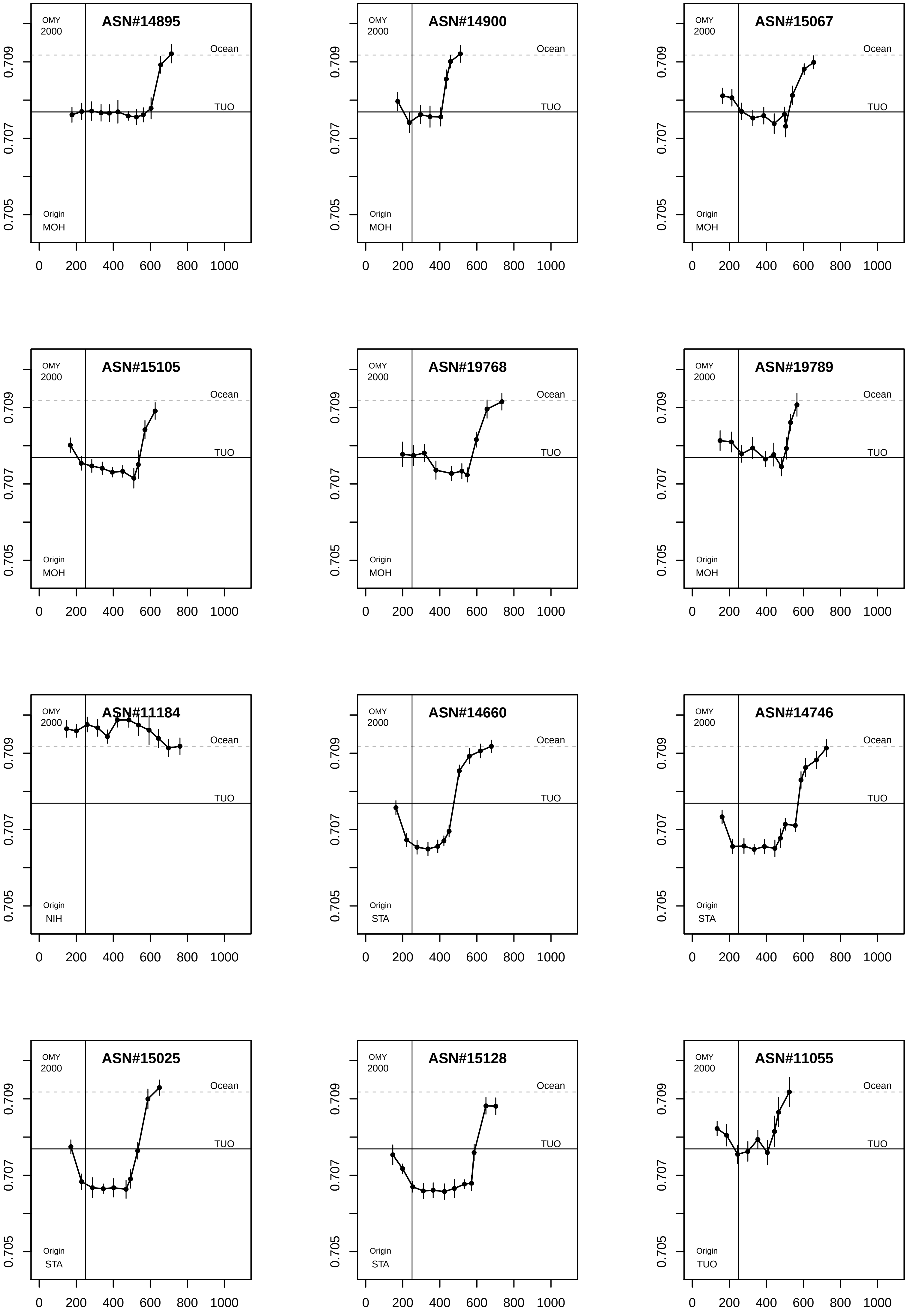
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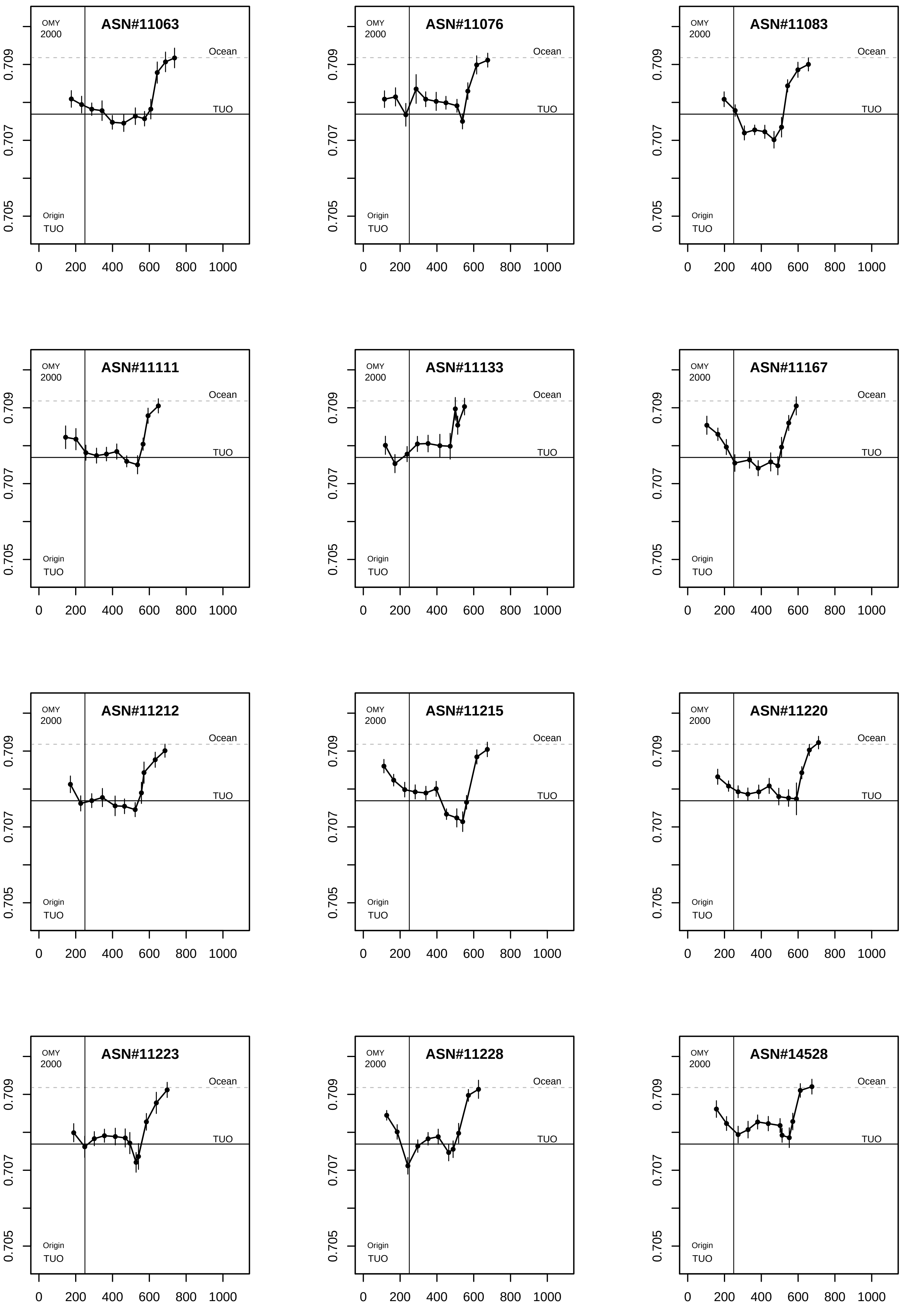

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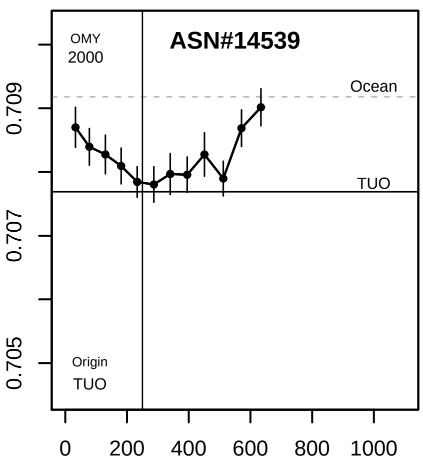
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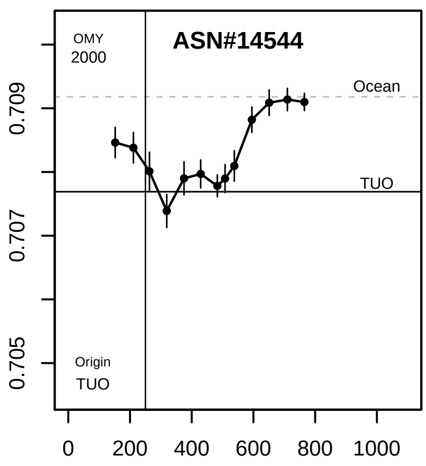
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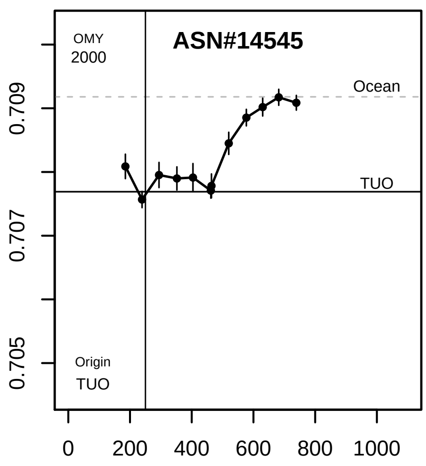
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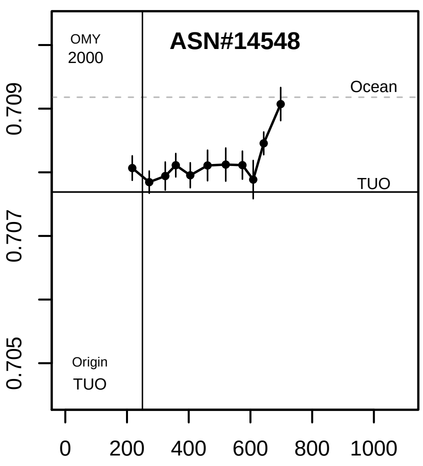
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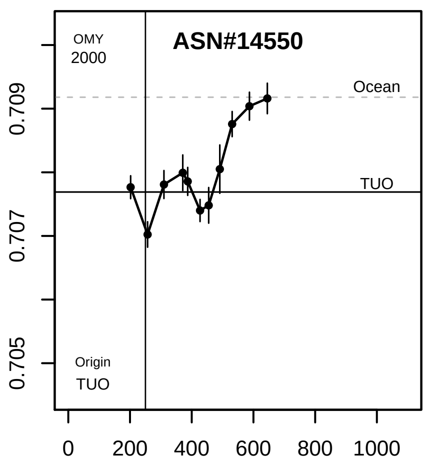
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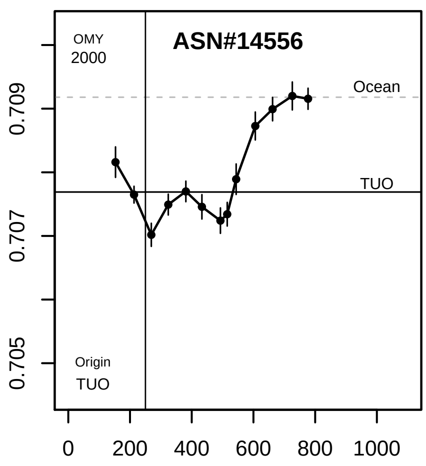
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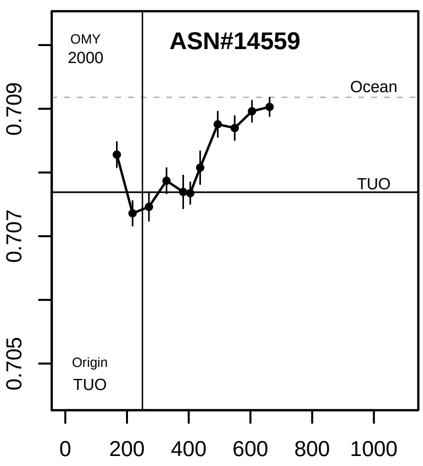
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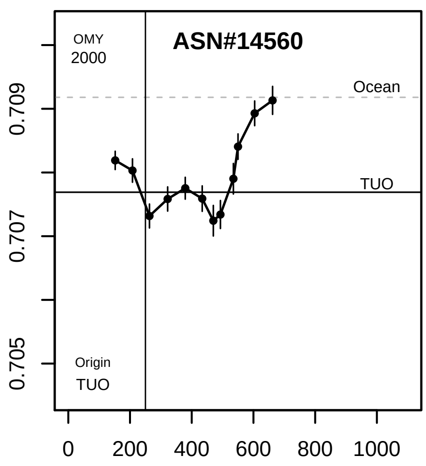
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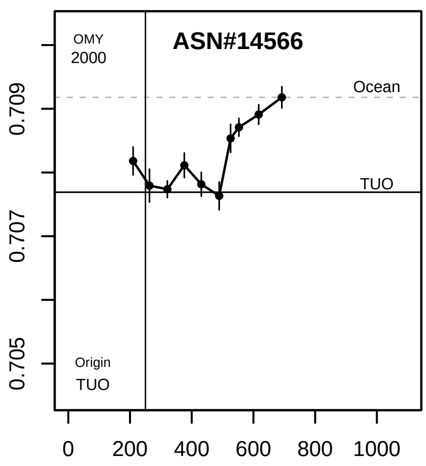
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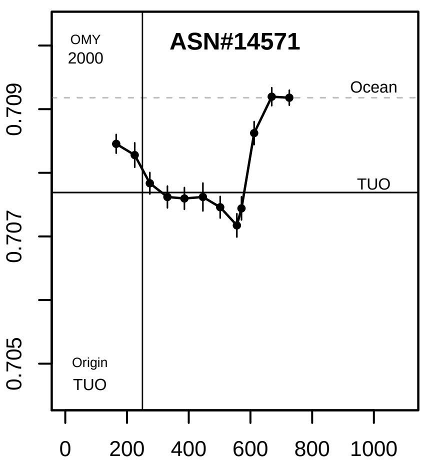
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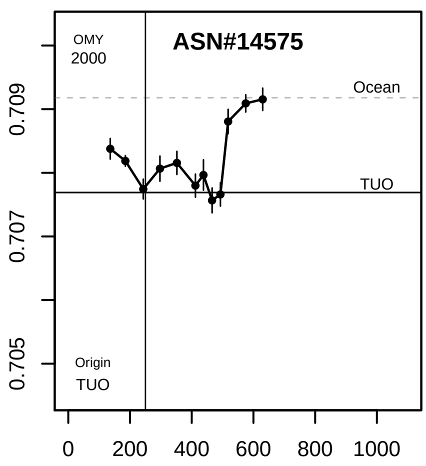
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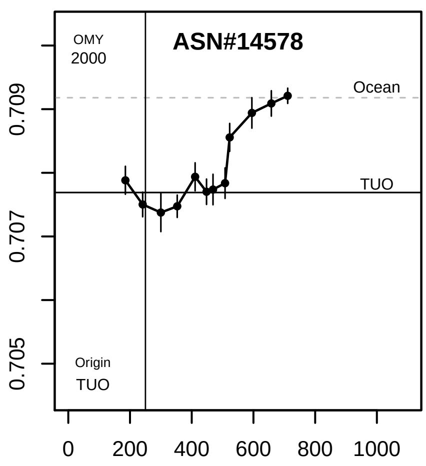
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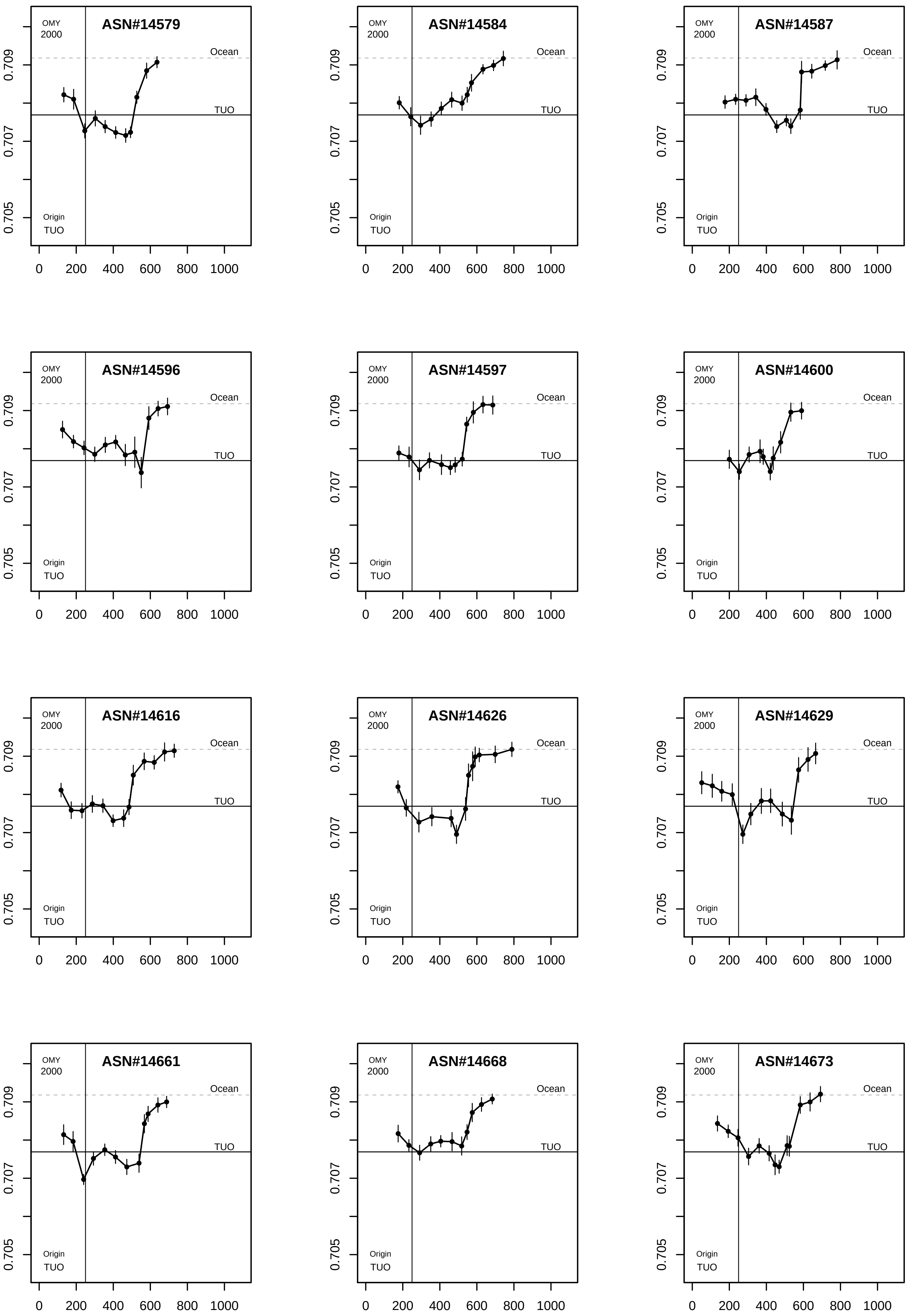
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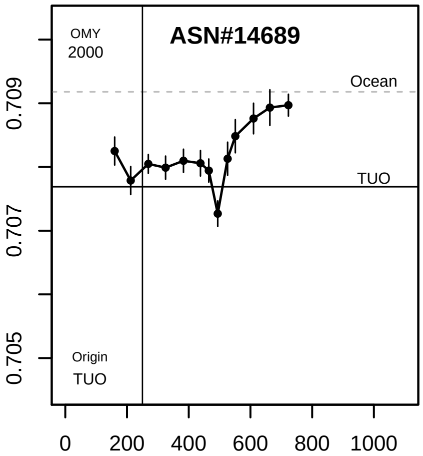
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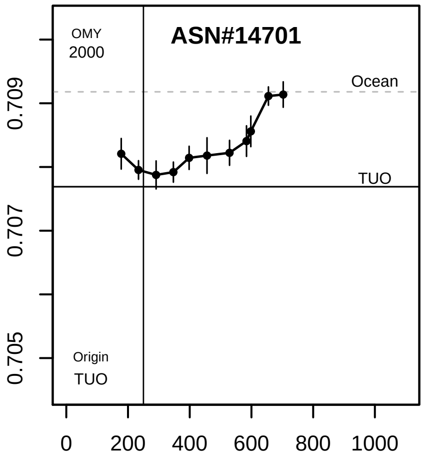
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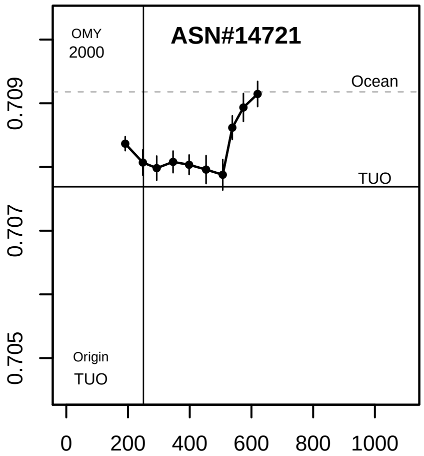
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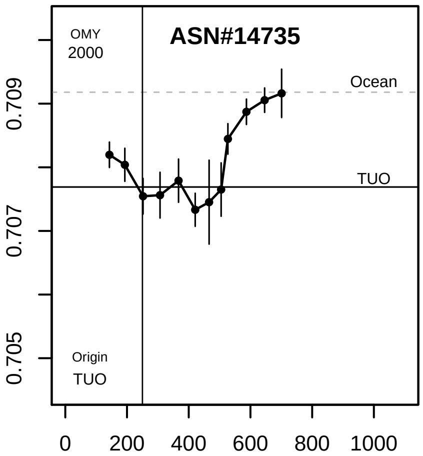
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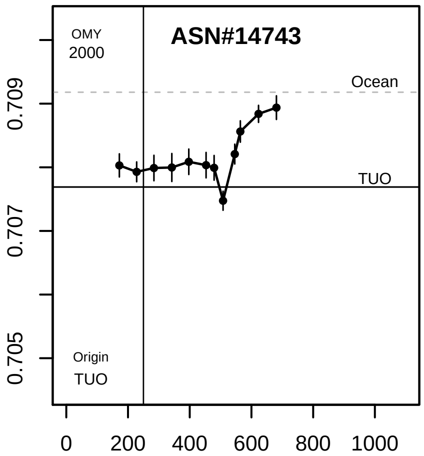
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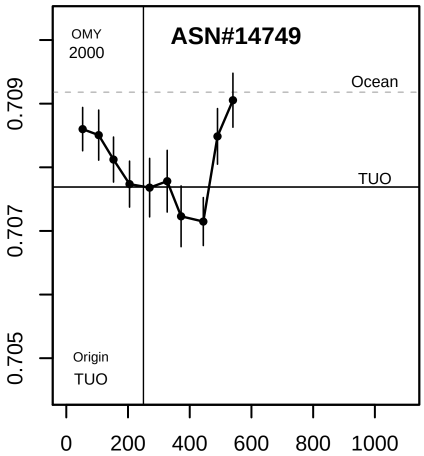
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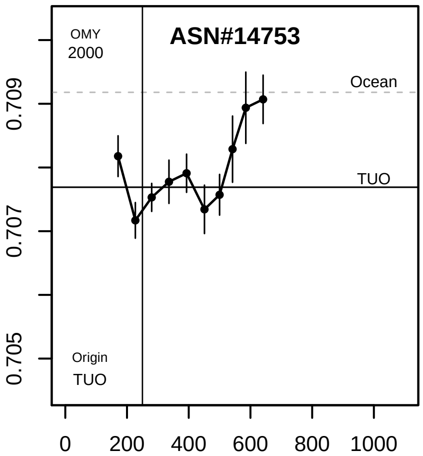
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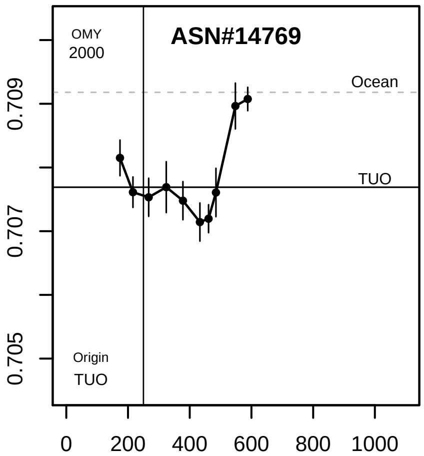
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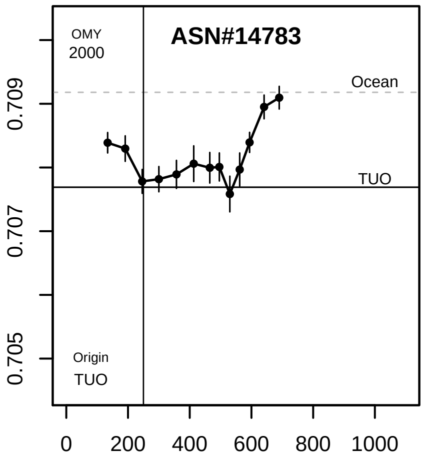
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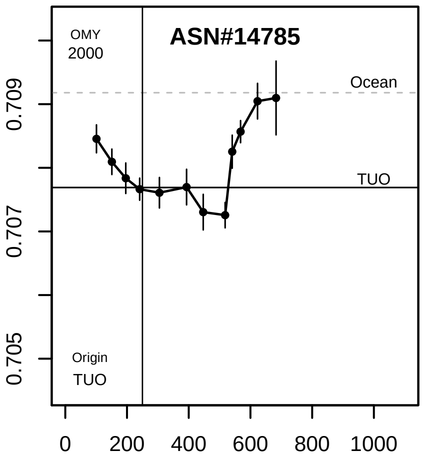
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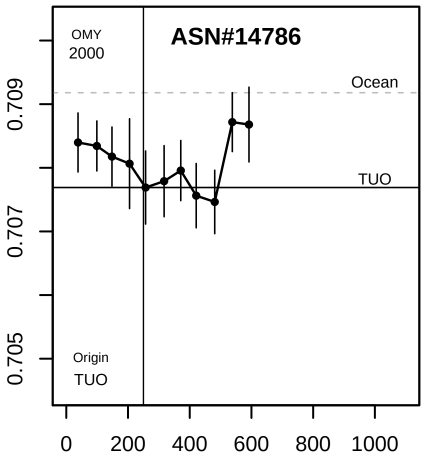
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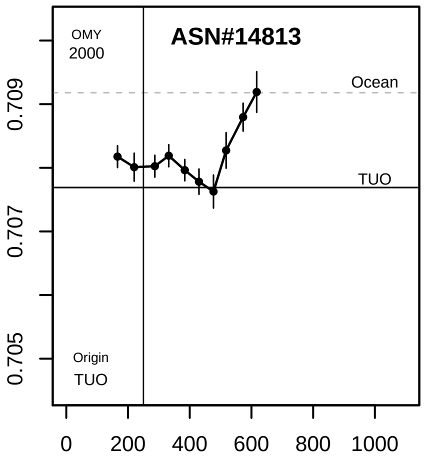
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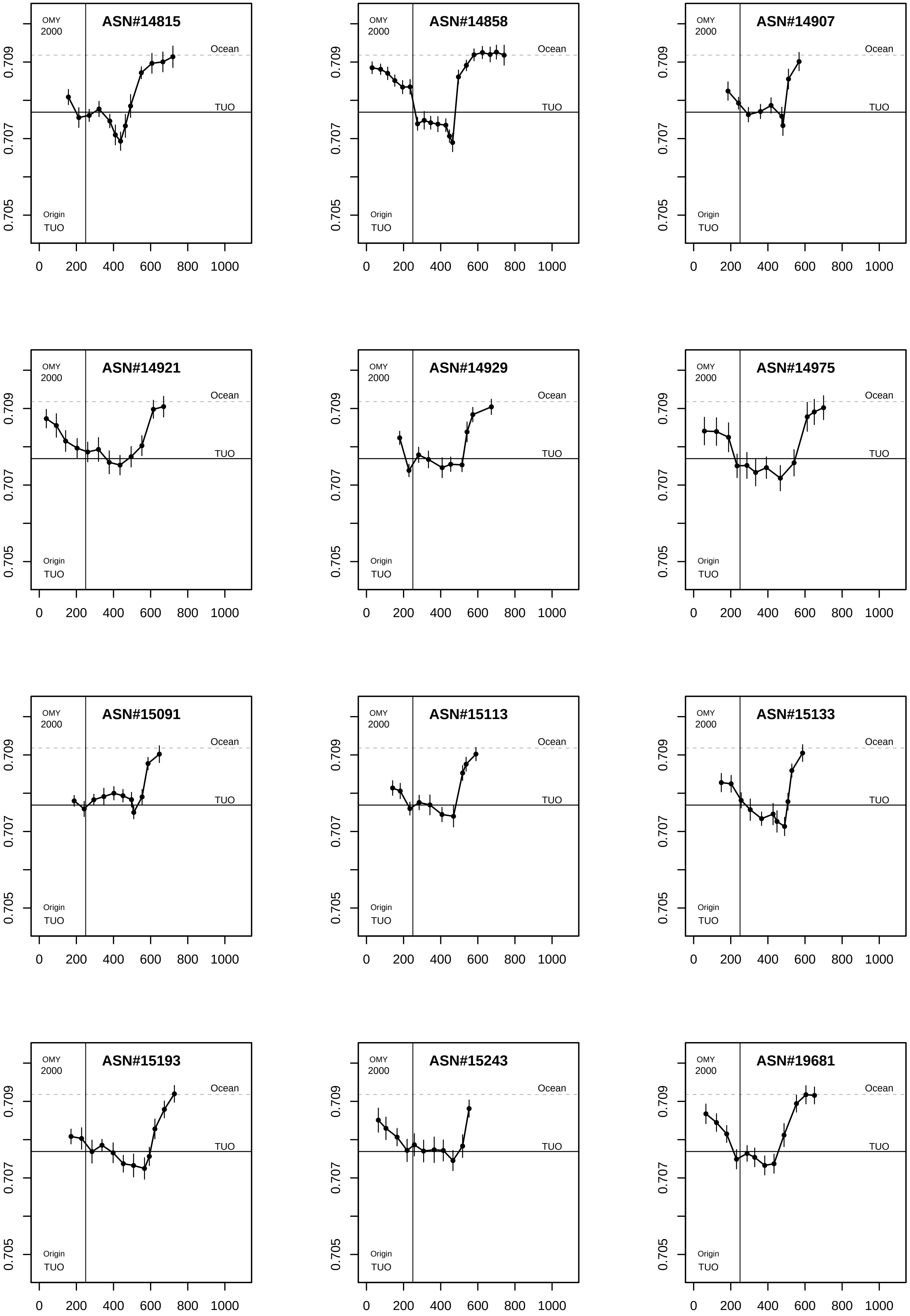

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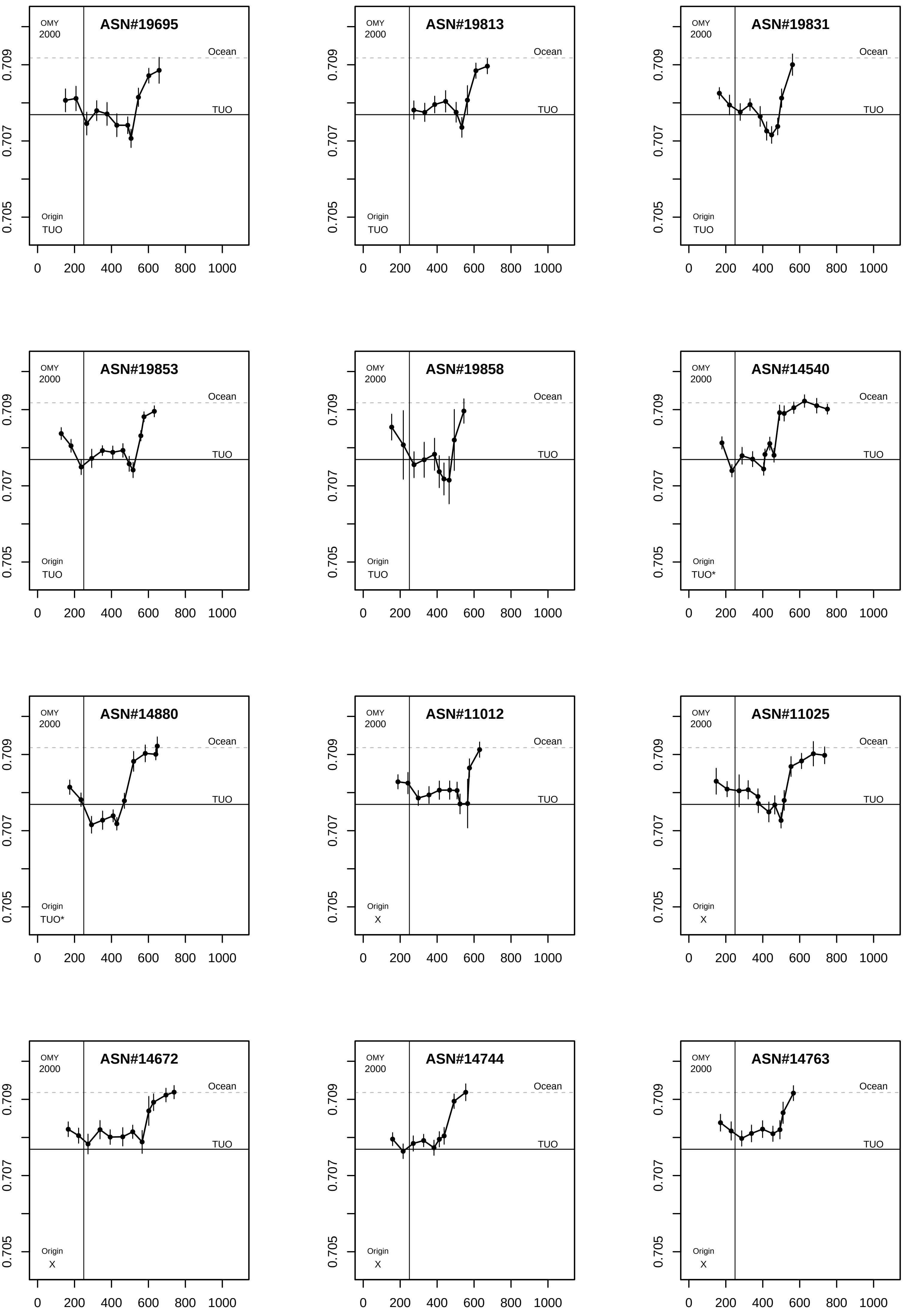

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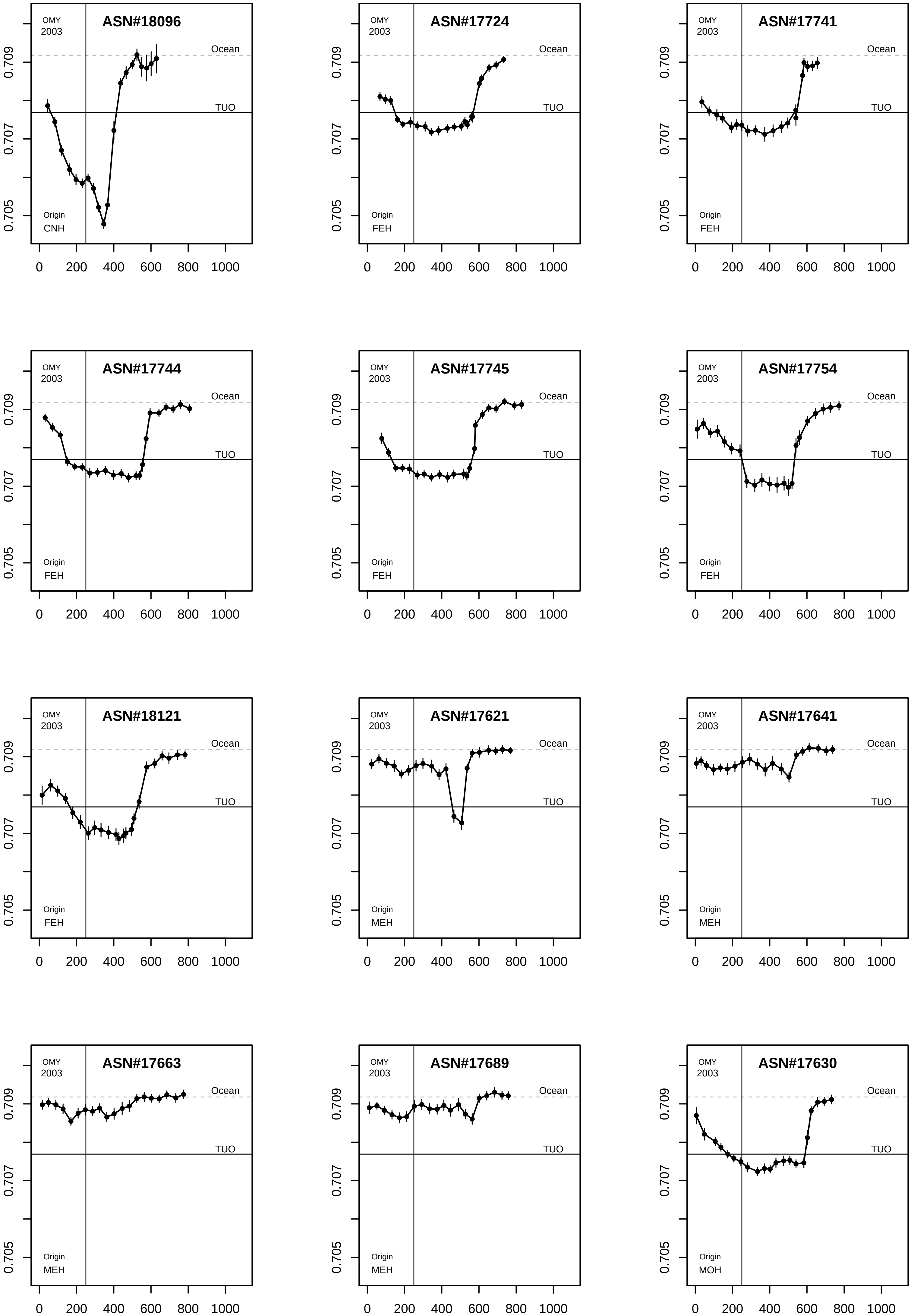
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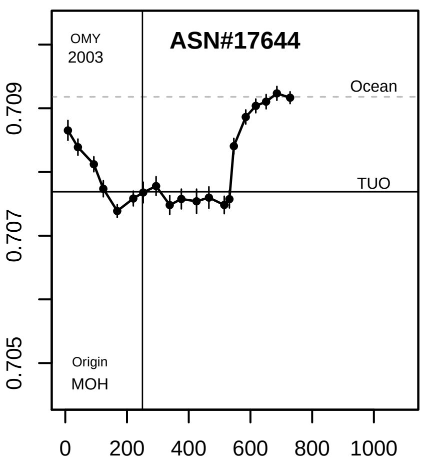
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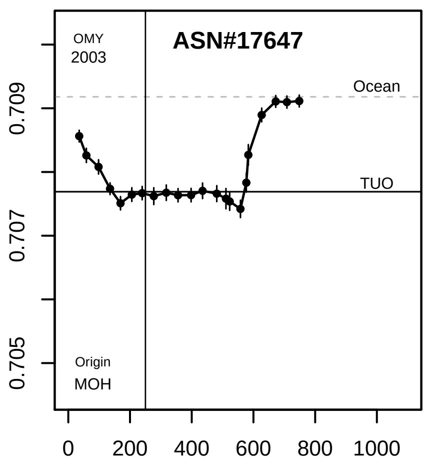
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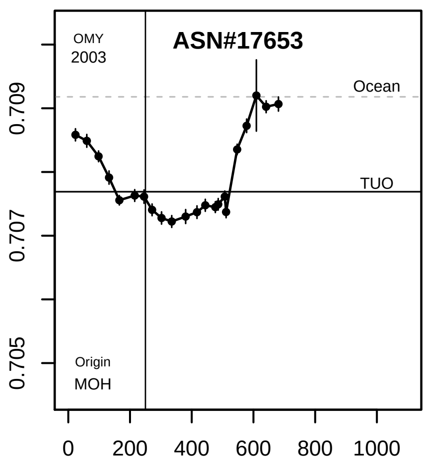
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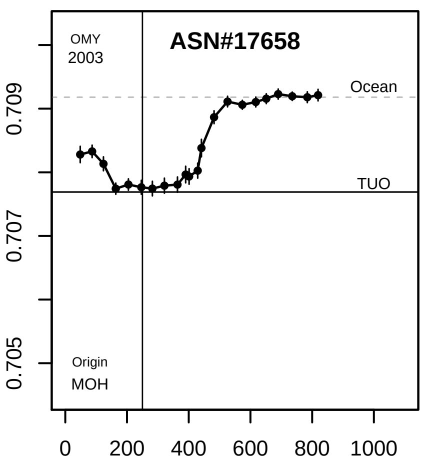
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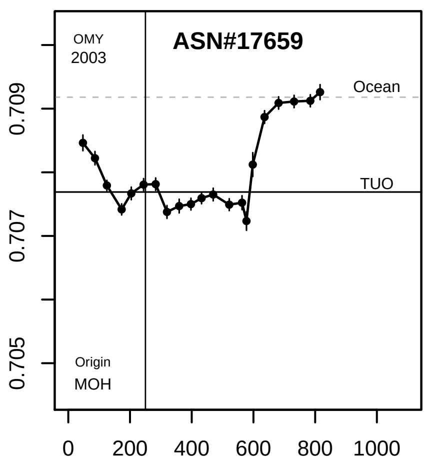
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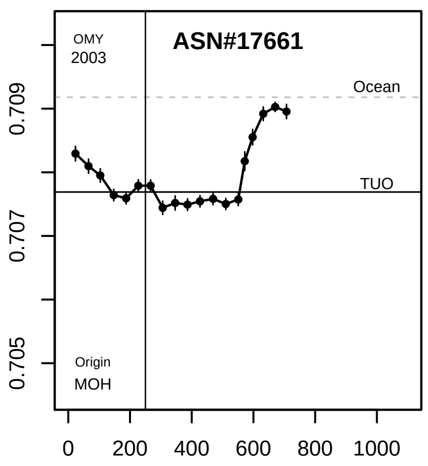
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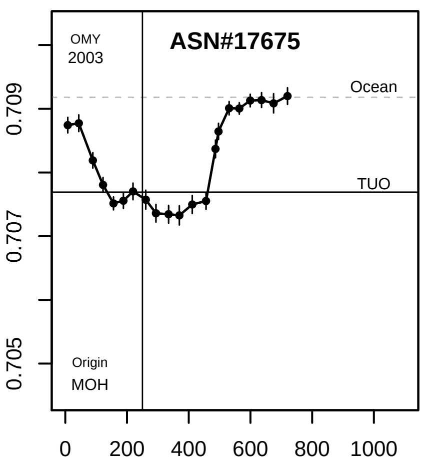
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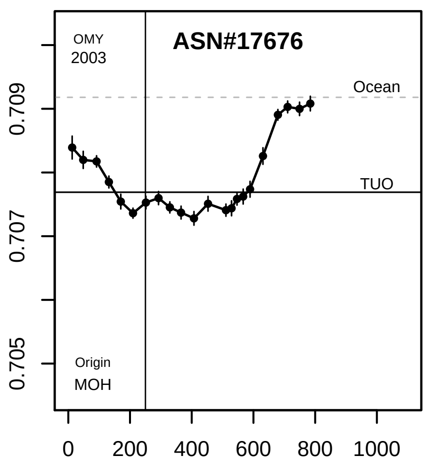
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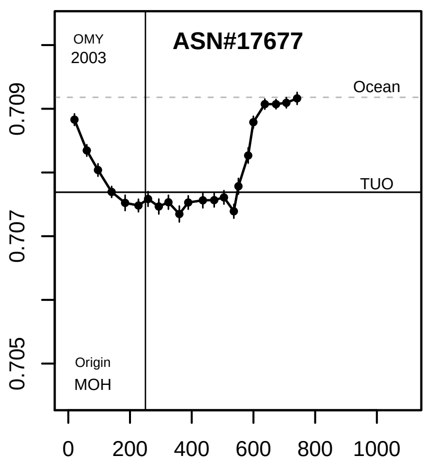
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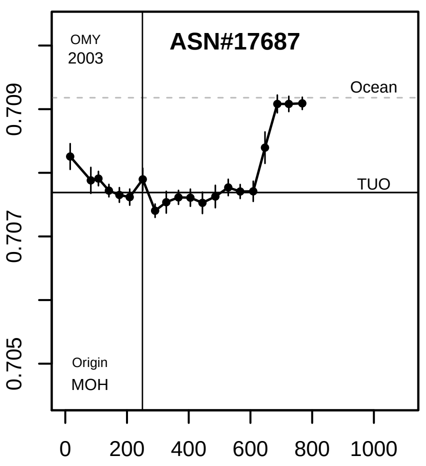
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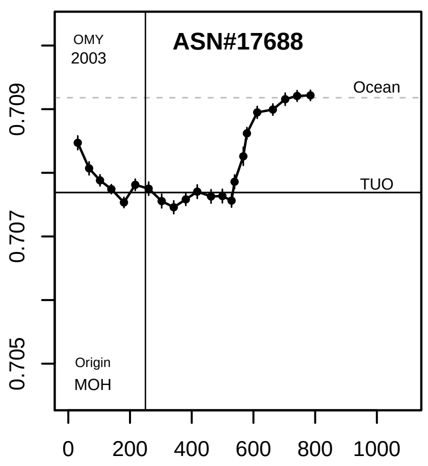
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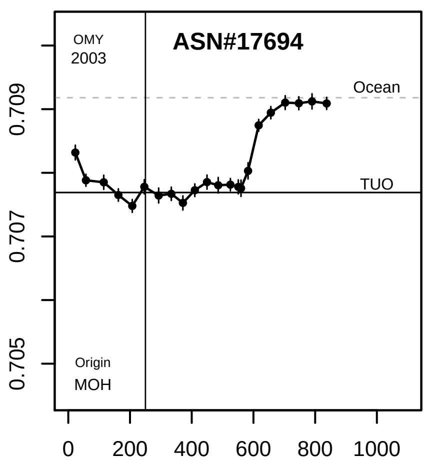
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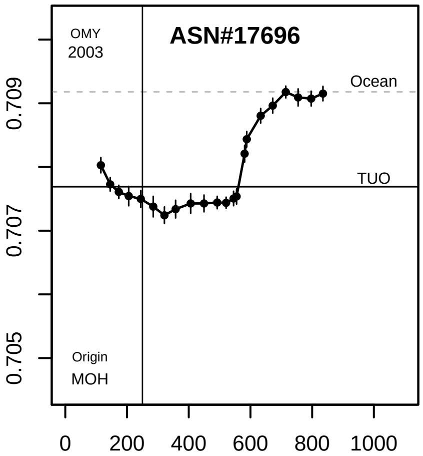
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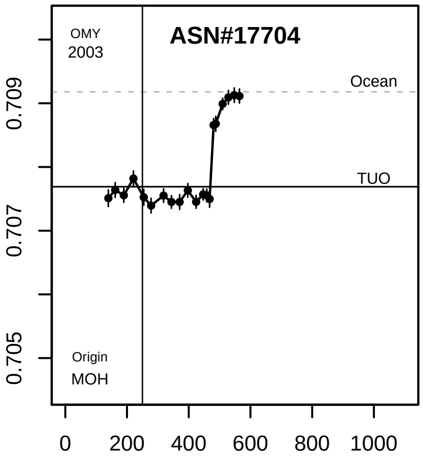
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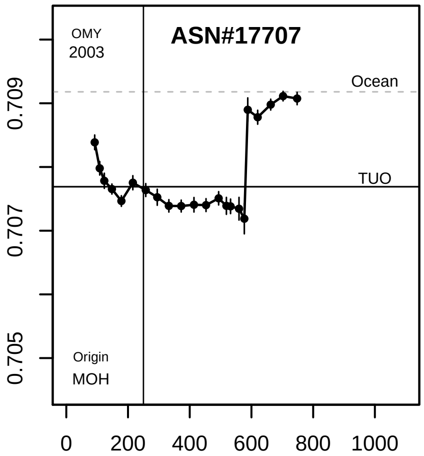
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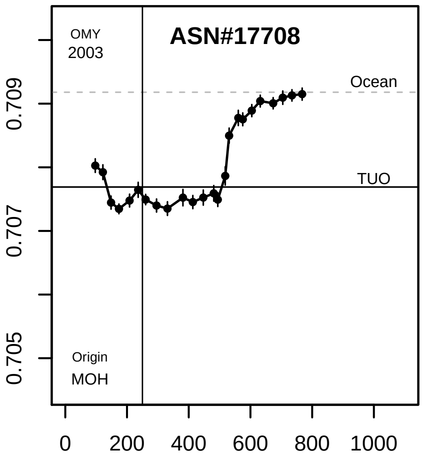
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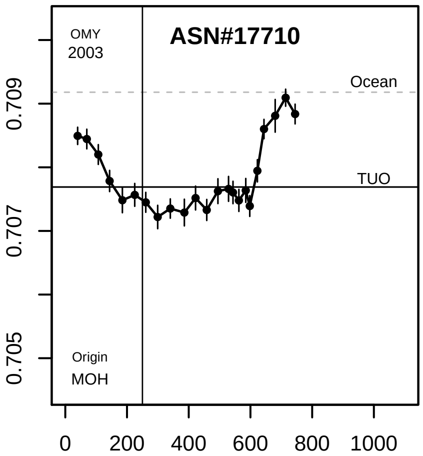
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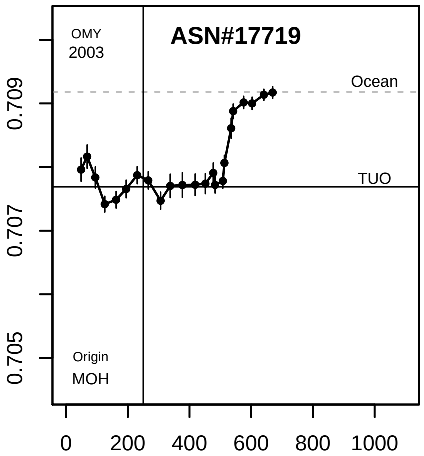
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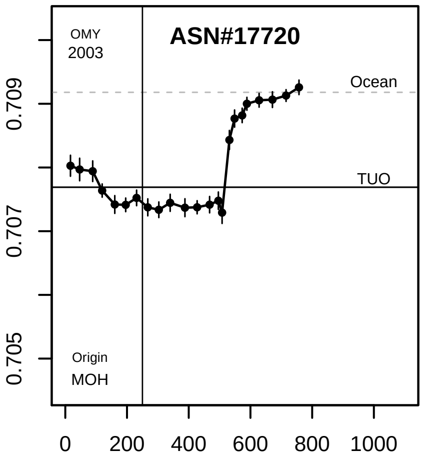
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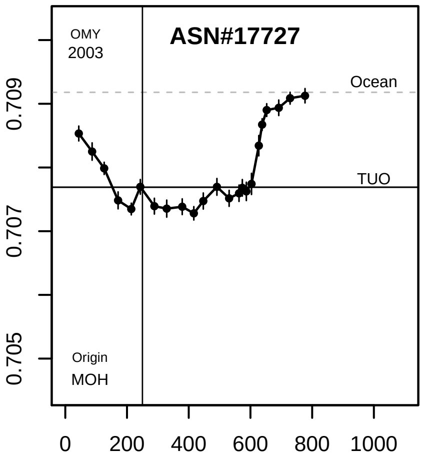
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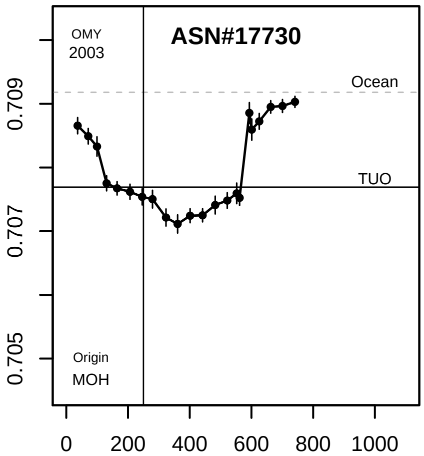
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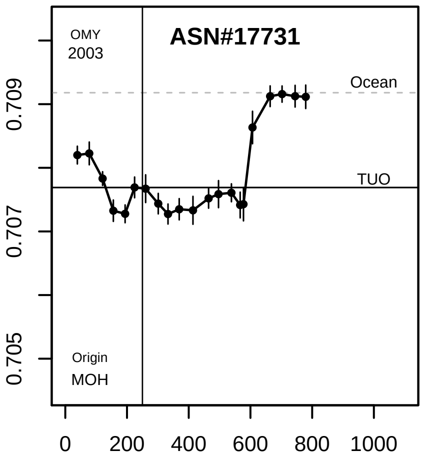
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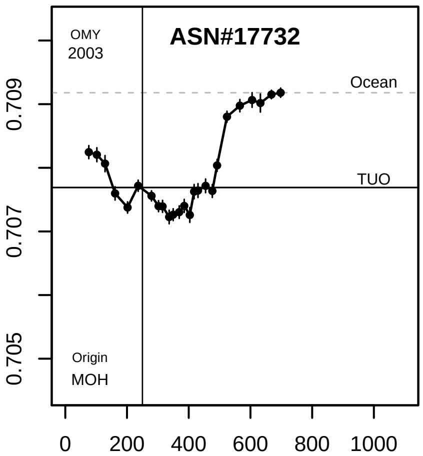
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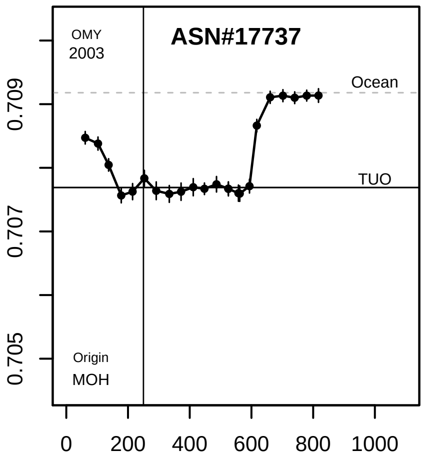
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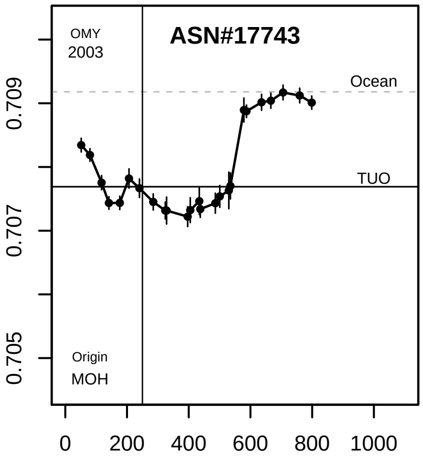
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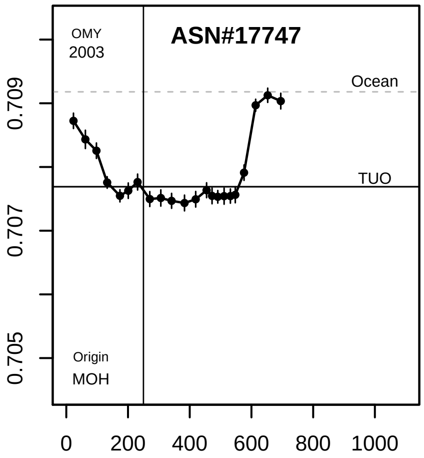
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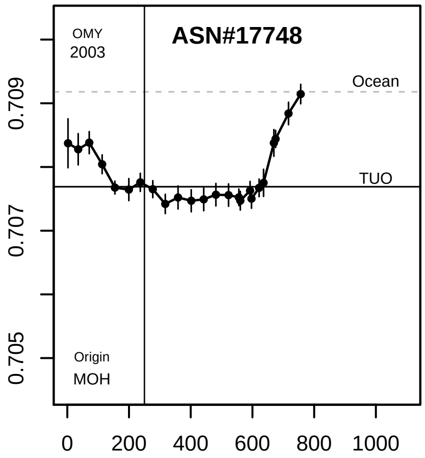
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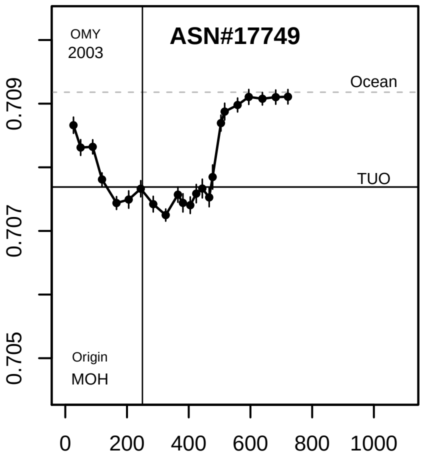
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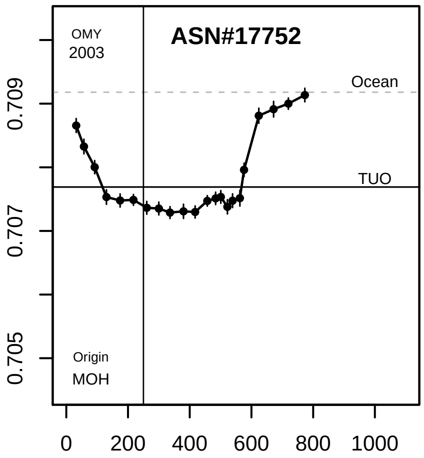
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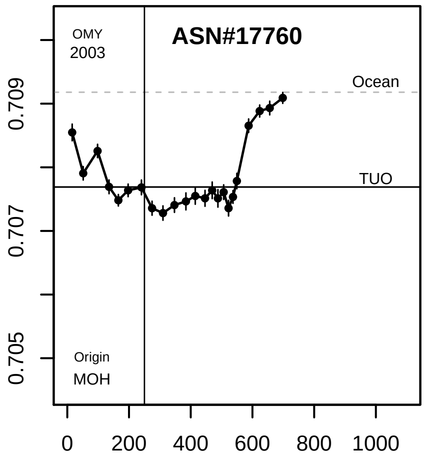
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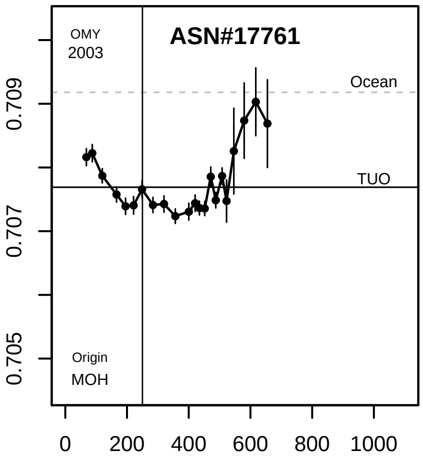
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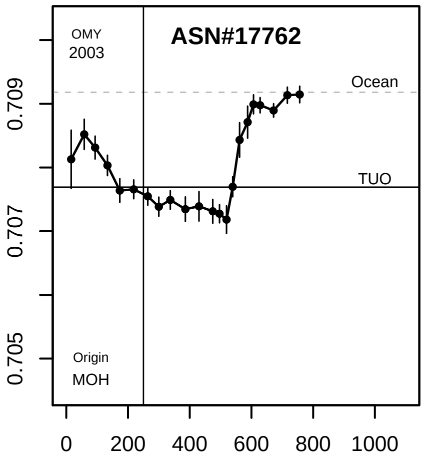
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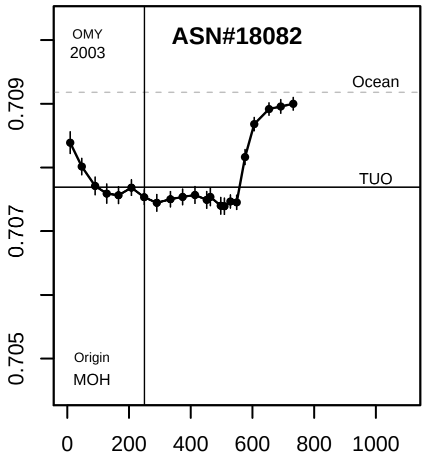
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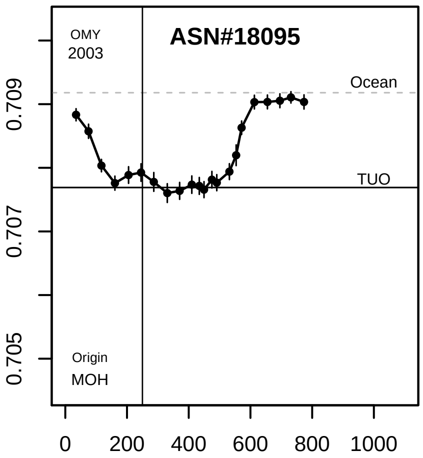
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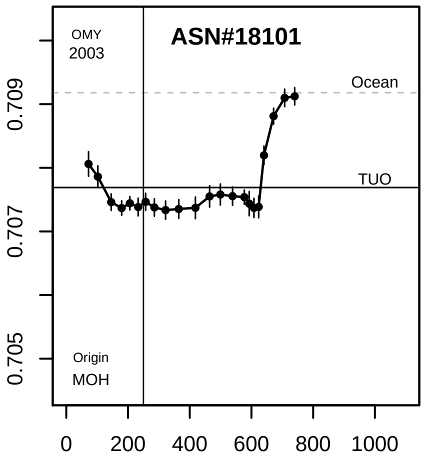
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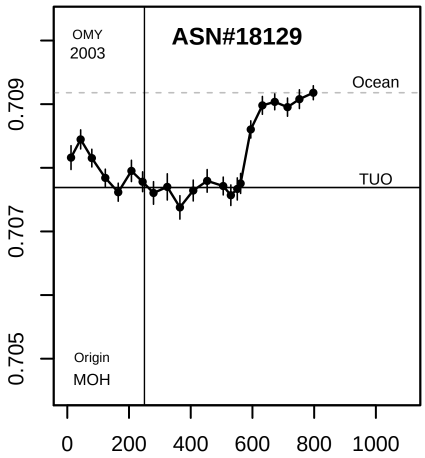
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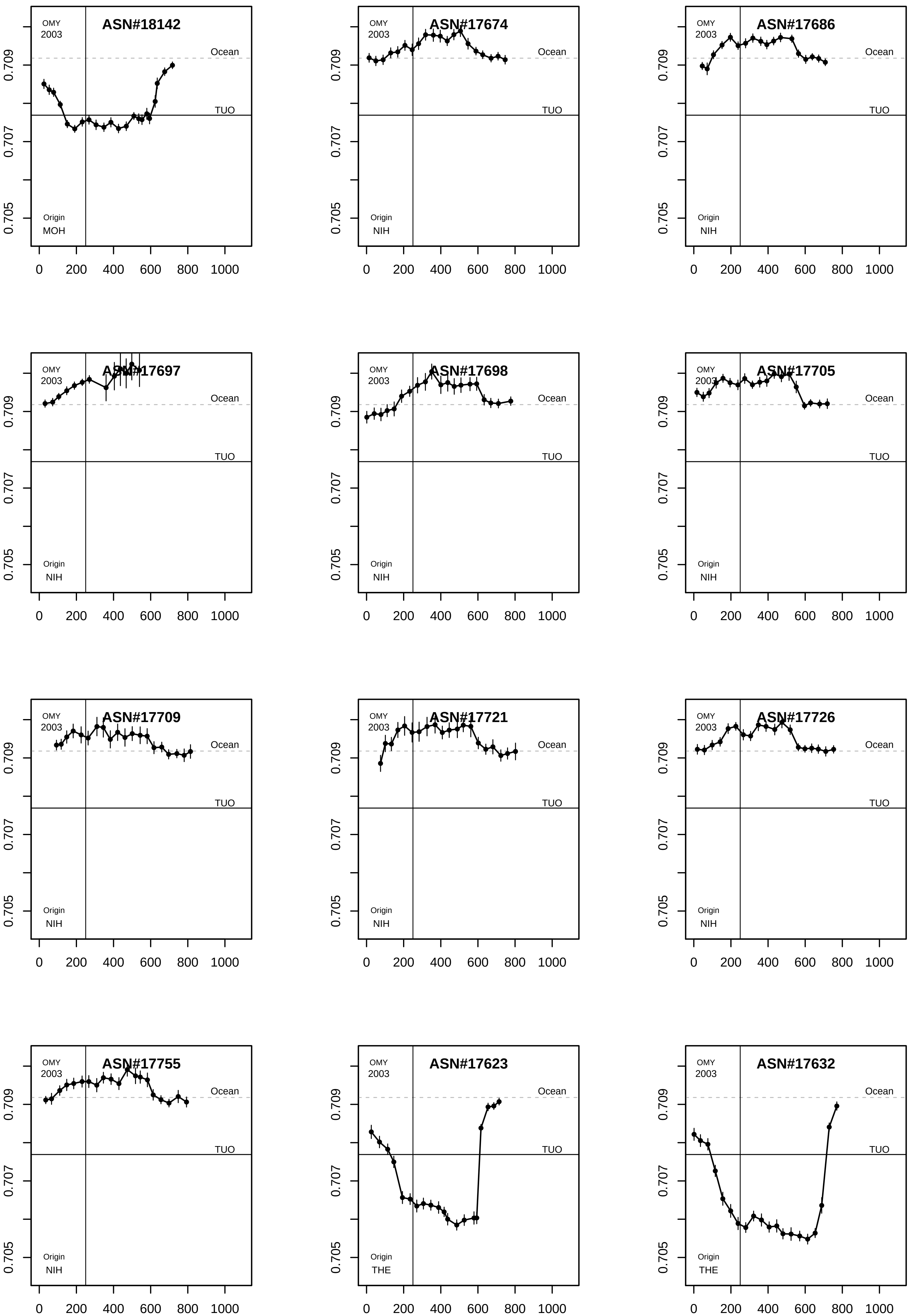

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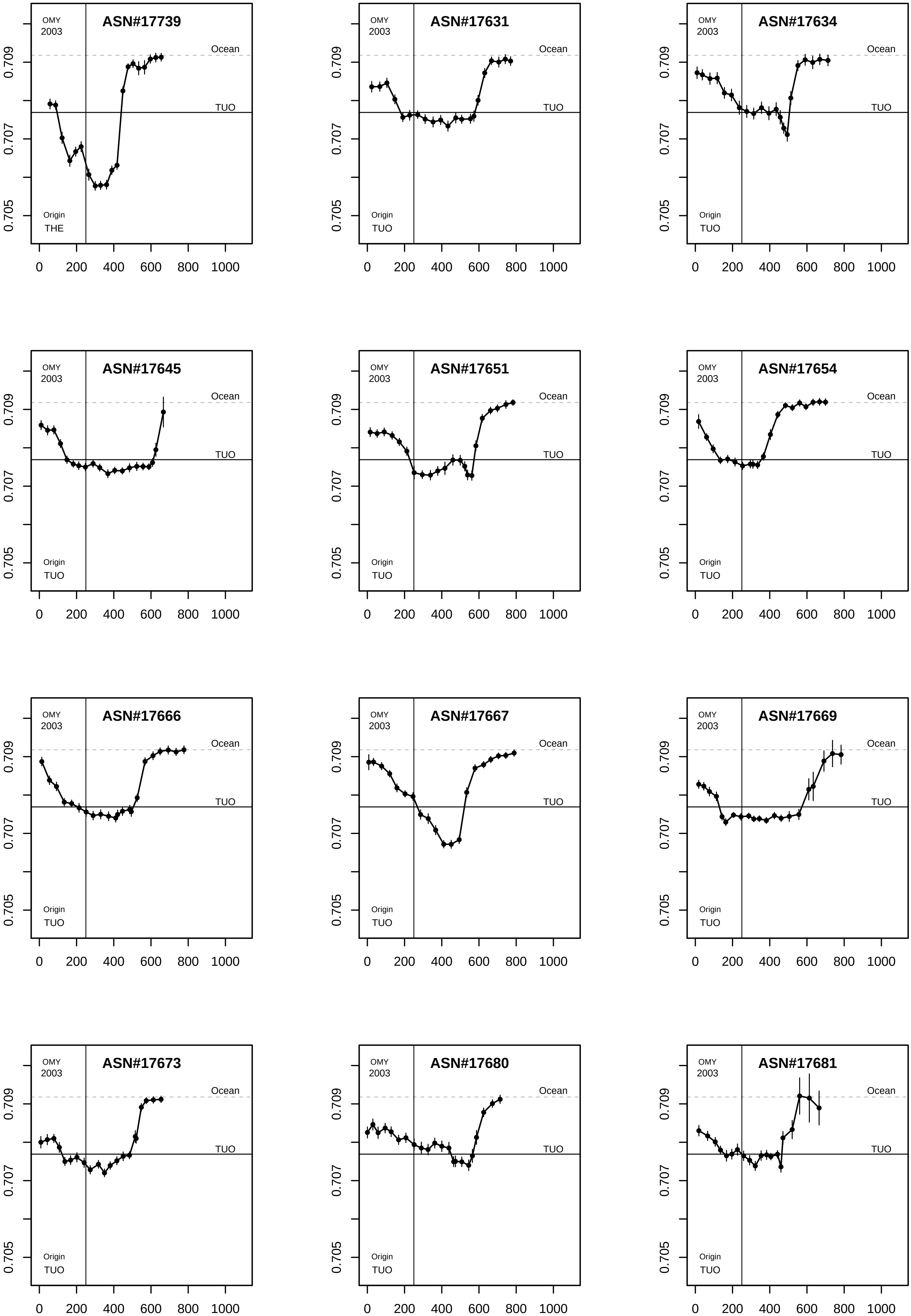

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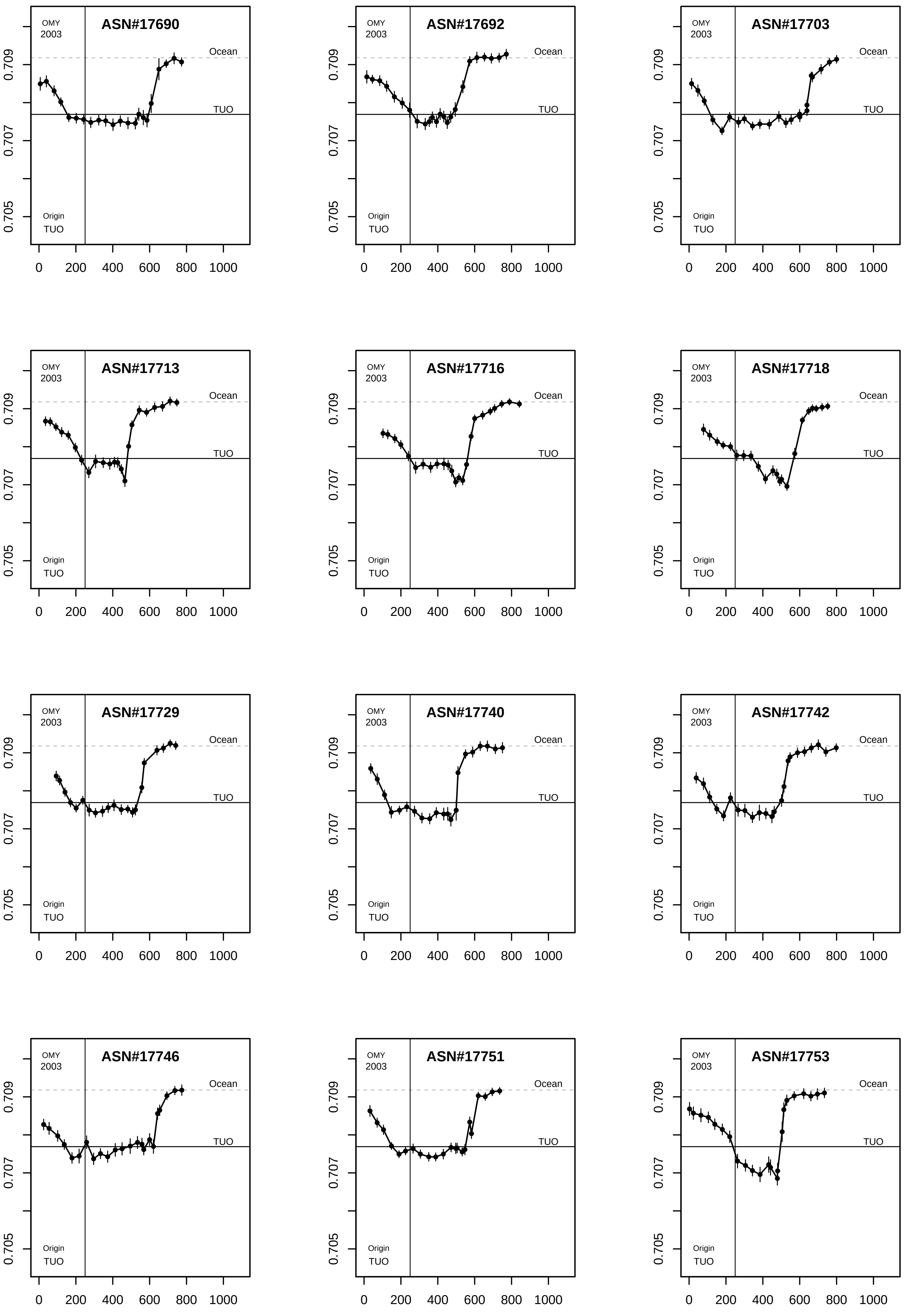

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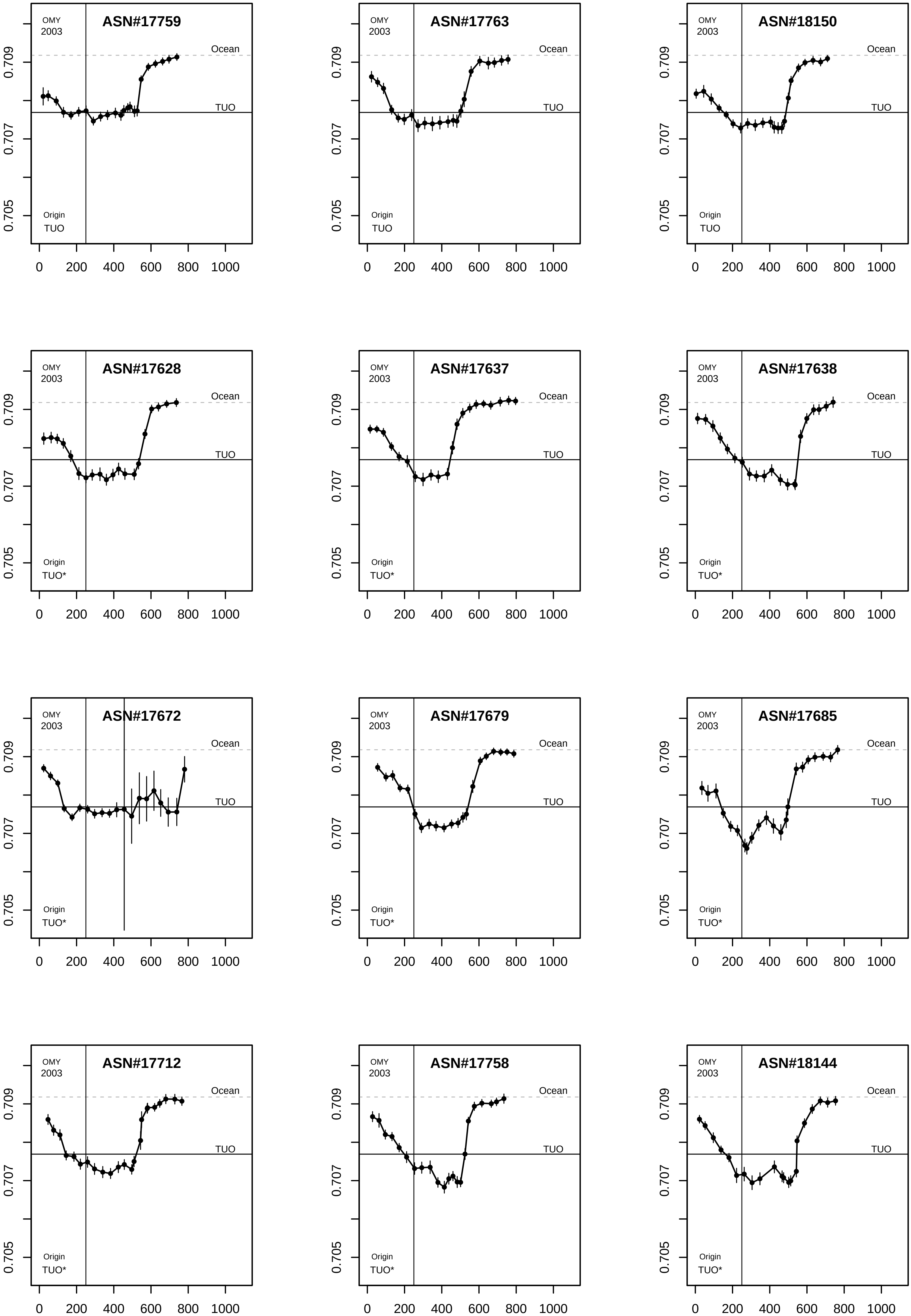

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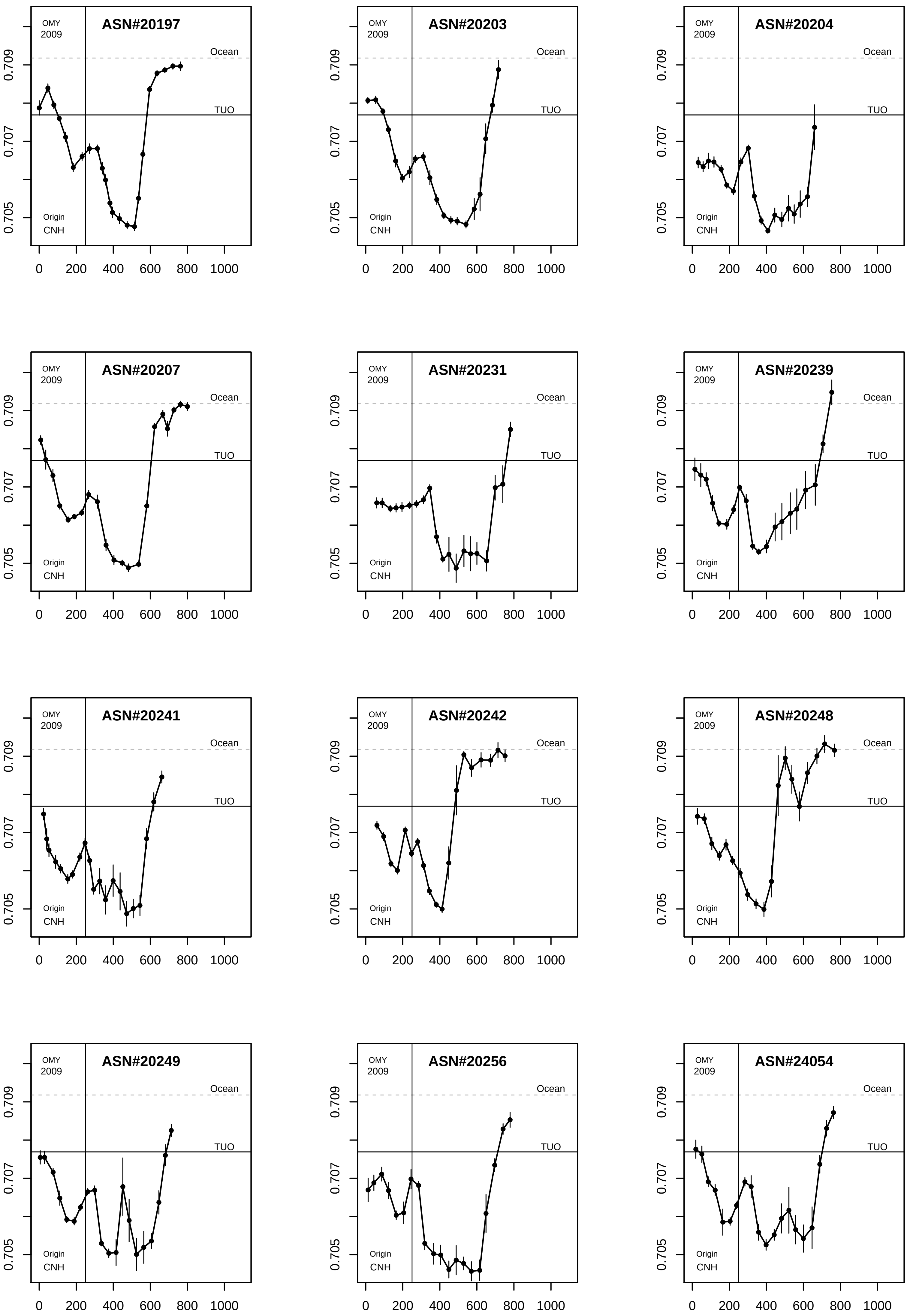
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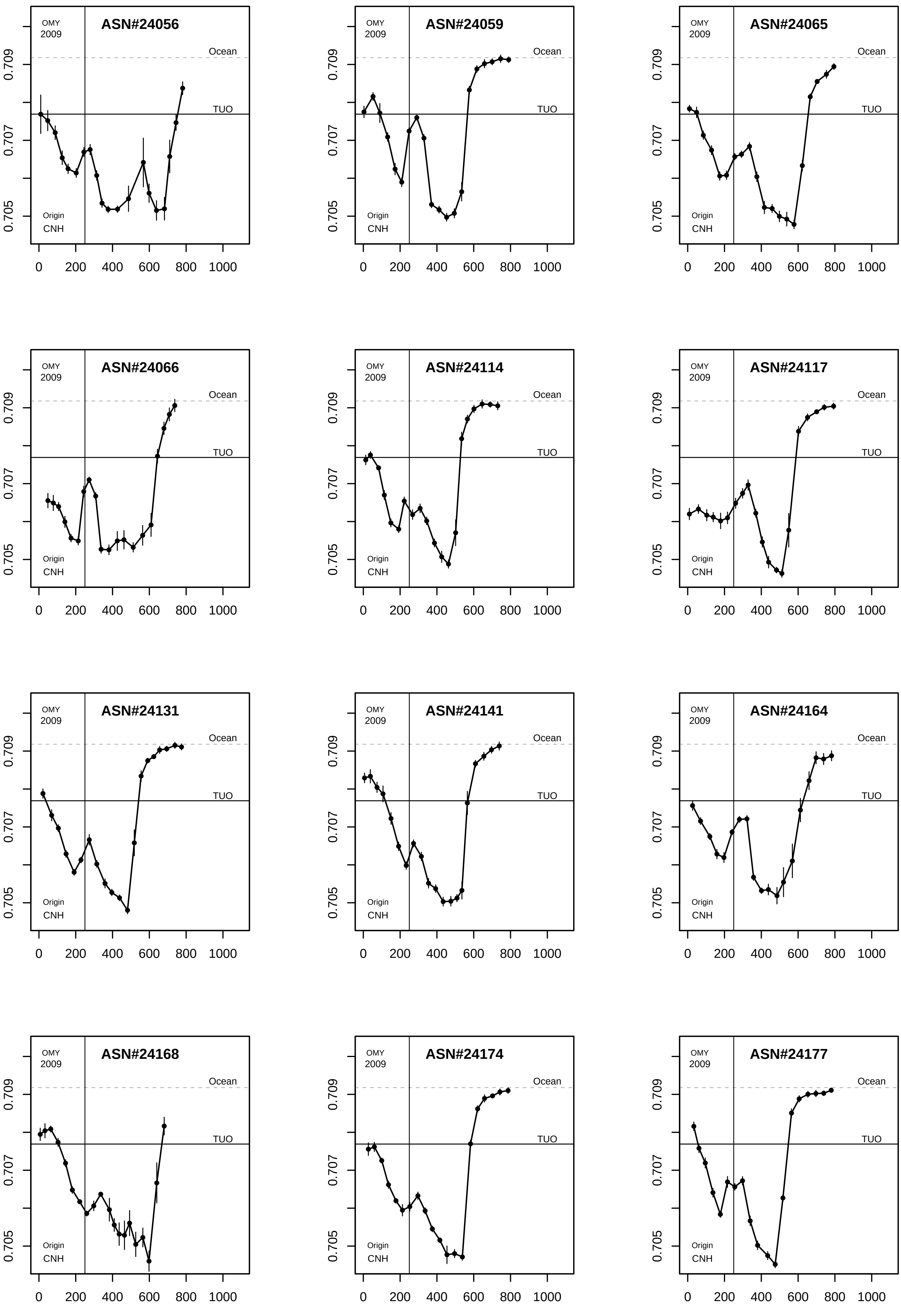
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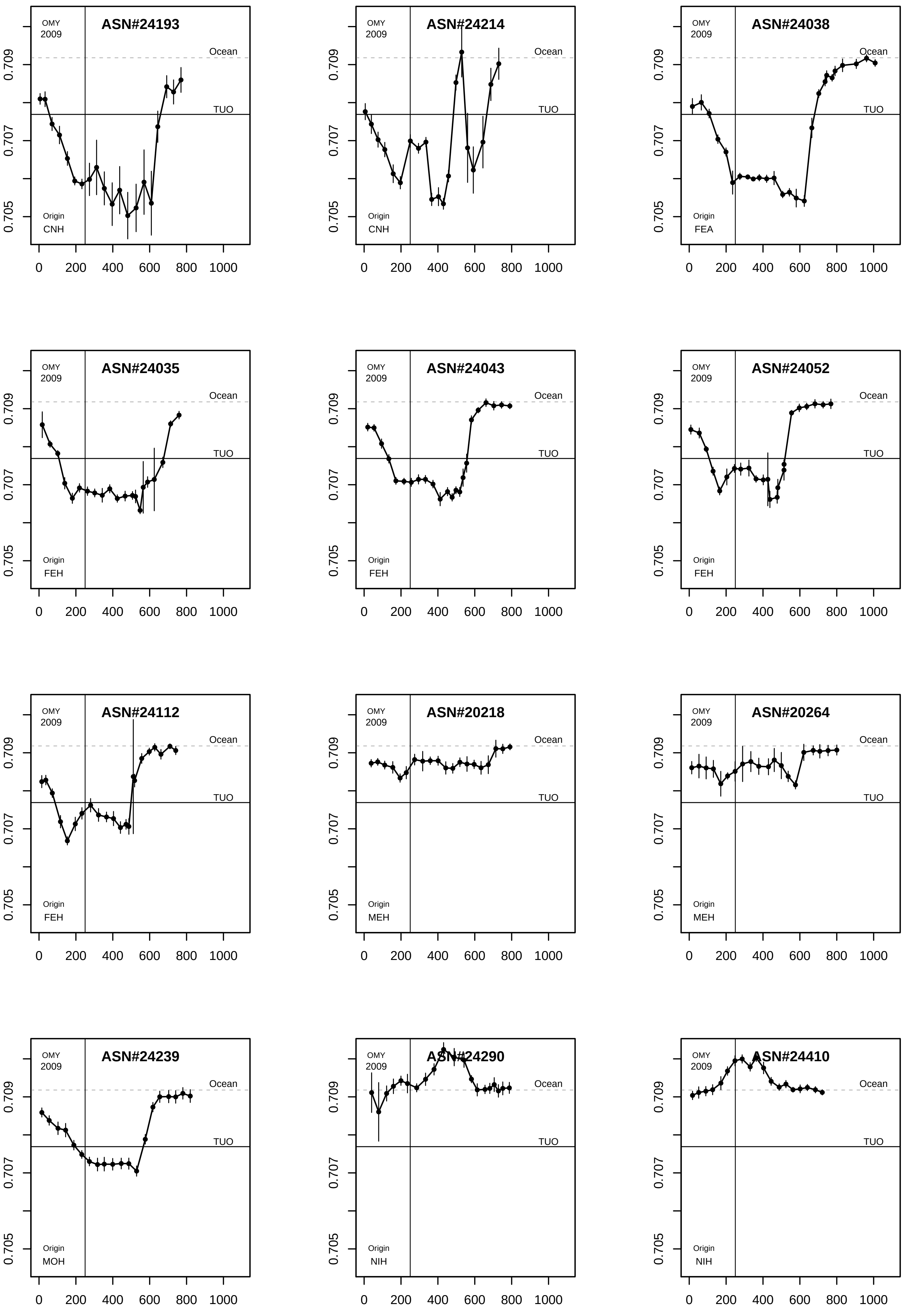

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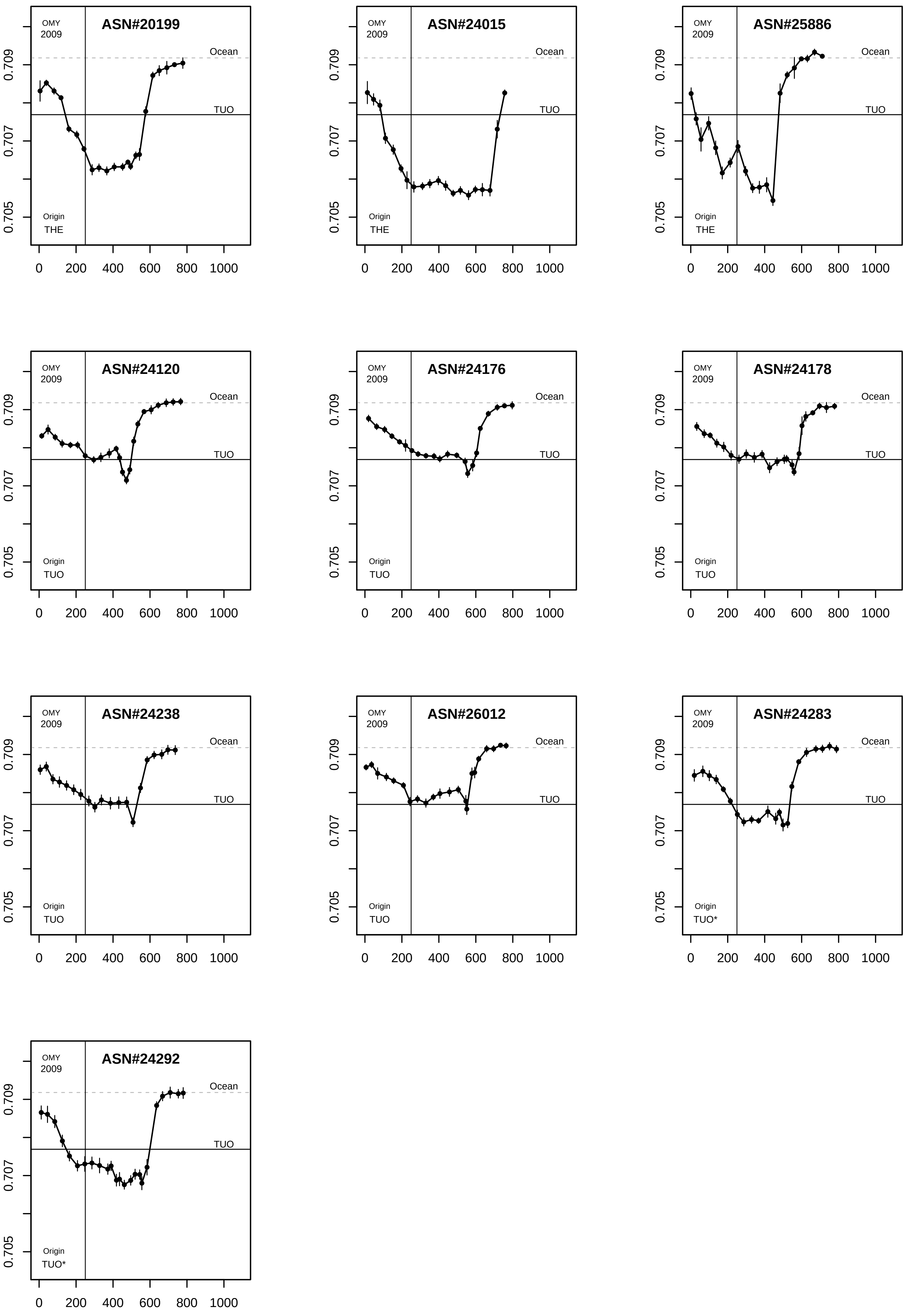
800
1000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Study Report W&AR-11
Chinook Salmon Otolith Study

Appendix B

Response to Draft Study Report Comments by
U.S. Fish and Wildlife Service

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RESPONSES TO DRAFT STUDY REPORT COMMENTS BY U.S. FISH AND WILDLIFE SERVICE

As part of the ongoing studies under the Integrated Licensing Process (ILP) for the Don Pedro Hydroelectric Project (Project), the Turlock Irrigation District and the Modesto Irrigation District, co-licensees of the Project (collectively, the Districts) conducted a study to identify the geographic origin and early life history rearing and emigration patterns of Tuolumne River fall-run Chinook salmon during above- and below-normal water year (WY) types. The draft report for W&AR-11 was provided to relicensing participants on March 16, 2015, for 30-day review. Comments on the draft report were provided on April 23, 2015 by the U.S. Fish and Wildlife Service (USFWS). This appendix repeats the USFWS comments and provides the Districts' response to each.

Page 4-5, Figure 4.2-2: How did the study address the overlap of the Tuolumne River with the Yuba River?

Although there is some geographic overlap of Sr isotope signature in various locations along the west slope of the Sierra Nevada, we are confident in the Tuolumne and Yuba River natal assignments made for this study. As stated in Appendix A, *Identification of Natal Origin*, the natal signature was determined by averaging the 87Sr/86Sr values that correspond with the otolith material deposited immediately after onset of exogenous feeding (but prior to emigration from the natal river). Linear discriminant function analysis (DFA) assignments for mean natal value were used to determine the river or hatchery of origin, with a mean 87Sr/86Sr value of 0.70823assigned to the Yuba River based upon 19 juvenile otolith samples collected in 2002, and mean 87Sr/86Sr values ranging from 0.70757 to 0.70783 assigned to the Tuolumne River based upon 54 juvenile otolith samples collected 1999–2011, as well as seven water samples collected in 1998 and 2013 (Table 3, Appendix A). However, fish that were assigned to the Yuba River by the DFA consistently had a low (<0.5) posterior probability of assignment to the Tuolumne River. As shown in Table 4 (Appendix A), the DFA assignments misclassified one of the 19 known Yuba River juvenile samples as originating from the Tuolumne River (5% error) and 5 of 61 known Tuolumne River juvenile samples as originating from the Yuba River (8% error). Since it is unlikely that a large number of wild Yuba River fish stray into the San Joaquin basin tributaries, individuals assigned to the Yuba River by the DFA were instead identified as of likely Tuolumne-origin (or "TUO*" in Appendix A) and excluded from further analysis because of the uncertainty.

Page 4-7: The report should perform a multivariate analysis to examine effects of flow regime, temperature and spawner density, similar to the analysis done by Zeug et al. (2014). In particular, the acre-days of floodplain inundation below (values based on U.S. Fish and Wildlife Service 2008) should be examined as a potential independent variable.

The comment invites an analysis of juvenile abundance in relation to potential explanatory factors analyzed by Zeug et al (2014) (i.e., spawner density, flow, temperature) as well as the influence of the duration of floodplain inundation during rearing. While the present study was not designed to examine interannual variations in juvenile production or subsequent escapement, the fact that no consistent differences in estimated growth rates were found for the outmigration years sampled (see also response to comment on Page 5-11) indicates that such a factorial data exploration would not be expected to provide additional insights into factors affecting juvenile growth trajectories or early ocean survival.

Page 5-11: Are there any density-dependent effects that might partially explain the observed year to year variation on growth rates? The statistical significant difference in growth rates given in Figure 9 of Appendix A should be given here. There is a limited ability to draw conclusions based on the small sample size (26 fish in 2003 and 5 fish in 2009).

As stated in several locations in the report, the evaluation of patterns in size and age at exit and growth rates for the below normal WY types represented in this study should consider the relatively small sample size (n=31 from outmigration years 2003 and 2009) vs. above normal/wet WY types (n=238 from outmigration years 1998–2000). However, the comment also appears to suggest that density-dependent competition for food resources within riverine, floodplain, and estuarine environments may be reflected in inter-annual variations in growth rates of juvenile fall-run Chinook salmon originating from the Tuolumne River. Although the present study was not designed to compare rearing densities by year or location, we undertook an additional analysis of individual growth trajectories accounting for ontogeny (i.e., variation in growth rates with size/age of fish) in order to further explore whether the mean increment widths (mean ±1SD) reported in Table 5.2-1 (and shown in Figure 9 of Appendix A) indicate variation in growth rate by WY and/or rearing location. Results indicate that no consistent differences in juvenile growth rates were observed by location, outmigration year or WY type in this study (see new Figures 5.2-2 and 5.2-3 in the report).

Page 6-1: "While these patterns are suggestive of a positive relationship between flow and the successful emigration of wild fish that later return as adults, confirmation of this relationship based on (Water Year) WY type should consider the relatively small sample size for below normal/dry WY types (n=31) vs. above normal/wet WY types (n=238)." While it *is* true that care must be taken when making inferences from small sample sizes, *it* is also true that the small sample sizes are the result of poor conditions. That is, that the sample size would likely have been larger had conditions during WY s 2003 and 2009 been adequate to ensure sufficient juvenile survival. Lateral, off-channel habitats (e.g. floodplain and side-channel habitats) are more likely to inundate during wetter year types, and have been shown to increase growth and survival in rearing juvenile Chinook salmon (Jeffres et al. 2008; Sommer et al. 2001; Junk et al 1989).

The Districts are well aware of the existing literature comparing fish sizes reared in floodplain and riverine environments by Sommer et al (2001) as well as studies showing increased growth in warmer side channel habitats (e.g., Jeffres et al. 2008, Limm and Marchetti 2009). While the commenter appears to suggest that inter-annual growth variations may be evident on the Tuolumne River, there is no support for this assertion in the current study because no consistent growth rate patterns were observed between WY type or rearing location (Tuolumne River vs Delta) in the present study (see also response to comment on Page 5-11).

Periods of high and low escapement of Chinook salmon originating from the Central Valley tributaries have been associated with climate driven changes in ocean conditions (MacFarlane et al 2005; Lindley et al 2009) and have been correlated with runoff patterns resulting in flood control releases and extended San Joaquin River basin outflows during spring (Speed 1993; TID/MID 1997, Report 96-5). For this reason, the low sample sizes of fish originating from below normal WY types may be attributable to a combination of factors potentially ranging from high predation rates in the Tuolumne River and Delta, to potentially poor growth conditions in riverine and estuarine habitats leading to reduced size at ocean entry, or to poor growth conditions in the Pacific Ocean. The present study was not designed to examine interannual variations in juvenile production or subsequent escapement, only the contributions of various size classes at emigration to subsequent spawner returns.

Page 6-2 states: "Based on Sr isotope ratios (87Sr/86Sr) and otolith microstructural features, the study results suggest that mean fish size at exit from the Tuolumne River showed no apparent relationship with WY type, with the exception of outmigration year 2000 when mean fish size was significantly different ($p<0.005$) from the other four years of the study. Mean fish size at freshwater exit from the Delta also did not exhibit a relationship with WY type." Is it reasonable to draw conclusions on whether or not there exists a relationship between WY type and mean fish size, given the small sample size representing below normal WY type? The sample size for dry WY types was significantly lower (2003 and 2.009 sample size = 31 fish; 15.5 fish on average per year) than wet year types (1998, 1999, & 2000 sample size = 238 fish; 79.3 fish on average per year).

As indicated in literature referenced in other comments, because studies of floodplain habitat rearing have indicated differences in fish sizes for fish reared within in-channel vs. floodplain and off channel habitats (e.g., Sommer et al 2001, Jeffres et al 2008) there is some basis to compare the results of the present study by WY type. That is, if floodplain habitats consistently provided growth benefits for rearing salmon, the high flows occurring during the above normal/wet WY types (i.e., 1998–2000) would be expected to provide evidence of enhanced growth conditions in comparison to the below normal/dry WY types represented (i.e., 2003, 2009).

Although the present study was not designed to examine interannual variations in juvenile production or subsequent escapement (see also response to comment on Page 5-11), additional analysis to standardize estimated growth rates to fish size (age), and thereby correctly account for ontogeny, indicates a high degree of growth rate variability within and between WYs and across otolith size (age) (see new Figure 5.2-3 in the report). While WY 2003 (dry) exhibits the highest estimated growth rates, variability during this year was also relatively high, and within the uncertainty of the data, it is not possible to state whether specific growth rates were in fact greater in WY 2003 than other years included in the study. The final report text has been modified accordingly.

Page 6-3: Under this discussion (Section 6.2) on growth and residence, the Districts should consider adding language discussing the potential that density-dependent factors may play a significant role in the variation in growth rate observed across years for Tuolumne River. For 2003 & 2009, a relationship could potentially exist between the low sample sizes and

the higher growth rates estimated for these years (if the low sample size is indeed indicative of low numbers of rearing fish) (see Table 5.2-1). Assuming a relationship between adult escapement numbers and juvenile rearing fish numbers: CDFW escapement values for 2003 and 2009 were 2,693 and 124 respectively; and escapement for 1998, 1999, and 2000 were 8,910, 8,232, and 17,873 respectively (representing the 3 highest escapement years over the past 28 years) (Azat 2014). This implies that significantly fewer numbers of rearing fish were present in 2003 and 2009 as compared to 1998-2000. Fewer rearing fish potentially means less competition and more resources (food & suitable rearing habitat) available, which could help to explain the higher growth rates.

While the commenter appears to suggest that inter-annual growth variations may be evident on the Tuolumne River, no consistent growth rate patterns were observed between WY type or rearing location (Tuolumne River vs Delta) in the present study (see also response to comments on Page 5-11). As stated in response to comment on page 6-1, the present study was not designed to examine interannual variations in juvenile production or subsequent escapement, only the contributions of various size classes at emigration to subsequent spawner returns.

Appendix A, Page 7, last paragraph: the text should say Fig. 9, Table 7, instead of Fig. 7, Table 9. There is no Table 9 in Appendix A.

Appendix A text has been corrected.

REFERENCES CITED IN THE RESPONSE TO COMMENTS

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