Response to Gilbert Cosio's comments on the article "Evolution of arability and land use in the Sacramento-San Joaquin Delta"

There are two primary areas of disagreement identified in Mr. Cosio's September 4, 2015 letter to Sam Luoma which are herein addressed sequentially: 1) land use and the causes and processes affecting arability and 2) reasons for changing land use. As stated in the article, our overall objective was to define processes and factors affecting future and historic reduced arability in Delta organic soils from the 1980s to 2012. We thus analyzed and assessed effects of interacting processes and factors that affect observed land-use and arability changes during this time period. Mr. Cosio's comments are greatly appreciated as they prompted us to look more closely at the data and available information and gain more insight.

Land use and the causes and processes affecting arability

Mr. Cosio stated that "Based on our experience and knowledge of the farm ground within the reclamation districts we represent, we have found that most of the current WNMF acreage cited in this paper is not the result of subsidence and seepage. There are a number of reasons each of these properties are not farmed, which are summarized in the following general categories" which include habitat, borrow pits, scour and "other". The other category included "things such as the City of Isleton sewer ponds; the Grand Island Corps of Engineers dredge disposal area; Prospect Island, which the landowners have never fully reclaimed since it flooded in 1995; and historic lakebeds that have never been farmed".

Mr. Cosio delineated a total of 37 locations from Figure 5 in the article representing 2012 which amounts to 1,354 ha or 3,344 acres. This is 48 % of the total area (2,800 ha or 6,914 acres mapped as wet, non- and marginally-farmable (WNMF) in 2012. The majority of the areas were delineated by Mr. Cosio as "habitat"; the total habitat area was 780 ha (1,929 acres) or 28% of the total area mapped as WNMF. Borrow areas encompassed 57.4 ha (142 acres), scour areas encompassed 272 ha (672 acres) and "other" areas encompassed 212 ha (524 acres) were also delineated.

Two of the categories, scour and "other' include almost entirely areas that were not farmed in the 1980s. In the "other" category, all areas were not farmed in 1980s. Since the article focuses on the historic increase of WNMF areas since the 1980s, these areas are not directly relevant to the article's conclusions. The photo series for areas in the habitat and borrow categories indicate that these areas evolved in locations that were becoming wet, difficult to farm or fallow in the 1980s and 1990s. Conversations with land managers indicate agreement.

During our investigation for the article, we examined the available aerial photo time series and assessed changes since the 1980s. The maps of the time series are shown in figures 1 through 5 in the article. We also provided example time series photos in the supplementary materials. In an appendix attached to this letter, we provide relevant aerial photos for the habitat areas delineated by Mr. Cosio.

Due to documented associations with organic soil thickness and land-surface elevation, we identified subsidence and consequent increasing seepage as key cause of land-use changes since the 1970s and

1980s. Deverel and Leighton (2010) reported measured land surface elevation changes on Bacon and Sherman islands ranging from about 0.5 to over 3 cm per year (see Figure 5 in their article) from the 1970s to 2006 for soil organic matter contents ranging from less than 10% to over 60%. These and other data presented in Deverel et al. (2016) demonstrate that subsidence occurs where there are soils within this range of percent organic matter. Deverel et al (2016) recently delineated the area where present-day subsidence likely occurs in the Delta. Subsidence has resulted in decreased in organic soil thickness. Thinner peats and consequent increased hydraulic gradients result in increasing seepage onto islands. In response to Mr. Cosio's comments, a summary and explanation of the photo time series for each area delineated and what is shows have been included by category (borrow, scour, habitat and "other").

Borrow Areas

Mr. Cosio stated that "borrow pits have been developed on many islands to supply the needs of levee rehabilitation projects. Most of the time material is excavated below the water table, and the property develops into a lake surrounded by riparian habitat." Our interaction with farm management personnel for the majority of areas delineated by Mr. Cosio revealed that the inability to farm effectively is a key management factor influencing the decision where to borrow material. Specifically, borrow sites are generally located in areas where organic soils are thin or have disappeared. Two adjacent soil types (organic and mineral) become less farmable for the typical irrigation regime (e.g., spud ditch or furrow irrigation). Organic soils hold moisture well whereas sandy soils drain quickly. Therefore, the resulting areas do not farm as well without modifying irrigation practices.

Consistently, in our article we identified diminishing organic-soil thickness as a key factor associated with diminished arability and changing agricultural land use (p. 27). We related this primarily to increased seepage issues but the contrasting soil-type effect also appears to affect ability to farm and has led to the formation of borrow pits. Eight of the ten borrow sites identified by Mr. Cosio are in areas of relatively thin organic soils and in the case of Bouldin and Holland, sandy areas are visible. The summary of photo time series (Table 1) demonstrates general consistency with reduced vegetation and wetness in these areas prior to excavation of borrow pits or in the case of Bouldin Island East and possibly Boudlin Island West, borrow pits were already present in the 1980s and thus not counted in our assessment of changes from the 1980s to 2012 (Table 1).

Table 1. Borrow areas delineated by Mr. Cosio

Location	Area in ha (acres)	Photo series description
Bacon Island Northwest	1.3 (3.2)	1987 Color Infrared (CIR) photo shows the area under cultivation with patches of low vegetative density (white areas) and higher moisture as indicated by blue coloring. Light areas in 1993 and 2005 photos suggest persistence of the same pattern. Borrow pit first appears in 2008 in this area with 2010 and 2012 photos showing the pit's progressive expansion.
Bacon Island Southeast	1.1 (2.7)	1993 photo shows the area being farmed, with possible areas of low vegetation. Borrow pit first appears in 2002 and remains constant in size for 2005, 2008, 2010, and 2012 photos.
Bouldin Island East	4.5 (11.1)	1987 CIR photo shows the location of the apparent borrow pit in a field with rows indicating cultivation, but sparse vegetative cover as indicated by the white coloring. Borrow pit is apparent in 1993, 2002, and 2012 photos.
Bouldin Island South	10.5 (25.9)	1987 CIR photo shows most of the area under cultivation with spots of low vegetation density as indicated by white. The northwest field appears fallow or

		recently harvested, with rows evidencing plowing but little to no vegetative cover. Photos from 1993 and beyond show borrow areas in areas where there were lighter colors in 1987 indicating low vegetation density.
Bouldin Island West	4.5 (11.1)	1987 CIR photo shows less cultivated areas in the middle of agricultural fields. The 2008 photo indicates the presence of borrow pits in these areas.
Canal Ranch	6.0 (14.8)	Aerial photo from 1987 shows sparse vegetation with dark streaks indicating high soil moisture. Photos from 1993 and 2002 show the land under cultivation before borrow takes place. Borrow areas occur before 2008.
Holland Tract North	11.0 (27.2)	White areas in 1987 CIR photo indicate sparse vegetation and blue areas indicate areas of high moisture. Magenta coloring indicates surrounding vegetated areas. Ponds (scour areas) in white areas in 1987 photo appear beginning in 1993. Ponds increased in number and size in 2002, 2008, 2009, and 2012 photos.
Holland Tract South	4.8 (11.8)	1987 aerial photo indicates sparse vegetation and wet areas where borrow pit is evident in 1993 and beyond.
McCormack-Williamson Island	9.7 (24.0)	1987 CIR photo shows area without vegetation. Borrow area appears in 2002 photo and remains constant in size through 2012 photo. This is an area of low organic matter soils (Egbert Mucky Clay Loam).
Rindge Tract	4.0 (9.9)	White areas in 1987 CIR photo shows the area under cultivation with streaks of low vegetation density. 1993 photo shows a borrow pit on some of this low vegetation area. Borrow area remains constant in size through 1998, 2002, 2006, and 2012 photos.
Total area	57.4 (142)	

Scour Areas

For all except the 9.7 ha (24-acre) area on McCormack-Williamson Tract, the 262 ha (647 acres) of scour areas were present and part of the total WNMF area in the 1980s. We sought to document and explain the increase WNMF area from the 1980s to 2012 and we included the scour areas in the "baseline" determination the WNMF areas. Since 96% of the scour area was included in the 1980s, the presence of the scour areas in 2012 does not influence our estimate of the historic change in WNMF areas.

Table 2. Summary of photo time series for scour areas delineated by Mr. Cosio.

Island and location	Area in hectares (acres)	Time series summary	Present in 1980s?
Bradford Island	65.5 (162)	1939 photo (pre-scour) suggests the area was not farmed. Scour first appears in 1987 CIR photo. Extent of non-arable area remains consistent with 1993, 2002, and 2008 photos. 2012 indicates increasing footprint (northward) of vegetation indicating wet conditions.	yes
Empire Tract	17.0 (42.0)	Photos from 1987, 1993, 2002, 2005, 2009, and 2012 show presence of scour area.	yes
Holland Tract	26.9 (66.4)	1939 (pre-scour) photo shows agriculture in the area. 1987 CIR photo shows agriculture disrupted by the scour lake, including fallow fields to the west of the lake itself. 1993, 2002, 2008, and 2012 photos show progressively widening wet-area vegetation west of the scour lake.	yes
McCormack-Williamson Island	9.7 (24.0)	Scour lake and associated wet area appear in 2002 and 2012 photos.	no
Sherman Island	6.4 (15.8)	1987 CIR photo shows the scour lake. The wet area progressively expanded to the north and east of the original scour lake through this time period.	yes
Tyler Island	9.5 (23.5)	1987 CIR photo shows the scour areas and the area surrounding the scour lake possibly being farmed. 1993, 2002, and 2012 photos show a large strip of non-arable land extending to the southwest of the scour lake.	yes
Venice Island East	14.5 (35.8)	Photo from 1987 shows the scour lake. The 1993, 2002, 2005, 2008, and 2012 photos indicate non-arable area surrounding the scour lake.	yes

Venice Island South	19.1 (47.2)	Photo from 1987 shows the scour lake. The 1993, 2002, 2005, 2008, and 2012 photos indicate non-arable area surrounding the scour lake.	yes
Venice Island West	20.0 (49.4)	Photo from 1987 shows the scour lake. The 1993, and 2002 photos show a non-arable area surrounding the scour lake. Progressively expanding wetness is visible to the northeast and southeast in the 2005, 2008, and 2012 photos.	yes
Webb Tract East	46.1 (114)	1939 photo (pre-scour) shows the area being farmed. 1984 CIR photo shows the scour lake surrounded by a small non-arable margin. Non-arable area remains consistent through 1993, 2002, 2008, and 2012 photos.	yes
Webb Tract North	37.3 (92.1)	1939 photo shows the area being farmed. 1987 CIR photo shows non-arable area surrounding the scour lake. Non-arable area remains consistent or undergoes slight expansion through 1993, 2002, 2008, and 2012 photos.	yes
Total area	272 (672)		

Habitat

Mr. Cosio stated that the areas were “deliberately developed into habitat” and not due to “inability to farm”. Mr. Cosio delineated habitat areas on Bishop Tract, Brack Tract, Brannan-Andrus, Empire Tract, Medford Island, Sherman Island, Tyler Island and Wright Elmwood Tract. Table A1 and figures in the Appendix show each habitat area and a summary of the photo time series. Information exchange with several Delta land managers indicated a strong preference to develop wetland habitat or allow locations to become habitat in wet areas that already have a tendency towards reduced arability. One long-time land manager of multiple islands said this was “absolutely” the case. Moreover, in some cases and as per conversations with growers and land managers, wetlands were created in a WNMF area because installation of additional drainage infrastructure did not remediate the situation.

The aerial photo series summarized Table A1 (please see Appendix) provides evidence of this preference for parcels where farming is more difficult due to increased wetness for those areas delineated by Mr. Cosio. Of particular importance is the insight provided by color infrared (CIR) photography from September 1984 and July 1987. This type of imagery is used extensively to assess agricultural vegetative health and the presence of water and bare soils[1]. For all the areas delineated as habitat by Mr. Cosio,

[1] See for example Anderson, W.H. USGS Open File Report 77-175,
http://cteco.uconn.edu/%5C/guides/Ortho_2010_4Band_NAIP.htm.
http://www.agriculturalmanagementsystems.com/agricultural_management_systems_faq.shtml#Q1
http://www.fsa.usda.gov/Internet/FSA_File/naip_info_sheet_2013.pdf

the 1980s photos indicated agriculture as the land use with varying degrees of wet conditions, bare soils and reduced vegetation.

"Other" Areas

All of the WNMF areas included in this category except the area on Prospect Island were present in the 1980s. Therefore, 39 ha (96 acres) were included in the 1987 and 1984 estimates of WNMF area shown in the 2015 article. As stated above, we sought to document and explain the increase in/of WNMF area from the 1980s to 2012 and included the "other" areas in the "baseline" determination the WNMF areas. Since all but one of these areas were included in the 1980s, the presence of the "other" areas in 2012 does not significantly influence our estimate of the change in WNMF areas or our conclusions. Moreover, the Prospect Island photos indicate the presence of wet and unfarmed areas beginning in the 1980s.

Table 4. Summary of photo time series for "other areas" delineated by Mr. Cosio.

Island and location	Area in ha (acres)	**Time series summary**	**Present in 1980s?**
Brannan-Andrus Island	13.5 (33.3)	Aerial photos from 1987, 1993, 2003, and 2012 indicate the area has been dedicated to manmade ponds, apparently for wastewater treatment.	yes
Grand Island South	20.4 (50.4)	1987 CIR photo shows the area not under cultivation. Area size, shape, and conditions remain constant through 1993, 2002, and 2012 photos.	yes
Grand Island North	9.5 (23.5)	1987 CIR photo shows the area not under cultivation. Area size, shape, and conditions remain constant through 1993, 2002, and 2012 photos.	yes
Holland Tract	9.0 (22.2)	1939 and 1993 photos show the area at least partially under cultivation, with streaks and spots. 1987 CIR photo confirms that these streaks indicate low vegetation density. Manmade ponds appear first in the 1987 photo. Ponds are not in use in 2002 and 2008 photos, but return in 2012 photo, along with some newly constructed ponds. The non-pond portions of the area are not under cultivation in the 2002, 2008, and 2012 photos.	yes
Prospect Island	173 (428)	1987 CIR photo shows the area not under cultivation, with dark spots and streaks suggesting high soil moisture especially in the southern portion. 1993 photo apparently shows the area not being farmed, with dark patches in suggesting non-arable areas, again in the south. In the 2002 photo the land use is not certain, but there is clearly more non-arable wet area. In the 2006, 2009, and 2012 photos, the whole area is wet and non-arable.	no

Total area	212 (524)		

Land use changes

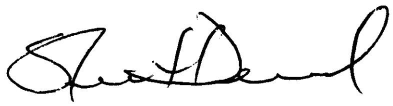
Mr. Cosio's letter stated that "The paper also cites seepage as the reason some farm ground has shifted use from field crops to pasture. We also think this assumption should be further investigated. In our experience, the shift most likely occurred due to water quality and the buildup of salts in the soils. For instance, most of the Sherman Island property was purchased by the state due to the inability to maintain water quality as agreed in the state contract with the North Delta Water Agency (NDWA)." In the article, it was stated that for Sherman and Twitchell islands, the shift was likely due to land management changes such as less drainage ditch maintenance. Steven Deverel personally observed these changes and discussed them with land managers. Part of the rationale for conversion to pasture was the ability to maintain shallow water tables that reduce subsidence rates relative to field crops. The senior author, Steven Deverel, also interacted with growers where salinity on Sherman had become a problem.

Contrary to Mr. Cosio's statement about irrigation-water salinity, the long-term trend for the last several decades for the western Delta has been toward fresher irrigation supplies. This trend includes the enactment of the State Board's "X2" standard which may freshen the western Delta at various times. Also similar land use changes were observed on Twitchell Island and other islands. It is noteworthy that we have also observed salinity buildup on other islands where irrigation-water salinity has remained low relative to the far western Delta. Deverel and others (2007) provided geochemical evidence that salts build up in peat soils due to oxidation of the peat. As the organic matter is oxidized, salts are left behind. Without adequate ability to drain, salts can build up. Moreover, it is well known that shallow groundwater evaporation leads to concentration of salts in the soils (Gardner and Fireman, 1958). This is the reason, drainage ditch depths of 5 feet or greater are recommended. When groundwater is shallower than this as has been the case on Twitchell and Sherman and other islands based on personal observation, shallow groundwater evaporation and peat oxidation can lead to the increased soil salinity.

Summary

Development of habitat and borrow pits are part of the mix of the increased area of WNMF areas documented in our paper whereas scour and other areas delineated by Mr. Cosio mostly are not. The key disagreement between the evidence presented in our paper and Mr. Cosio is the reason for the development of borrow and habitat areas. The preponderance of evidence presented here and in the paper (analysis of historical aerial photos and conversations with land management personnel) indicates that the borrow and habitat documented shown in Mr. Cosio's letter evolved in locations where there likely were wetter conditions, fallow areas and/or soil conditions that were no longer conducive to farming using common used irrigation methods. In light of the evidence, what are the likely causes of increased wetness and reduced arability? Peat disappearance is an apparent precursor to locating borrows pits. Also, wetlands have been located in areas of increasing wetness and reduced arability and most of these areas are in elevations below -2 m, where organic soils are thinnest and close to levees. The physics of the situation are stated in the paper and reiterated here. As peats become thinner due to oxidation, vertical exit gradients and upward flow from the mineral materials under the peat increases. This has resulted in more water flowing into the peat soils and creation of WNMF areas.

We thank Mr. Cosio for his comments and welcome future dialog about this subject and other important topics related to Delta land use and hydrology.



Steven Deverel, Ph.D., P.G.
HydroFocus, Inc.
Davis, CA

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Appendix – Aerial Photographic Images for Habitat Areas

Use of Color Infrared Imagery

The color infrared (CIR) imagery is useful for discerning features such as vegetation that reflect a distinct signature in the infrared spectrum as follows.

- Intense bright red typically represent vigorously growing, dense vegetation that is producing a large amount of chlorophyll.

- Lighter tones of red, magenta, pinks generally represent vegetation that does not contain as much chlorophyll such as mature stands of evergreens. Agricultural fields nearing the end of the growing season, and dead or unhealthy plants often appear in less intense reds, green, or tan.

- White, blue, green, or tan. These colors often represent soils. Darker shades of soil generally indicate higher moisture levels or organic matter. Soil composition also affects soil color appearance, with clayey soils appearing in darker tans and blue-greens, and sandy soils appearing white, gray, or light tan. Pale or light blue can also represent sediment-laden water. Buildings and manmade materials such as concrete and dry gravel generally appear white to light blue in CIR photos.

- Dark blue to black - Water ranges from shades of blue to black depending on the clarity and depth. Usually, the clearer the water, the darker the color. However, shallow streams will often display the colors associated with the materials in their stream beds. If the stream bed is made of sand, the color will appear white or very light tan due to the high reflective property of sand. Asphalt roads generally appear dark blue to black.

Photo Series for Habitat areas

Table A1. Summary of photo time series for habitat areas delineated by Mr. Cosio.

Island	Area in hectares (acres)	Time series summary	Approximate present-day soil organic matter percentage	Habitat present in the 1980s?	Distance to channel or slough in meters (feet)	Elevation in meters (feet)
Bishop Tract	20.5 (50.6)	September 1984 CIR (color-infrared) photo shows blue areas indicating wet conditions. Constructed wetlands apparent in 1993 overlay the 1984 wet areas. Wetlands were surrounded by fallow areas in 1998 and 2002. Wetlands were surrounded by farmed areas in 2008 and 2012.	6%	No	420 (1,338)	-1.31 (-4.30)
Brack Tract	190 (470)	July 1987 CIR photo shows entire area in agriculture, and evidence of wet conditions (dark blue) and plant stress (magenta). 1993 photo indicates similar conditions. 2002 photo shows presence of wetland in western fields in the location of wet conditions apparent in the 1987 photo. Fallow and irregularities in areas in the eastern area near the slough are apparent where wet conditions were observed in the 1987 CIR photo. Wetlands present eastern area 2006–2012.	45%	No	Immediately adjacent	-2.82 (-9.25)
Brannan-Andrus	45.7 (113)	1987 CIR photo shows that the area is delineated for farming with variable-density vegetation and wet conditions. The remainder of the area is bare soil, with dark spotting indicating zones of high soil moisture. 1993 photo indicates similar conditions. Photos from 2002 to 2012 show transition to wetlands.	11%	No	118 (1,043)	-0.44 (-1.44)
Empire Tract	45.6 (113)	September 1987 CIR image and 1993 photo show that the area delineated as habitat in Mr. Cosio's letter was farmed.	45%	No	Immediately adjacent	-3.95 (-12.96)

Island	Area in hectares (acres)	Time series summary	Approximate present-day soil organic matter percentage	Habitat present in the 1980s?	Distance to channel or slough in meters (feet)	Elevation in meters (feet)
		White and magenta areas in the CIR photo indicate bare soil and some stressed vegetation. The 1993 photo shows area as being farmed although there is evidence for variable density vegetation. 2002–2012 photos indicate wetland conditions.				
Holland Tract	14.8 (36.6)	The July 1987 CIR shows white, blue and red/magenta colors indicative of bare soil and wet conditions with some vegetation. 1993 –2012 photos indicate the area was possibly used as pasture. Ponding and wetlands appear from 1993 to 2012.	0%	No	588 (1,929)	-1.94 (-6.36)
Medford Island North and South	40.7 (101) 56.7 (140)	July 1987 CIR images show white areas near channel indicating bare soil and 1993 photo indicates similar and apparently agricultural conditions. 2002–2012 photos indicate transition to wetland conditions.	6%	No	Immediately adjacent	-2.79 (-9.15)
Ryer Island	41.2 (102)	July 1987 CIR photo shows blue and white colors associated with bare soil and moist conditions, though field patterns suggests area had been farmed recently. 1993 and 2002 photos show apparent farming under marginal conditions. Land use is unclear in 2005, but marginal conditions have progressed since 2002. Constructed habitat appeared in 2008 and 2012.	0%	No	Immediately adjacent	-0.93 (-3.05)
Sherman Island Mayberry Farms Wetland	128 (317)	July 1987 CIR photo shows that entire area was farmed. Blue and magenta colors indicate vegetated and wet conditions. In 1993, 2002 and 2005 a mixture of wetland and pasture areas can be seen. 2006, 2008, 2010 and 2012 show a progression from wet areas to constructed wetlands in 2010	17.5%	Partially	Immediately adjacent	-3.94 (-12.92)

Island	Area in hectares (acres)	Time series summary	Approximate present-day soil organic matter percentage	Habitat present in the 1980s?	Distance to channel or slough in meters (feet)	Elevation in meters (feet)
		and 2012.				
Tyler Island	197 (486)	July 1987 CIR photo shows about half of the area being actively cultivated with bright red (healthy) vegetation, with the other half as bare soil or fallow and of varying moisture. Blue areas indicate high moisture. Field patterns suggest that the bare fields were cropped recently. 1993 photo indicates areas of marginal farming. 2002 photo indicates wet conditions and evidence of agricultural use. 2006–2012 photos indicate progressing wetness and presence of wetland.	17.5%	No	Immediately adjacent	-3.53 (-11.58)
Wright-Elmwood Tract	18.8 (46.4)	September 1984 CIR photo indicate the area was farmed. Blue coloring indicates wetness. Constructed wetland habitat appears in 1993, 2002, 2008, and 2012.	40%	No	Immediately adjacent	-1.28 (-4.20)
Total area	780 (1,929)					

Comparison of 1980s Color Infrared and subsequent photos

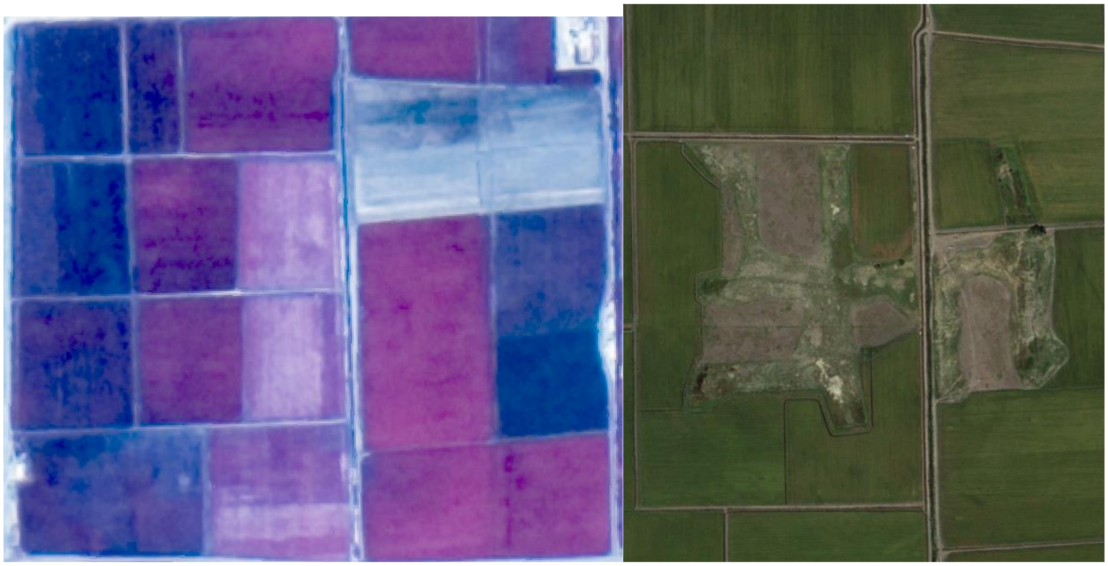


Figure A1. Bishop Tract, 1984 CIR (left), 2012 (right). Light colored and bluish red areas became wetland area.

Figure A2. Brack Tract, 1987 CIR (left), 2012 (right). Dark blue, bluish red, magenta (wetter) areas in 1987 were wetland in 2012.

Figure A3. Branan-Andrus Island, 1987 CIR (left), 2012 (right). White, light blue, bluish red areas (wet and non-cultivated areas) in 1987 were habitat in 2012.

Figure A4. Empire Tract, 1987 CIR (left), 2012 (right). White (fallow) areas in 1987 were wetland in 2012.

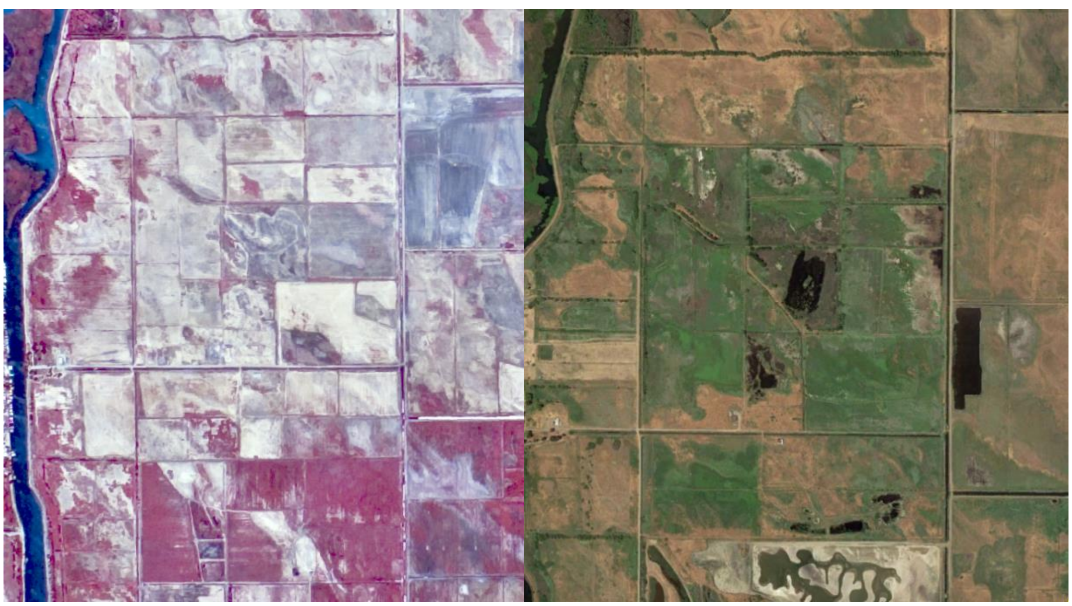
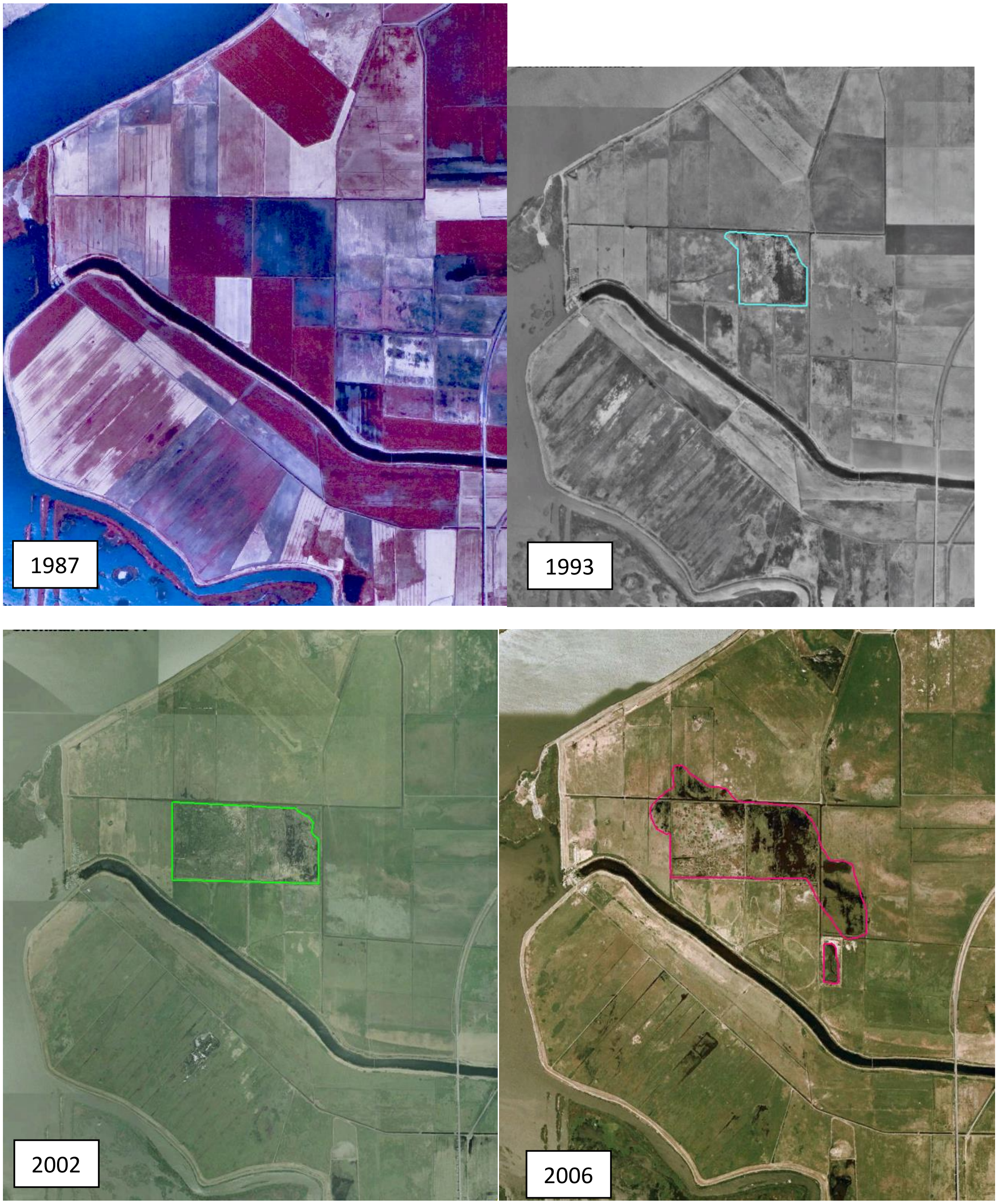


Figure A5. Holland Tract, 1987 CIR (left), 2012 (right). While and bluish white areas in 1987 were wetland in 2012.

Figure A6. Medford Island (north), 1987 CIR (left), 2012 (right). White areas in 1987 were wetland in 2012.

Figure A7. Medford Island (south), 1987 CIR (left), 2012 (right). White areas in 1987 were wetland in 2012.

Figure A8. Ryer Island, 1987 CIR (left), 2012 (right). Bluish-white areas in 1984 were wetland in 2012.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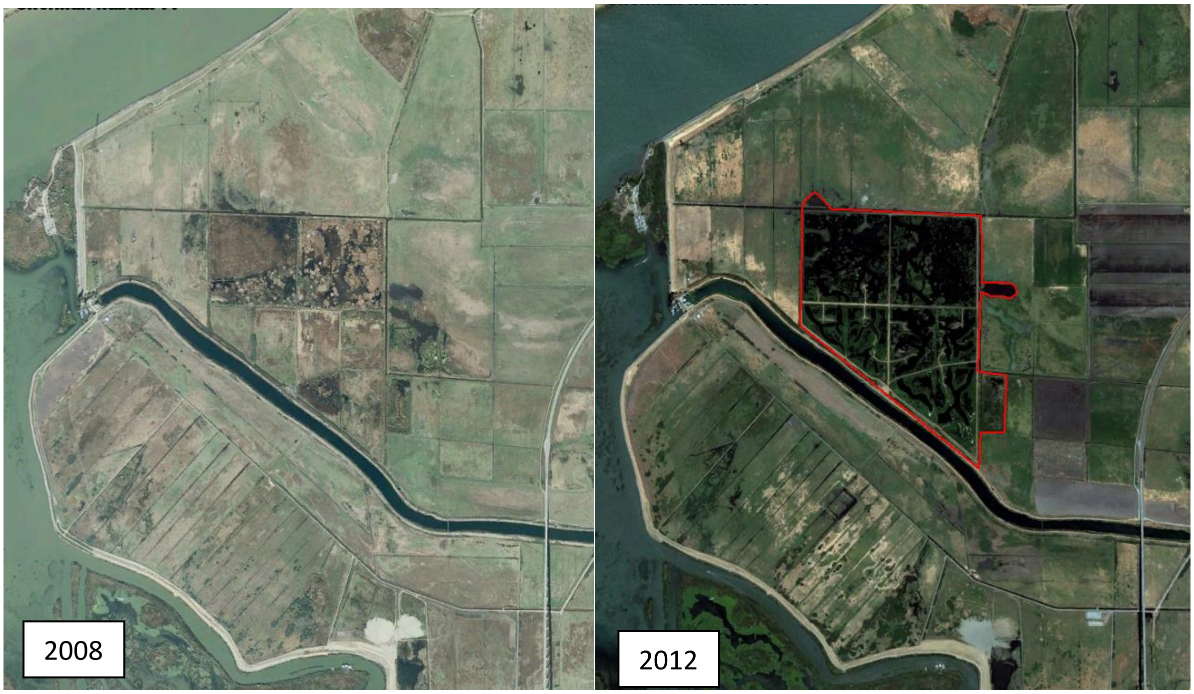

Figure A9. Sherman Island, 1987 to 2012. Photos show a progression from wet farmed areas to wetlands in 2012.

Figure A10. Tyler Island, 1987 CIR (left), 2012 (right). White area in center of 1987 photo became part of wetland by 2012.

Figure A11. Wright Elmwood Tract, 1984 CIR (left), 2012 (right). Blue and reddish blue areas were wetland in 2012.