FINAL REPORT

Aquatic Insects and Waste Agricultural Seeds in Post-Harvest Flooded Agricultural Fields in the Southern San Joaquin Valley, California

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30 MARCH 2006

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EXECUTIVE SUMMARY: California's Tulare Lake Basin (TLB) in the southern San Joaquin Valley once contained the largest freshwater lake west of the Mississippi River and provided critical habitat for millions of Pacific Flyway waterbirds. Today the TLB is one of the most productive agricultural areas in the world but few wetlands remain; late summer habitat is especially limited. Irrigated cotton agriculture dominates the TLB landscape, with cotton planted for two years followed by one year in a rotational crop. After harvest each year, some TLB fields are flooded to remove accumulated salts, control crop disease, and provide soil moisture. Because late summer flooding of harvested crop fields could provide large areas of waterbird habitat during an especially critical period, pilot conservation programs to promote the practice have begun. To guide these programs, we measured availability of waste agricultural seeds and aquatic insects, both important waterbird foods, and how these items varied by crop type and water depth in fields. During August-October 2003 and 2004, we collected pre-flood soil samples to measure waste agriculture seed in tomato, wheat, and cornfields and trapped emerging aquatic insects to measure emergence rates and calculate production of insects in flooded tomato, wheat, and alfalfa fields. We also conducted a lab experiment of *Chironomidae* larvae (main insect in flooded fields) growth and survival relative to water temperature fluctuation that we had observed in flooded fields.

Waste agricultural seed density varied greatly within and among fields but crop type averages did not differ significantly (tomato: 7.3 g/m^2, range = 0-20; wheat: 6.9 g/m^2, 0-31.5; corn: 4.4 g/m^2, 0-17.5). After the first 2 weeks of flooding, average daily number and mass of insects that emerged in tomato (635 individuals/m^2/day, SE = 73; 181 mg/m^2/day, SE = 18) were greater than in wheat (219 individuals/m^2/day, SE = 32; 81.3 mg/m^2/day, SE = 13,) or alfalfa fields (260 individuals/m^2/day, SE = 64; 75 mg/m^2/day, SE = 20). More individuals and a greater mass of insects emerged during late than during early-season sampling intervals in tomato and alfalfa fields but not in wheat fields. Chironomids were the most (tomato: 96.2%; wheat: 90.4%; alfalfa: 56.8%) and muscids the second-most common (tomato: 2.8%; wheat: 6.8%; alfalfa: 38.9%) emerging insect. Water temperature fluctuation, depth, and number of emerged insects in fields were all strongly related (r^2 > 0.86), with greater emergence in deeper water that had less temperature fluctuation. In the lab, chironomid larvae survival was 4x greater and total biomass 2x greater in the 6˚C-daily amplitude than in the 17˚C-daily amplitude treatment. Based upon emergence:production ratios from a similar environment applied to emergence in TLB fields, we calculate that after 2 weeks of flooding, chironomid production in flooded tomato, wheat, and alfalfa fields during August-October averaged 578.8 mg/m^2/day, 185.8 mg/m^2/day, and 115.7 mg/m^2/day, respectively.

Resource management programs that enhance waterbird value of TLB fields while maintaining or improving their agricultural production have great potential to help restore waterbird abundance in TLB. Because most waterbird species that use flooded TLB fields optimally forage in water ≤30 cm deep but invertebrate production was best in deeper, more temperature-stable water, we recommend that most of each field be maintained at ≤30 cm but with some deeper areas.

INTRODUCTION

The Tulare Lake Basin (TLB) in central California is located in the southern portion of the San Joaquin Valley (SJV) at the confluence of the Kings, Kern, Kaweah, and Tule rivers. The historic Tulare Lake was 37 feet deep at its fullest, covered 490,000 acres, and was the anchor of a wetland complex that covered over 650,000 acres (Hansen 1994, Natureali.com 1998). The Tulare Lake wetland complex was a center for Native Americans and early European settlers, as well as critical habitat for millions of migratory birds traveling the Pacific Flyway and other wildlife (Weis 1938). However, like many other wetlands in California, expanding agricultural operations in the early 1900's created an increased demand for water and farmland, and eventually led to a reduction of Tulare Lake and its associated wetlands. As a result, the landscape in and around the Tulare Lake changed drastically, and what was once the largest freshwater body west of the Mississippi River became one of the most productive agricultural areas in the world. Kings County, which contains most of the TLB, now produces agricultural crops of value in excess of 1.2 billion dollars (Kings County 2005), and is the driving force of the regional economy.

Parts of the TLB do still become periodically inundated during extreme flood events. However, only remnants of the historic wetland area in the TLB remain, confined primarily to privately owned waterfowl hunting clubs, former agricultural ground that has been enrolled in wetland reserve programs, and the Pixley and Kern National Wildlife Refuges. Because of altered hydrology and the high cost and low availability of water, most of these wetlands do not flood until late fall, leaving early migrant and resident birds without adequate habitat.

Cotton agriculture dominates the TLB landscape, in both acres planted and economic value. Fields in the TLB are typically planted in a three-year rotational pattern, with cotton planted for two years, followed by one year in a rotational crop. The rotational crop selected for planting is market driven. Wheat, alfalfa, tomato and safflower have been the most common rotational crops with tomatoes becoming more common and safflower less common recently (N. Heeringa, Boswell Corporation, personal communication). Like nearly all agriculture in the arid west, crops in the TLB require regular irrigations to grow. However, TLB soils are comprised of heavy clay and prone to salt accumulation, which can reduce agricultural production if carried to the root zone by rising water tables. In addition, *Thielaviopsis basicola*, commonly known as Black Root Rot, is a naturally occurring fungal cotton pest that is prevalent in the soils of TLB and can reduce cotton yield (B. Roberts, personal communication).

Each year, some TLB fields are flooded after harvest to remove accumulated salts, control crop disease, and provide soil moisture. Post-harvest, late summer flooding (LSF), typically begins in mid-August and lasts through October (November some years). Shortly after rotational crops are harvested during July and August, an earthen border is placed around fields to be flooded and the field is filled with water up to approximately one meter deep. Underground tile drains are installed in these fields, so that when soils are flooded, the head pressure from the water drives the accumulated salts into the drains and out of the fields. Inundation of soils for as long as six weeks during ambient temperature of $\geq 30°C$ (86°F) is an effective means of fungal control (Rourke and Nehl 2001). Although LSF is primarily for soil reclamation and fungal control, like water applied to fields later in the year, LSF also provides subsurface soil moisture, improving

the seedbed for the upcoming cotton planting. The combination of these benefits has made LSF a common agricultural practice throughout TLB, and is done regularly if water is available.

Flooded agricultural fields are the most abundant wetland habitat in the TLB during August-October (Fleskes 1999) and support large populations of waterbirds during this time of year. About 20-50% of shorebirds counted in the TLB during 1992-95 (Shuford et al. 1998) and 59-74% of the waterfowl counted in the TLB during 1980-87 (Barnum and Euliss 1991) were on post-harvest flooded agricultural fields. Fleskes et al. (2003) reported that northern pintails (*Anas acuta*), the most abundant waterfowl species wintering in the TLB (Barnum and Euliss 1991), selected flooded fallow and post-harvest flooded safflower fields and avoided post-harvest flooded alfalfa and cotton fields while selection of post-harvest flooded wheat/barley fields varied greatly.

Factors driving differential use of TLB fields by waterbirds have not been investigated. Most waterbirds are opportunistic and select feeding habitats that provide abundant food (Austin and Miller 1995, Bellrose 1980). Although food habits of waterbirds on TLB fields have not been reported, both invertebrates and seeds are important food sources in other habitats (Beam and Gruenhagen 1980, Connelly and Chesemore 1980, Euliss 1984, Miller 1987). In the Sacramento Valley, rice fields are abundant and waste rice comprises the greatest portion of the winter diet of pintails (Miller 1987). Waterfowl consumed tomato seeds on post-harvest flooded tomato fields in the Sacramento-San Joaquin River Delta region of California (Wickland et al. 1999). Ducks feeding in marshes and evaporation ponds in TLB relied heavily upon midge (Chironomidae) larvae throughout the winter (Euliss and Harris 1987, Euliss et al. 1991).

Thus, availability of waste crop seeds, chironomids, and other aquatic invertebrates probably greatly impacts use of TLB fields by waterbirds (Fleskes et al. 2003).

There is currently no information on the densities of these waterbird food items in TLB fields and how they vary among crop types or other factors. This information is necessary for the Central Valley Joint Venture (Central Valley Habitat Joint Venture Implementation Board 1990) and other waterbird conservation programs to estimate the habitat value and waterbird energy derived from flooded agricultural fields. The goals of our study are to elucidate the ecological value of flooded agricultural fields, the differences in ecological value among crop types, the food resources available to waterbirds, and the opportunity for reconciliatory uses of agricultural areas by wildlife.

STUDY AREA

We studied availability of waste seeds and invertebrates in LSF fields within the TLB (Fig. 1). The TLB is generally defined as land at or below the 207-foot elevation line at approximately latitude 36˚ 00' N., longitude 119˚ 45' W (Tulare Lake Basin Water Storage District 1981). We obtained access permission from the largest landowner in the TLB and from lands managed by the Bureau of Land Management. We selected fields from these landowners that were planned to be flooded for a minimum of 20 days during August to October; actual duration of flooding ranged from 21-45 days. The landowner controlled which fields were flooded and the duration of the flooding. The field portion of this study was conducted on two LSF alfalfa fields in 2003 and four LSF wheat and five LSF tomato fields in 2004. Fields varied from 5 to 190 ha each, and totaled approximately 668 ha (1650 acres).

METHODS

SEED SOIL SAMPLES

We sampled corn, wheat, and tomato field soils for seeds >20 days after all mechanical tilling was completed and 2-14 days before start of flooding (except the corn field was not subsequently flooded). Alfalfa fields were not sampled for waste seeds, because the alfalfa was being grown for hay, and was cut before having set seed. We excavated the top 15 cm of soil inside of a 0.09 m^2 sampling frame at random locations within each field. This depth represents the approximate maximum depth that seeds would be available to waterbirds in these fields (Swanson 1983). We washed soil samples through a 255-μm sieve to separate the plant biomass from the soil. The plant biomass was then placed into a drying oven at 80° C for 48 hours to ensure constant mass. We then separated all agricultural waste seeds from the remaining plant biomass and weighed all seeds in a sample together to the nearest 0.01g. Waste seed density was compared across field types with one-way ANOVA. Post-flooding variables such as water temperature, depth, and flooding duration were not included in this analysis since variation in seed density is due to pre-flooding factors such as crop type and harvesting methods.

INSECT EMERGENCE

We measured rates of insect emergence from LSF wheat, tomato, and alfalfa fields using modified "Week" emergence traps (LeSage and Harrison 1979). Traps were constructed using a 0.25 m^2 square base made out of ABS plastic pipe, with four 1 cm wooden dowels inserted into the corners. The dowels supported a Plexiglas collecting head, kill jar, and netting connecting the collecting head to the base. We constructed the

kill jar using a 500 ml polypropylene jar with a foam-lined lid in which we cut a hole to match the exit hole into the Plexiglas collecting head. The jar was filled with approximately 250 ml of killing solution, made by combining equal parts ethylene glycol, ethanol, and water (F. Schreiber, California State University-Fresno, personal communication). Traps were floated on the surface of the water and anchored to the substrate with a 30 cm reinforcing bar or wooden dowel. The weight of the trap forced 1-2 cm of the base below the surface of the water, effectively preventing the traps from collecting insects in the neuston. In 2003, we attached HOBO StowAway TidbiT temperature loggers (Onset Computer Corporation 2003) underwater on the substrate beneath each trap. The loggers collected temperature data every 30 seconds while the traps were in the fields. Temperature loggers were initially attached to the traps in 2004, but were lost in the fields after a disturbance. We tried to retrieve the loggers after the water was removed from the fields, but the above average rainfall of winter 2004 and spring 2005 made access to the fields impossible, until after the fields had been disked and planted.

Emergence traps were installed two weeks after each field was completely flooded. This interval was to allow aerially dispersing insects adequate time to lay eggs, complete larvae development, and emerge as adults (Oliver 1971, Euliss 1984, Pritchard et al. 1996). This delay also avoided variability in production associated with differences in abundance of aquatic insect eggs and larvae in delivered water and allowed us to focus on measuring the impacts of field characteristics (e.g., crop type, water depth) on production. Three traps were deployed in each field using a stratified random design to account for potential within-field variation in flooding depth. Agricultural fields in the

TLB have an engineered slope to facilitate the movement of water across the field for both flooding and draining. To control for possible within-field variation due to that slope, we partitioned the fields into three depth gradient sections and randomly placed traps within each section. Water depth at each trap was measured at the initial trap set. We visited traps every 3-4 days (using a small johnboat) in each field to remove kill jars from the collecting heads and install new kill jars with fresh killing solution. Water level likely varied little across collection periods since land owners replenished water lost to evaporation, but were unlikely to add excess water due to cost. Traps were removed one day before the landowner drained the field.

In the lab, we separated the insects from the remaining killing solution and stored them in jars with 70% ethanol. We sorted insects by taxonomic family (Merritt and Cummins 1995), counted individuals, and weighed each family group. To expedite analysis of large captures, we sub-sampled collected individuals by placing all collected individuals from a single trap and collecting interval into a square dish with a grid of 36-13 mm x 13 mm squares. We then randomly identified and counted the individuals within five of the squares. Mass was determined by collecting representative samples of each family, drying the samples in a drying oven at 80° C for 48 hours (to a constant mass), and then determining the average per capita weight of each family to the nearest 0.01g. We took the average weights from each family and then multiplied that by the number of individuals from each family.

Insect emergence rate (# · trap^{-1} · d^{-1}) was analyzed across crop type, field, trap, water depth, and duration of flooding. We also analyzed for the potential temporal correlation of samples collected from the same trap over time. Overall, six models

testing sources of variation in log-transformed emergence rates were run using the SAS (SAS Institute 2004, Littell et al. 1996) PROC MIXED procedure, which allows for analysis of variance and covariance models with balanced or unbalanced data, fixed or random effects, and also repeated measures. All models included a term for crop type, depth, and the interaction between these two factors. Three models included linear and quadratic terms for the effect of the number of days a field was flooded, while the remaining three did not. Within each of these two groups of three models, one model included trap as a random factor nested within field, with field a random factor as well. Since these random effects were weak, another version of the model was run without these random effects. The final version of the model included a term to estimate and test the effect of temporal correlation among samples taken from the same trap. The autoregressive term is based on a first-order autoregressive structure (AR(1)). Selection of the best model for our analysis is based on the model with the lowest AIC term (Akaike's Information Criterion; Akaike 1973). $AIC = -2 \ln L + 2p$, where L is the likelihood for an estimated model with p parameters.

In order to facilitate comparisons to other emergence studies, we used emergence/production (E:P) ratios reported for a similar high temperature, low flow aquatic system (Jackson and Fisher 1986) to calculate daily chironomid production in LSF fields based upon our emergence data. Because abiotic conditions and emergence rates in Jackson and Fisher's system during their periods I and III were most similar to our LSF fields, we used the average daily E:P ratio of those two periods (0.252) to calculate chironomid production in each of our field types based upon our emergence data.

INCUBATOR EXPERIMENT- SURVIVAL & BIOMASS

Data early in the study suggested a strong and significant negative correlation between water depth and the amplitude of daily water temperature flux. Likewise, emergence rate had a strong positive correlation with water depth. We used a controlled growth chamber experiment to investigate the potential mechanistic link between chironomid survival and growth with water temperature fluctuation. We programmed two Conviron E15 environmental chambers (Conviron 2004) to mimic temperature fluctuation regimes that we had measured in the field. To correct for differences in programmed air temperature fluctuation and measured water temperature fluctuation, we placed temperature loggers in the same conditions (water volume, container, etc.) as the larvae and adjusted the air temperatures to create the intended diel water temperature fluctuations. We programmed the first chamber (Hi Flux) to have a 17˚C-daily water temperature amplitude, fluctuating between 15˚C and 32˚C and the second chamber (Lo Flux) to have 6˚C-daily water temperature amplitude, fluctuating between 21˚C and 27˚C. These temperature fluctuation regimes corresponded respectively to deep and shallow water flooding depths. Both chambers were programmed to receive 13 hours of light.

Chironomus dilutus egg masses were obtained from the U.S. Geological Survey (USGS) culture in Columbia, Missouri. We divided the egg masses into segments of approximately 20 eggs each and randomly placed segments, one at a time, into seven, 500 ml polyethylene jars containing 2 cm of fine washed sand and 20 cm of tap water that we first conditioned by placing in an open container to allow any chlorine gas to dissipate. The constant depth across both temperature flux regimes allowed us to directly

address the effects of temperature fluctuation alone while controlling for other potential effects of water depth. We continued to randomly allocate egg mass segments to each jar until each held approximately 200 eggs. Each jar was then randomly assigned to one of the treatment regimes and immediately placed into the appropriate environmental chamber. The jars were provided light aeration and covered with no-see-um netting. Two days after the eggs hatched, chironomid larvae were fed Tetramin Flake slurry (Tetramin Flakes blended with conditioned water) (E. Greer, personal communication). We supplied food every three days and maintained water in each jar at 20 cm by adding conditioned water daily as necessary. We changed water weekly by pipetting the surface water out and re-filling the jars with clean, conditioned water. Larvae grew in the environmental chambers for 30 days. After 30 days, we poured the entire jar contents through a 255-µm sieve. We counted larvae (all were live) and preserved them in vials containing 70% ethanol. We estimated total larval biomass from each replicate to the nearest 0.01g by weighing all larvae from a vial together after drying them at 80° C for 48 hours (to a constant mass) in aluminum weigh boats. The numbers and total biomass of surviving larvae were compared between the two temperature regimes with Student's t-tests for independent samples.

RESULTS

WASTE SEED DENSITY IN FIELDS

We collected a total of 52 soil samples from different crop types (tomato, wheat, and corn) during 15 August - 15 September 2003 and 15 August – 15 September 2004. Waste agricultural seed density varied greatly within and among fields, but crop type was not a significant source of variation ($F_{2,49} = 0.551$, $P = 0.58$). Waste seed density

averaged 7.3 g/m^2 (SE = 1.56, range = 0 - 20) in tomato fields, 6.9 g/m^2 (SE = 1.47, range

= 0 - 31.5) in wheat fields, and 4.4 g/m^2 (SE = 2.36, range = 0 - 17.5) in cornfields.

EMERGED INSECTS IN FIELDS

We compiled a total of 609 trap days in three different crop types (tomato, wheat,

alfalfa), collecting over 56,000 individual emerged insects during 6 September - 29

October 2003 and 21 August - 18 October 2004.

Emerged Individuals-- Variation in insect emergence rate was best explained

(lowest AIC) by a model which included a term for temporal correlation across samples

from the same trap, and main effects of crop type, depth, and their interaction. The effect

of crop type was significant ($F_{2,31}$ = 8.29; P = 0.0013), but depth ($F_{1,31}$ = 1.32; P = 0.26)

and their interaction were not ($F_{2,31}$ = 2.60; P = 0.09). Tomato fields averaged

significantly more emerged individuals than either wheat or alfalfa fields. Emergence

averaged 635 (SE = 73, range = 137-2702) individuals $\cdot$ m^{-2} $\cdot$ day^{-1} in tomato fields, 219

(SE = 32, range = 42-1814) individuals $\cdot$ m^{-2} $\cdot$ day^{-1} in wheat fields, and 260 (SE = 64,

range = 27-1720) individuals $\cdot$ m^{-2} $\cdot$ day^{-1} in alfalfa fields. Emergence increased with

inundation duration in tomato and alfalfa fields but declined over time in wheat fields

(Fig. 2).

Emerged Mass-- The rates of emerged individuals and their total biomass was

highly correlated ($r_{1,150}$ = 0.85; P<0.001), likely due to low species richness and

taxonomic similarity across crop types. Both variables were log-transformed to achieve a

normal distribution (Kolmogorov-Smirnov test for normal distribution; P > 0.05).

Average emerged mass was greater in tomato fields than either wheat or alfalfa fields.

Total mass of emerged individuals averaged 181 mg $\cdot$ m^{-2} $\cdot$ day^{-1} (SE = 18, range = 46-

636) in tomato fields, 81.3 mg · m^{-2} · day^{-1} (SE = 13, range = 12-868) in wheat fields, and

75 mg · m^{-2} · day^{-1} (SE = 20, range = 6-520) in alfalfa fields. Emergence mass increased

with inundation duration in tomato and alfalfa fields but not in alfalfa fields (Fig. 3).

Species Composition-- Chironomidae was the most common family of insects that

emerged from all field types (tomato: 96.2%; wheat: 90.4%; alfalfa: 56.8%), with

muscids usually the second most common (tomato: 2.8%; wheat: 6.8%; alfalfa: 38.9%)

(Fig. 4). Combined, chironomids and muscids accounted for >95% of the individuals

emerging in all three field types. Arcsin squareroot transformed muscid percentages

varied significantly among crop types (ANOVA $F_{2,146} = 99.0$, $P < 0.001$). Alfalfa fields

averaged a larger proportion of muscids (comprising 38.9% of the emerged population)

than did either wheat (6.8%) or tomato fields (2.8%), such that all pairwise combinations

were significantly different (Tukey's HSD post-hoc test $P < 0.001$).

Water Depth and Insect Emergence Response--Regression was used to examine

the effect of depth on the rates of both emerged individuals and emerged biomass. The

rates of emerged individuals and biomass were log transformed and averaged across both

field and crop type. Depth was also averaged across field and crop type. Depth

explained only 22% ($r^2 = 0.219$) of the variation in the number of log-transformed

emerged individuals, but the relationship was significant ($F_{1,35} = 9.79$, $P = 0.004$). The

regression was also a poor fit for log-transformed emerged biomass ($r^2 = 0.31$), but the

overall relationship was also significant ($F_{1,35} = 15.82$, $P < 0.001$).

Calculated Daily Chironomid Production--Average chironomid emerged dry mass

in tomato, wheat, and alfalfa fields were 145.9, 46.8, and 29.2 mg · m^{-2} · day,

respectively. Daily production (calculated by dividing the emerged dry mass by the

0.252 E:P ratio) for tomato, wheat, and alfalfa fields was 578.8, 185.8, and 115.7 mg ·

m^{-2} · day, respectively.

LABORATORY EXPERIMENT- SURVIVAL & BIOMASS—

The number of live chironomid larvae that survived differed significantly between

the low flux (6°C-daily amplitude) and high flux (17°C-daily amplitude) treatments ($t_{1,12}$

= 4.6, P = 0.0006). Nearly four times more larvae hatched and survived in the low flux

($\bar{x}$ = 33.57 individuals, SE = 4.7, range = 15 - 48) than in the high flux treatment ($\bar{x}$ =

8.86 individuals, SE = 2.56, range = 0 - 17; Fig. 5). Total biomass of chironomid larvae

per replicate also differed significantly between treatments ($t_{1,12}$ = 2.98, P = 0.012) with

average biomass per replicate in the low flux treatment ($\bar{x}$ = 39.60 mg, SE = 3.74, range

= 24.9 - 54.3) nearly twice that in the high flux treatment ($\bar{x}$ = 19.64 mg, SE = 5.57,

range = 0 - 35.4; Fig. 6).

DISCUSSION

Fleskes et al. (2003) found that northern pintail use of LSF fields in the TLB

varied by crop type. Our results indicate that differential use of LSF fields by pintails

and other waterbirds may be at least partially due to differences among crop types in

aquatic insect abundance. Although average waste seed densities did not differ

significantly among crop types, waste seed densities did vary greatly among individual

fields. In addition, seeds had a very patchy distribution in fields that resulted in highly

variable estimates that may have prevented us from detecting important biological crop

type differences. Further, we caution that our results should not be interpreted to suggest

that seed availability does not impact use of fields by waterbirds. Waterfowl feed heavily

on seeds when available and select feeding habitats that provide abundant food (Bellrose 1980, Austin and Miller 1995).

We detected significant differences in both the number and total biomass of emerged insects among LSF crop types. Tomato fields had a higher average number of emerged individuals and emerged mass than either alfalfa or wheat fields. We suspect that these differences may be due to differences in the amount of residual crop biomass left after harvest. Alfalfa and wheat harvest leaves relatively little plant biomass in the fields whereas the bulk of the tomato plant is left in the field after fruit are pulled from the vines (R. Moss, personal observation). This additional plant biomass could enhance insect production in two ways. First, the decaying organic matter could directly provide a food resource for detritivorous aquatic insects, and indirectly through the enhanced availability of inorganic nutrients available for autochthonous primary production (Batzer and Resh 1992). Secondly, the additional plant biomass in tomato fields could enhance habitat complexity resulting in higher insect densities relative to other crop types. Either or both of these factors could be driving the greater production of invertebrates in tomato than in alfalfa and wheat fields that we observed. Additional studies incorporating stable isotope ratio analyses on aquatic insects, waste crop biomass, and autochthonous organic matter would help resolve the role of crop type on variation in insect production in flooded agricultural fields.

We calculated invertebrate production in LSF fields by applying E:P ratios (Jackson and Fisher 1986) to our estimates of emergence. We used emergence traps instead of repeatedly collecting soil core samples (Swanson 1978) to more directly measure invertebrate production (Waters 1977, Benke 1984), because a previous

sampling attempt found a high frequency of cores with no larvae and extreme difficulty in traversing the unconsolidated field bottoms to collect cores (D. Barnum, personal communication). We judged that it was not feasible with our resources to attempt to collect, and then separate larvae from the clay substrate, in the numerous core samples that the patchy distribution of larvae would have dictated. The indirect method we used to calculate production from emergence data does assume that the factors controlling production (i.e., faunal composition, temperature, food resources, birth and death rates, etc.) in our and Jackson and Fisher's (1986) environments were similar. Jackson and Fisher's (1986) environment, while a stream, was similar to LSF fields in having very low discharge, similar mean temperatures during the equivalent time period, and not suspected to be nutrient limiting. Emergence rates of chironomids in both systems were nearly identical and E:P ratios were derived from a similar mix of species. The chironomid production that we calculated for LSF fields in the TLB averaged 293.4 mg · m^{-2} · day (tomato = 578.8 mg · m^{-2} · day, wheat = 185.8 mg · m^{-2} · day, alfalfa = 115.7 mg · m^{-2} · day), which was similar to what Jackson and Fisher (1986) reported for time periods I (309 mg · m^{-2} · day) and III (364.7 mg · m^{-2} · day). Daily chironomid production in LSF fields in the TLB was higher than reported for many other environments (see Table 7 in Benke 1993). However, with the relatively short duration that LSF fields in the TLB were flooded, annual production was below average compared to other systems that were abiotically similar. While our calculation of production may not be as accurate as a more direct measurement, it does provide resource planners a reasonable estimate of invertebrate production in post-harvest flooded TLB fields where no previous data exist.

We did not measure invertebrate production until after fields had been inundated for two weeks. The time required for chironomids to establish populations is extremely unpredictable because eggs and larvae may be present in some water sources but not others (Euliss and Grodhaus 1987). Adult chironomids can develop from eggs in as little as two weeks given favorable temperatures (Euliss 1984). Thus, the two weeks we waited to trap greatly increased the likelihood that any emerging adults we trapped had developed from eggs laid by aerially dispersing adults rather than from eggs or larvae present in the water delivered to flood the field. This sampling delay reduced variability in production that could have been caused by differences in water sources and allowed us to focus on measuring impacts of field characteristics (e.g., crop type, water depth) on production, which was our main interest. We speculate that chironomid production during the few days each field was being flooded until the first two weeks after it was completely inundated would average less than what we measured starting two weeks after complete inundation. Until further information becomes available, we suggest assuming chironomid production is zero when water is first applied, with production increasing linearly until day 14 when it reaches the crop-type averages we report.

The relationship we observed between water depth, insect productivity and survival helps explain the considerable spatial heterogeneity in insect emergence and emerged mass within a field. Depth and its effect on benthic habitat temperature fluctuation, appears to play an important role in the survival and growth of chironomids. Maintaining a water depth of 1 meter (the deepest we measured except for the borrow ditch ringing each field) in fields would reduce temperature fluctuation and produce more invertebrates than more shallow water. However, the water costs to maintain deeply

flooded fields could be prohibitive and would probably reduce LSF field acreage. Also, most waterbird species that use these fields (e.g. shorebirds and dabbling ducks) optimally forage in water $\leq$30 cm deep (Safran et al. 1997, Isola et al. 2000). Providing a range of fields depths through creative grading, discing, timing of flooding, or changes in other management techniques would promote both aquatic insect production and optimal waterbird foraging. Thus, we recommend that most of the field be maintained at $\leq$30 cm but with some deeper areas.

Practices that improve the wildlife value of agricultural fields in the TLB would greatly improve local habitat conditions for waterbirds and other wildlife. Nearly all of the TLB is currently managed as highly valuable and productive agricultural ground. Although large areas of the TLB sometimes flood in late winter, the scarcity of late-summer habitat is likely an important factor limiting regional waterbird abundance (Fleskes et al. 2002). Most efforts to restore habitat in the region have focused on taking marginal agricultural ground out of production and restoring it to wetlands. While vital for maintaining wildlife populations, this effort has occurred at a relatively small scale and is not likely to create enough suitable habitat to fully restore waterbird populations in the region. Creative cooperative management programs, such as the Landowner Incentive Program, which is an effort to reverse the decline of special status species in the Central Valley of California through enhancement and management of private lands (LIP 2005), could greatly enhance the waterbird value of these agricultural fields, while maintaining or even improving their agricultural production.

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Figure 1. Study Area.

Figure 2. Number of emerged insects (individuals $\cdot$ m^{-2} $\cdot$ day^{-1}) by crop type during each of five, 3-4 day sampling intervals on post-harvest flooded fields in the Tulare Lake Basin, California during August-October, 2003 and 2004.

Figure 3. Total mass of emerged insects (mg $\cdot$ m^{-2} $\cdot$ day^{-1}) by crop type during each of five, 3-4 day sampling intervals on post-harvest flooded fields in the Tulare Lake Basin, California during August-October, 2003 and 2004.

Figure 4. Composition of emerged insects by crop type on post-harvest flooded fields in the Tulare Lake Basin, California during August-October, 2003 and 2004.

 Figure 5. Number of live chironomid larvae per replicate in a high-fluctuation temperature (high flux) vs. low-fluctuation temperature (low flux) lab environment.

Figure 6. Total mass of live chironomid larvae per replicate in high-fluctuation temperature (high flux) vs. low-fluctuation temperature (low flux) lab environment.
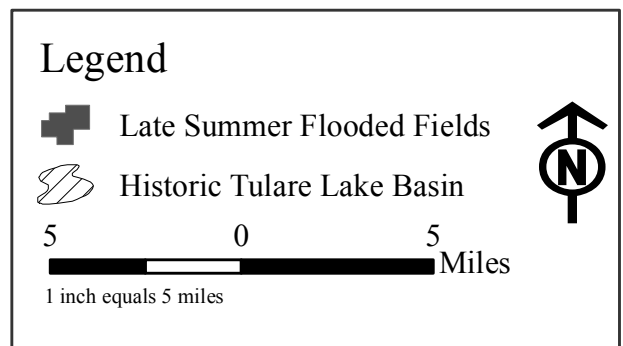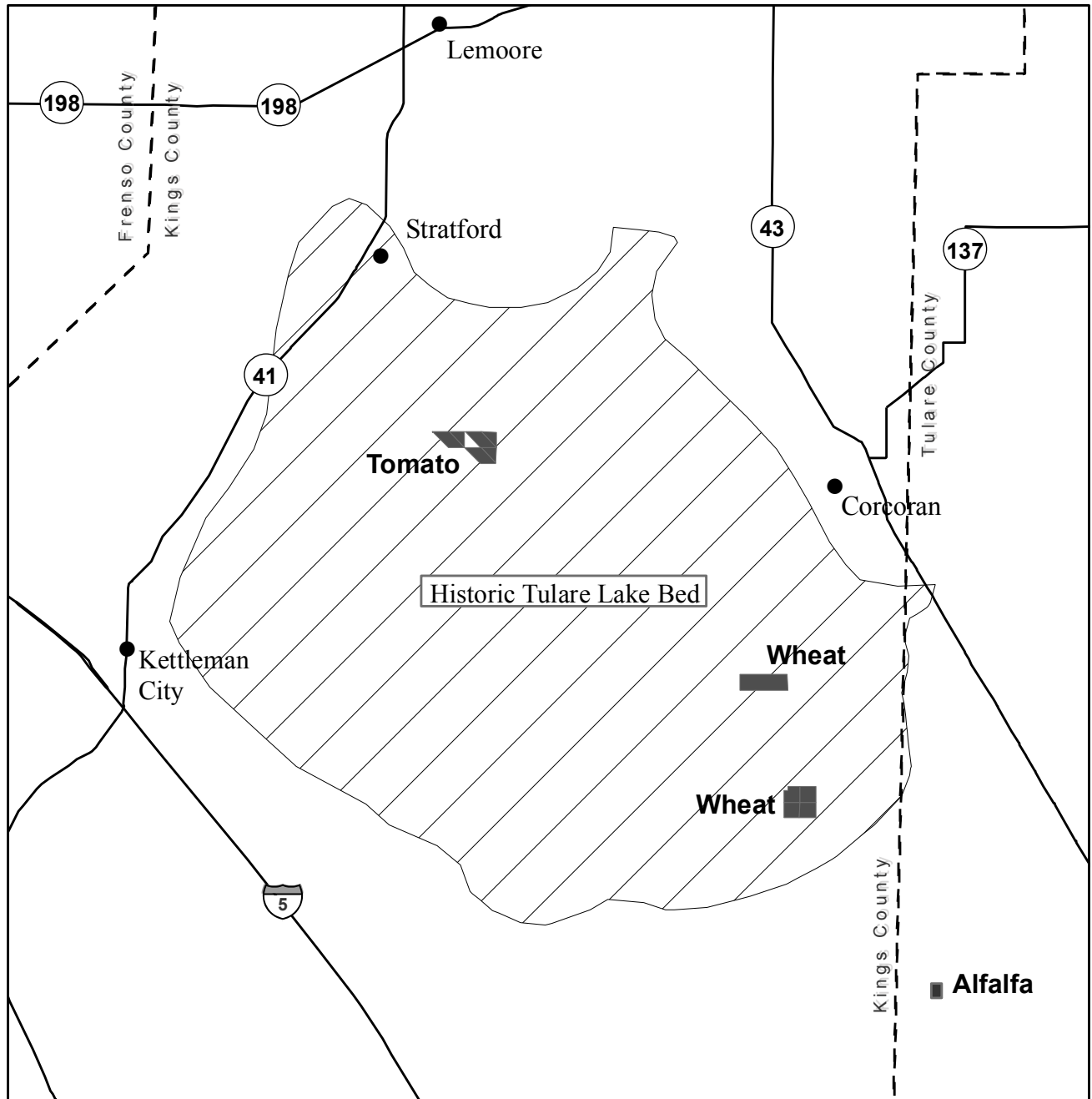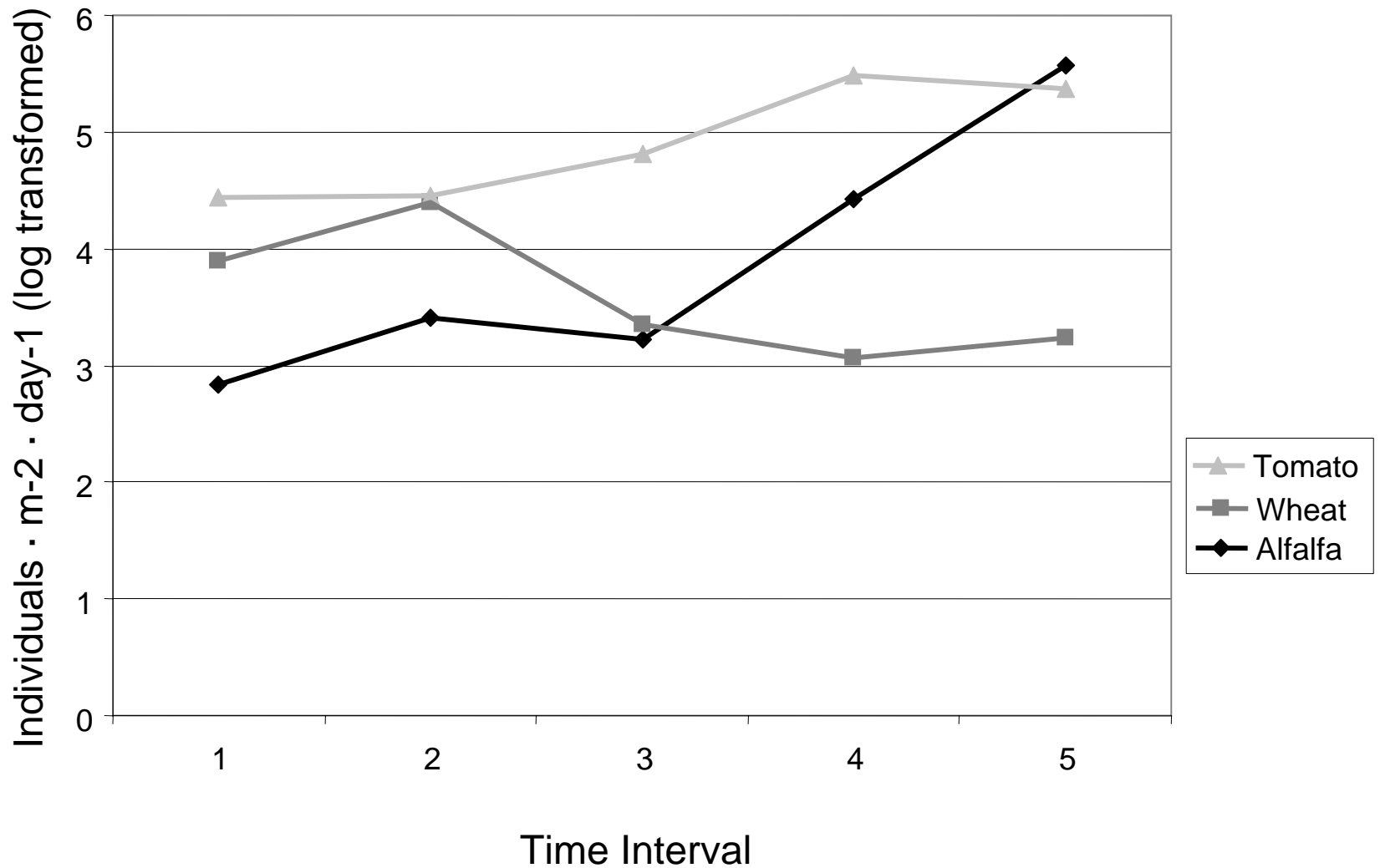
Lemoore

198 198

Frenso County

Kings County

Stratford

41

43

137

Tulare County

Tomato

Corcoran

Historic Tulare Lake Bed

Wheat

Kettleman City

Wheat

5

Kings County

Alfalfa

Study Area

Legend

Late Summer Flooded Fields

Historic Tulare Lake Basin

5   0   5
Miles

1 inch equals 5 miles

N

Figure 1. Study Location

Figure 2. Number of emerged insects (log transformed individuals $\cdot$ m^{-2} $\cdot$ day^{-1}) by crop type during each of five, 3-4 day sampling intervals on post-harvest flooded fields in the Tulare Lake Basin, California during August-October, 2003 and 2004.
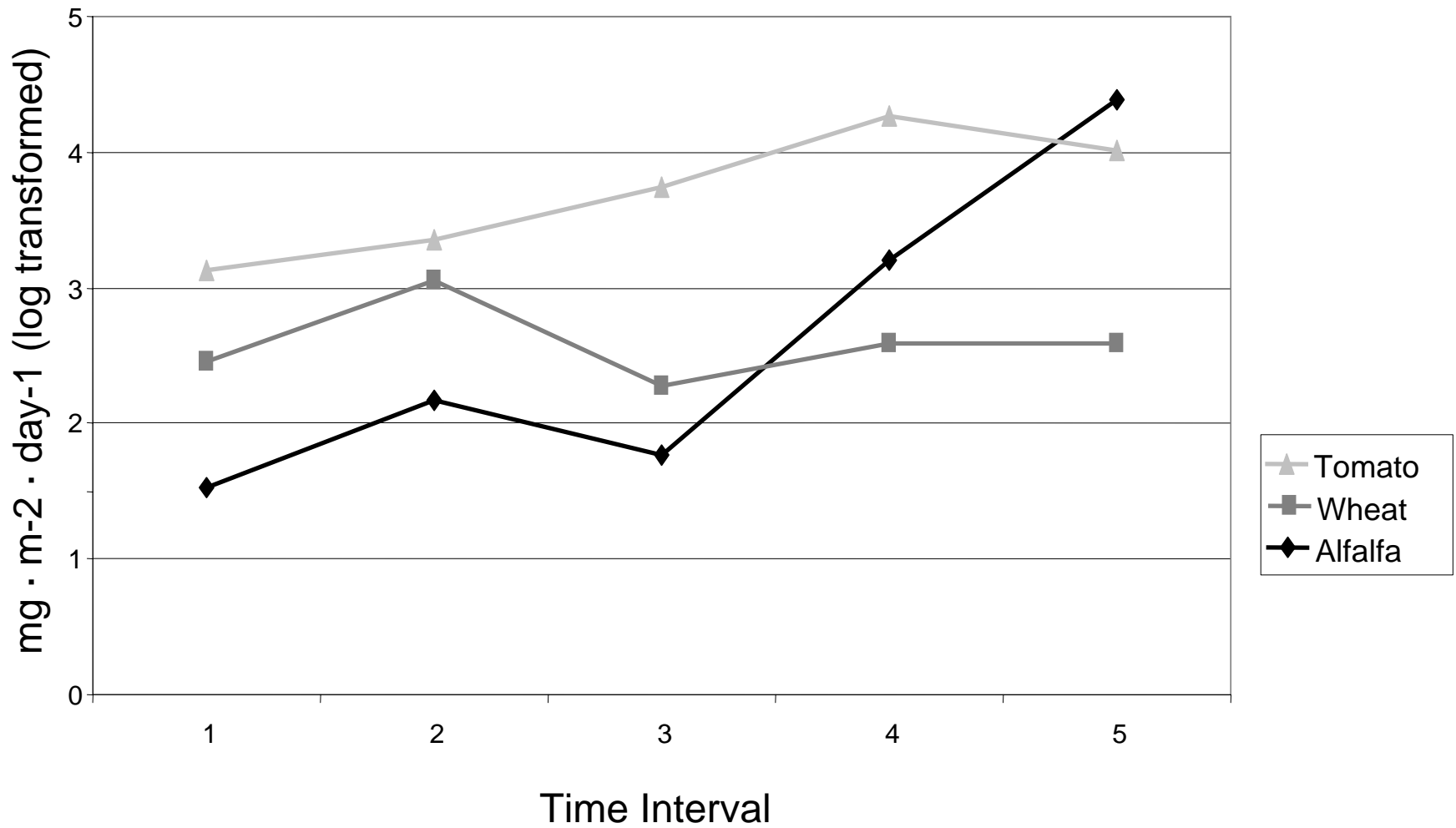
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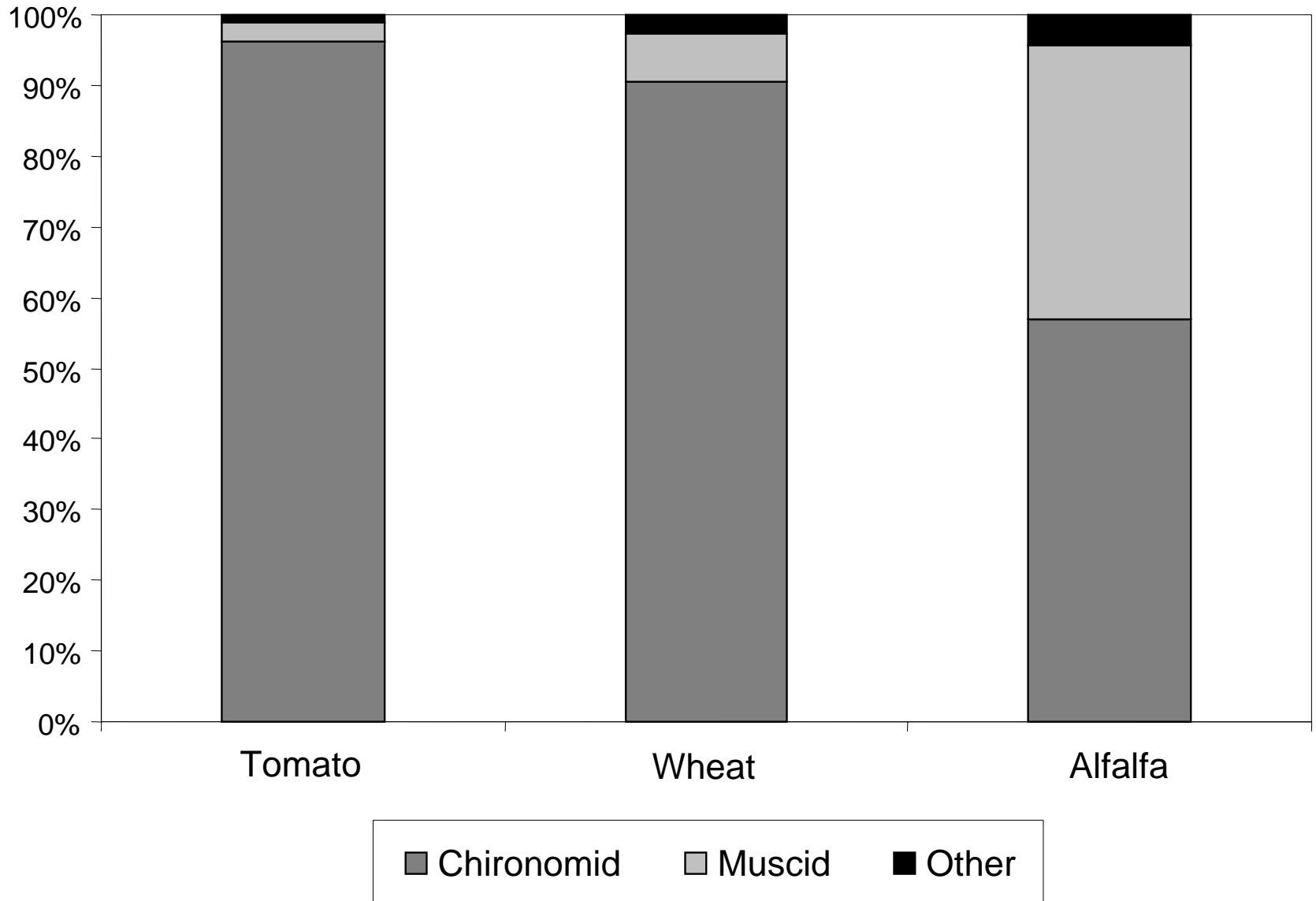
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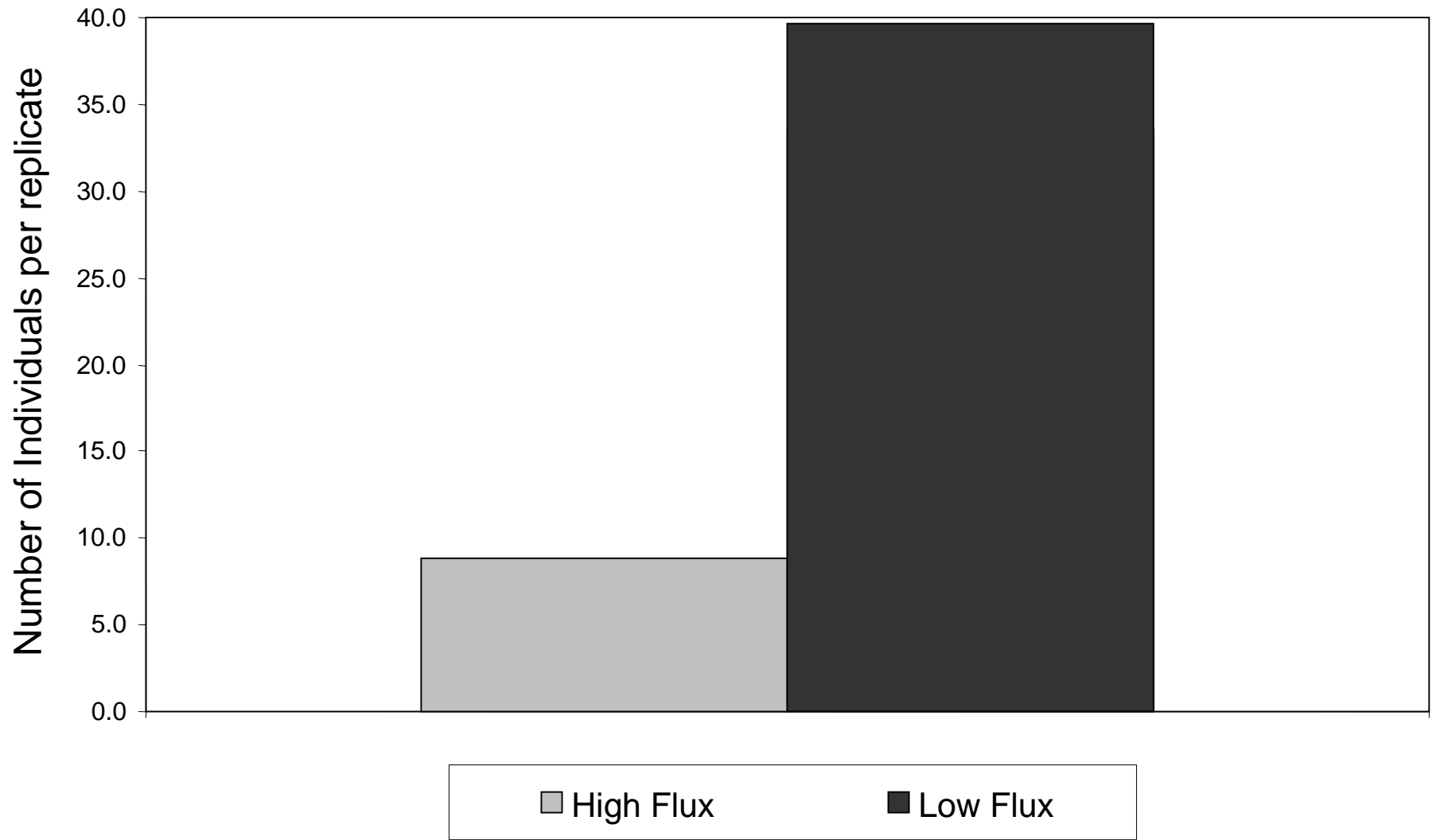
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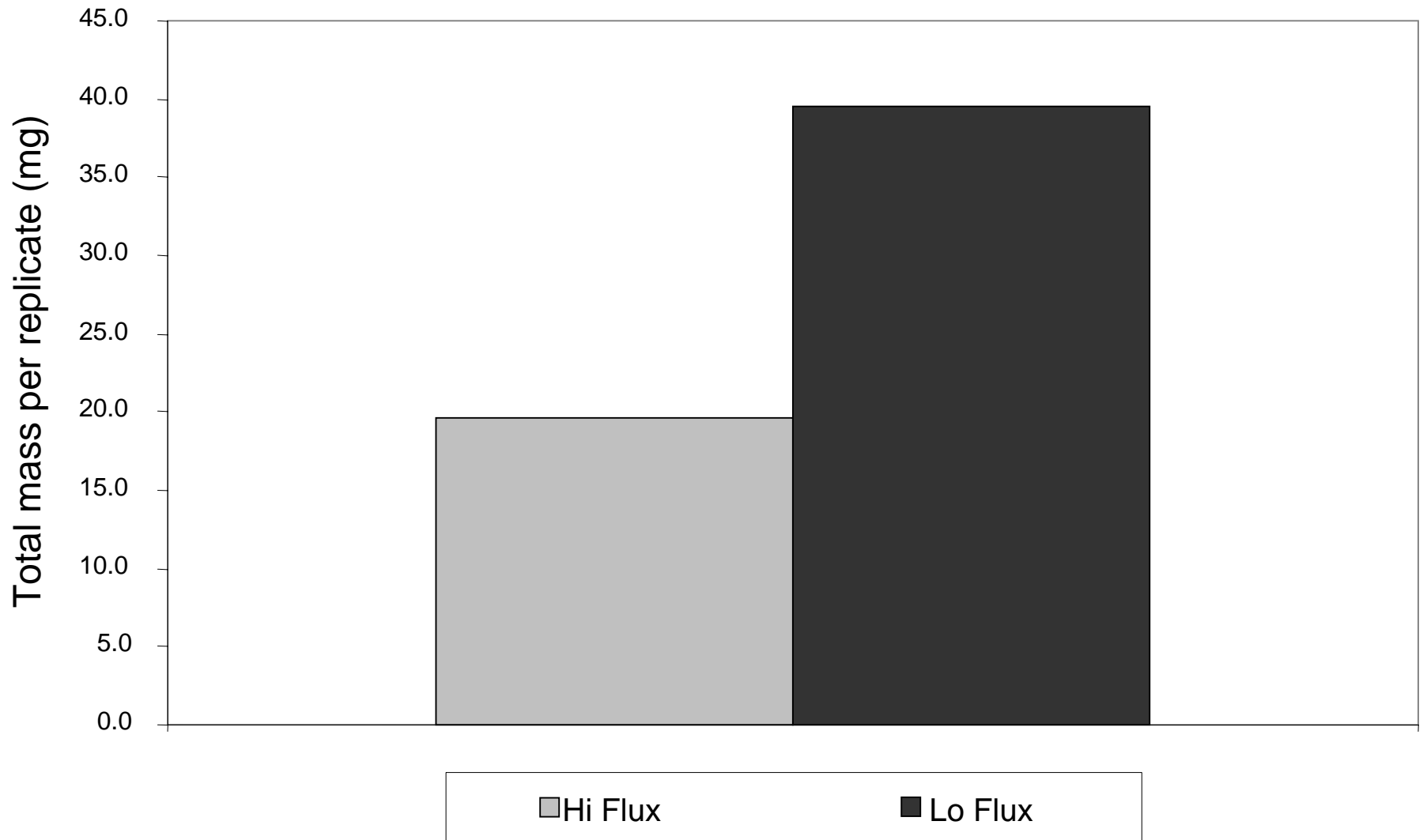
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