Effects of Ammonia/um and Wastewater Effluent Associated Contaminants on Delta Smelt

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Acknowledgments

- IEP-POD for funding LC50 and field studies
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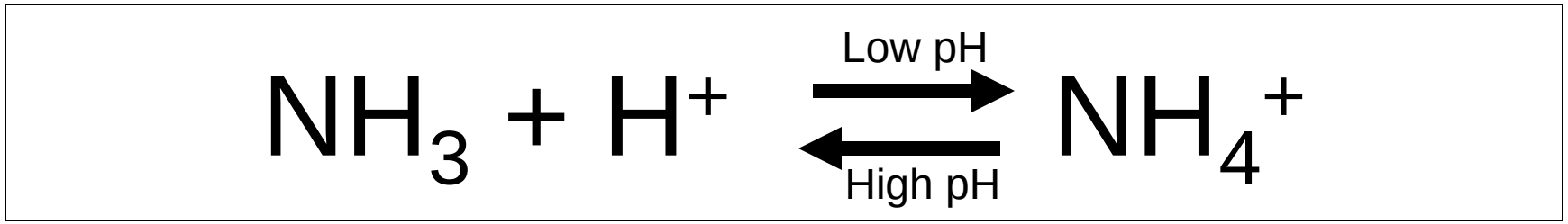
- UC Davis Fish Conservation and Culture Laboratory, Byron, CA, for providing Delta smelt and plentiful advice
- Sacramento Regional Wastewater Treatment Plant (SRWTP) for providing effluent
- Chris Foe, CVRWQCB, for collecting Sacramento Rivers water and effluent
- All staff members of ATL



Un-Ionized Ammonia

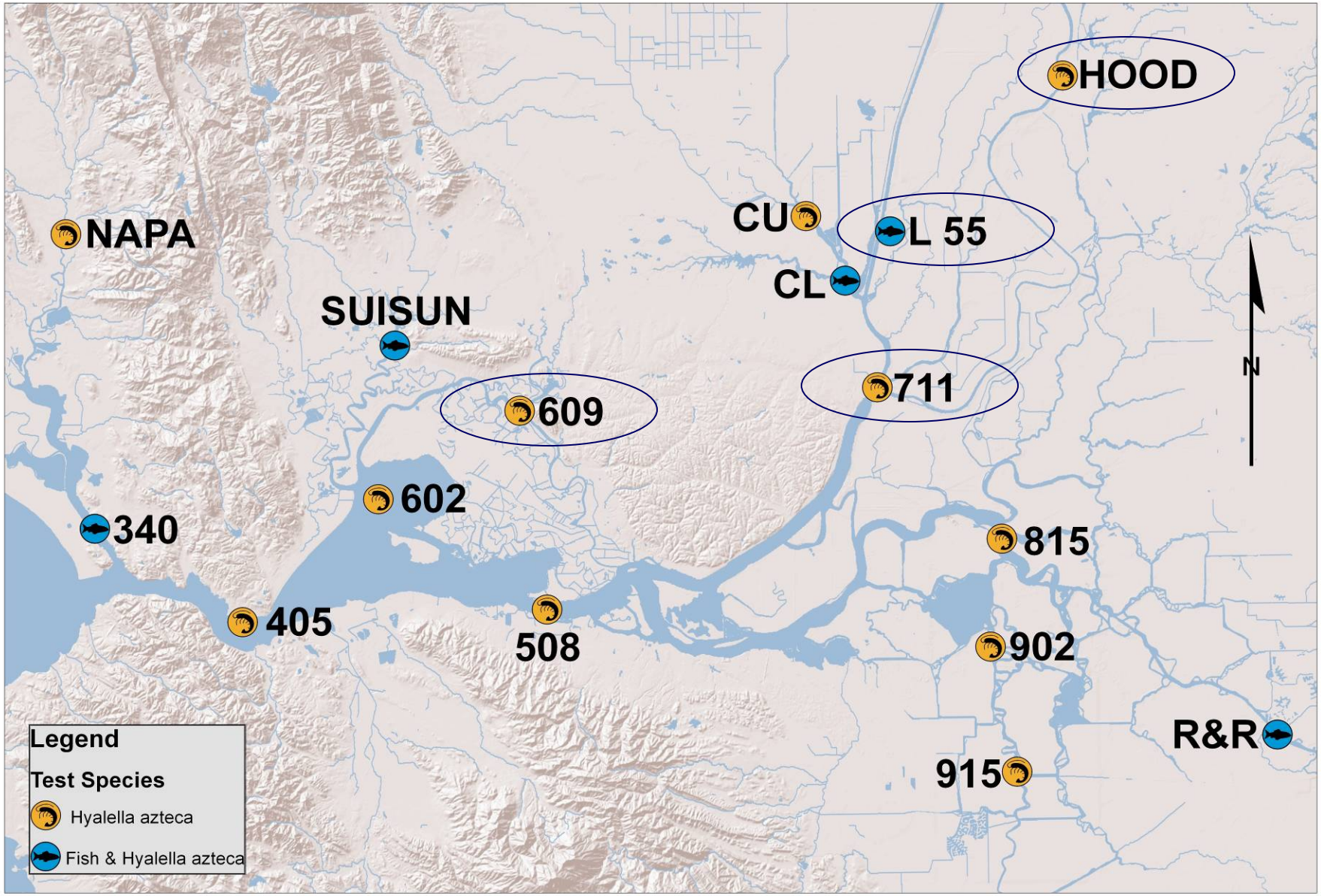
Ammonium

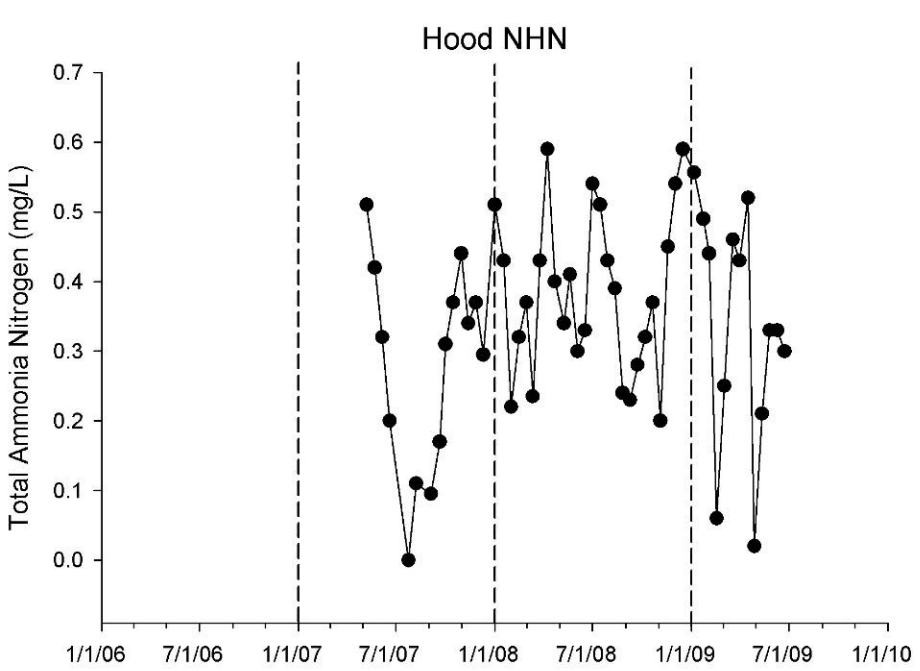
Total Ammonia/um

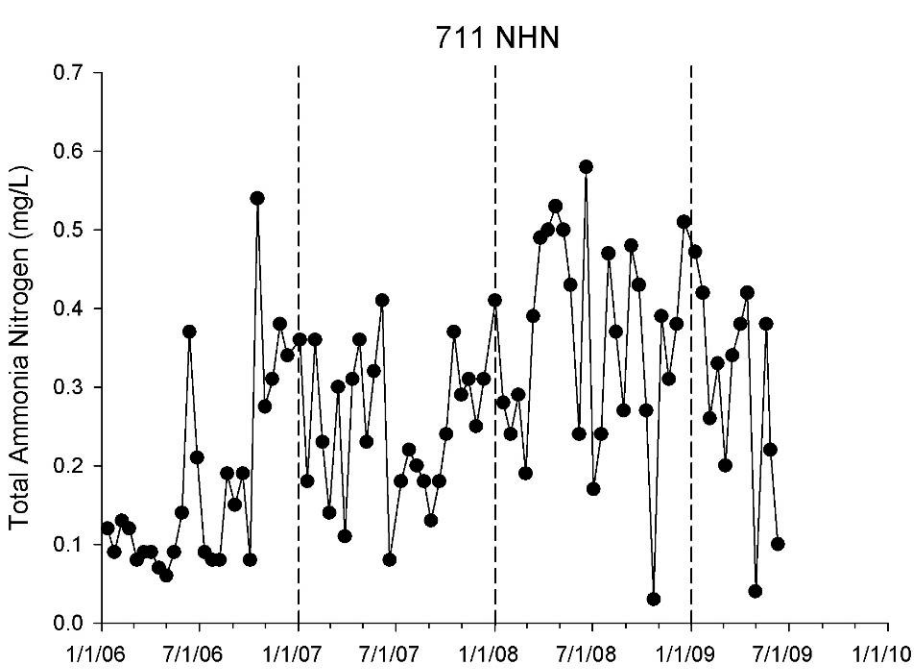
Total Ammonia/um and Un-ionized Ammonia 2006-07

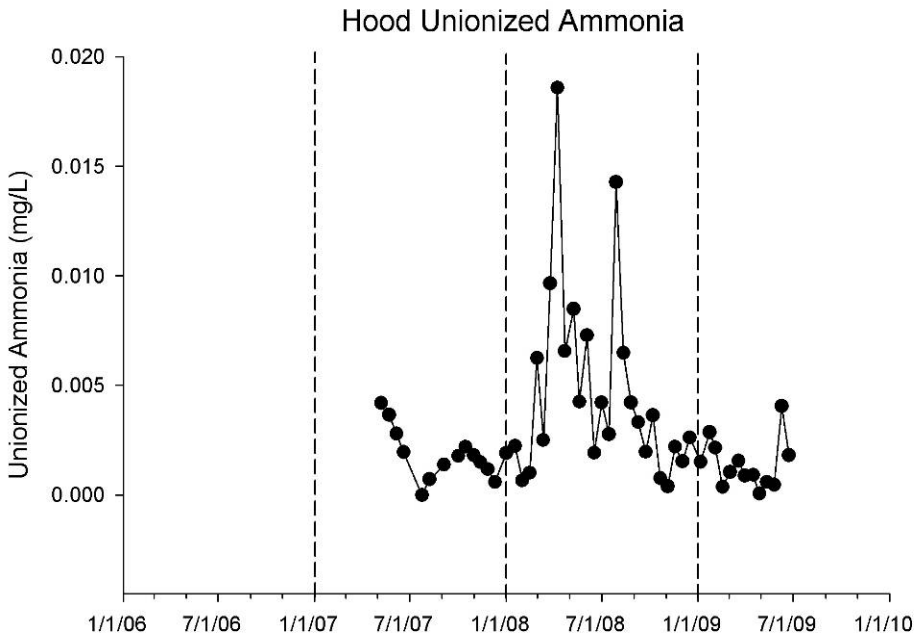
Site	Total Ammonia Nitrogen (mg/L)					Unionized Ammonia (mg/L)			
	N	Mean	SD	Range	Rank	Mean	SD	Range	Rank
323	14	0.11	0.04	(0.06 - 0.2)	BC	0.001	0.001	(0 - 0.003)	ABCD
340	39	0.08	0.07	(0 - 0.33)	C	0.001	0.001	(0 - 0.002)	D
405	47	0.13	0.08	(0 - 0.49)	B	0.002	0.001	(0 - 0.006)	ABC
504	50	0.1	0.06	(0 - 0.26)	BC	0.001	0.001	(0 - 0.005)	CD
508	50	0.1	0.06	(0 - 0.24)	BC	0.001	0.001	(0 - 0.006)	CD
602	49	0.11	0.07	(0 - 0.27)	BC	0.001	0.001	(0 - 0.005)	ABCD
609	50	0.12	0.08	(0 - 0.27)	B	0.001	0.001	(0 - 0.003)	CD
704	50	0.11	0.07	(0 - 0.3)	BC	0.001	0.001	(0 - 0.005)	BCD
711	50	0.21	0.11	(0.06 - 0.54)	A	0.003	0.003	(0 - 0.013)	A
804	50	0.09	0.06	(0 - 0.29)	C	0.002	0.002	(0 - 0.008)	BCD
812	48	0.09	0.06	(0 - 0.29)	C	0.001	0.001	(0 - 0.005)	CD
902	50	0.06	0.05	(0 - 0.24)	C	0.001	0.002	(0 - 0.01)	CD
910	50	0.15	0.1	(0 - 0.44)	B	0.002	0.002	(0 - 0.007)	ABCD
915	50	0.07	0.07	(0 - 0.38)	C	0.001	0.001	(0 - 0.006)	CD
Hood	14	0.28	0.15	(0 - 0.51)	A	0.002	0.001	(0 - 0.004)	ABCD
Light 55	48	0.12	0.08	(0 - 0.29)	B	0.003	0.003	(0 - 0.012)	AB

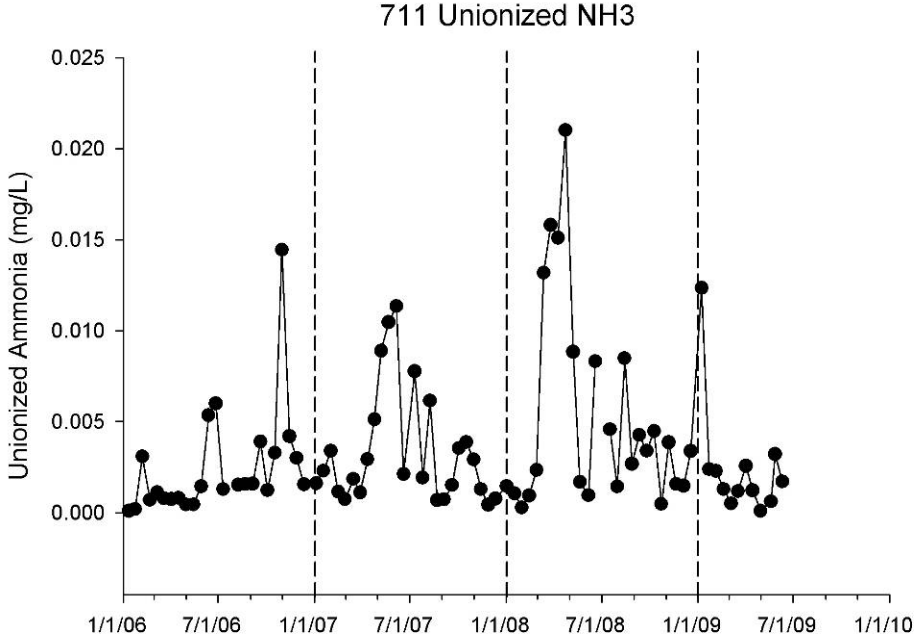
POD 2008 WATER TOXICITY SAMPLING LOCATIONS

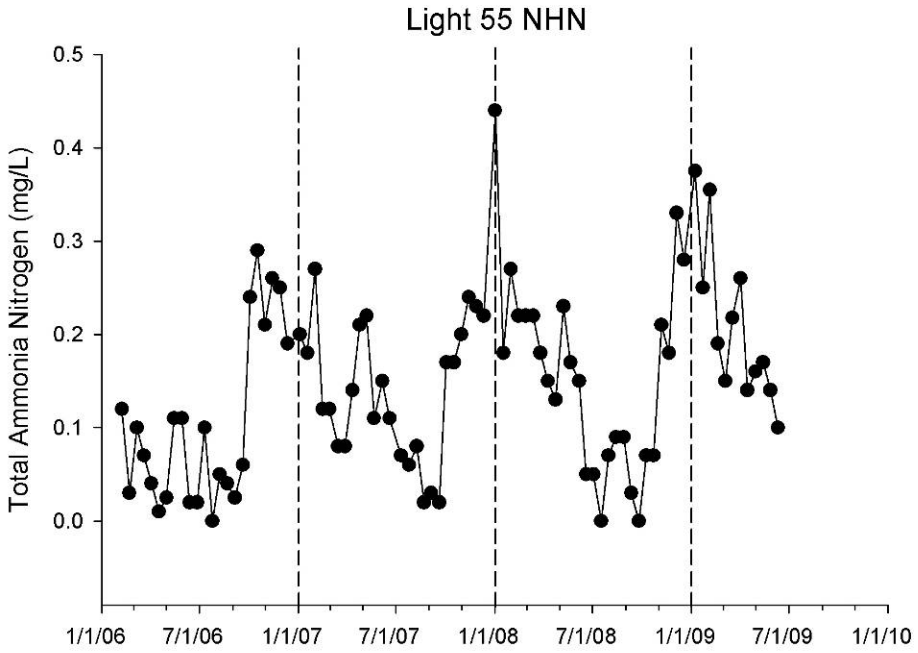


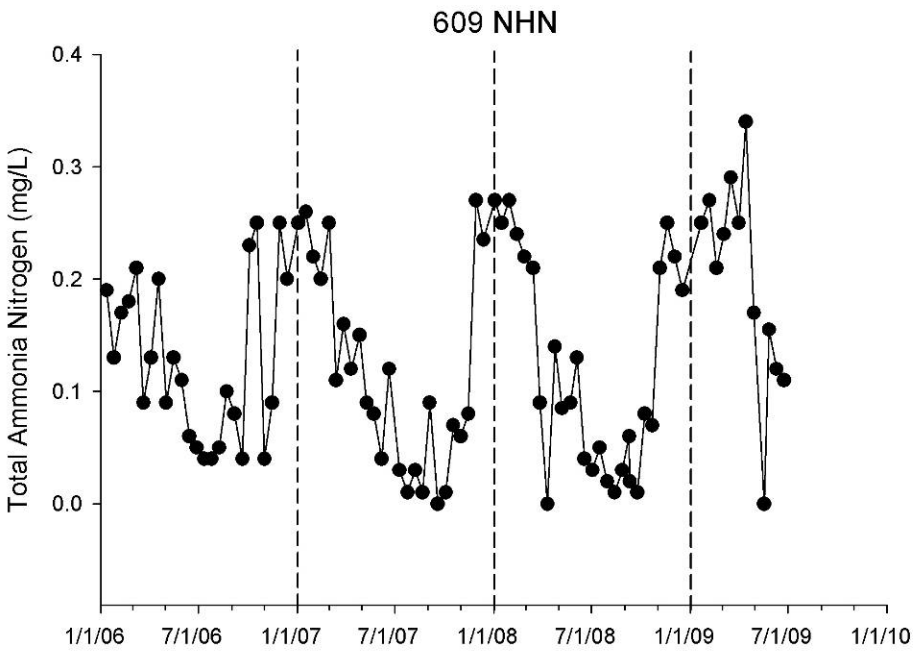

Hood NHN
Total Ammonia Nitrogen (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10

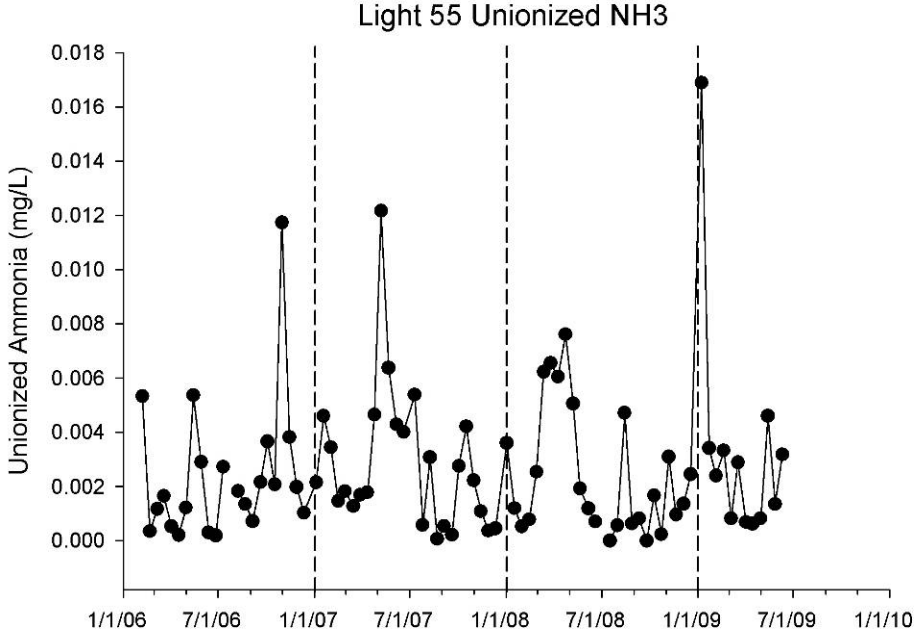

711 NHN
Total Ammonia Nitrogen (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10

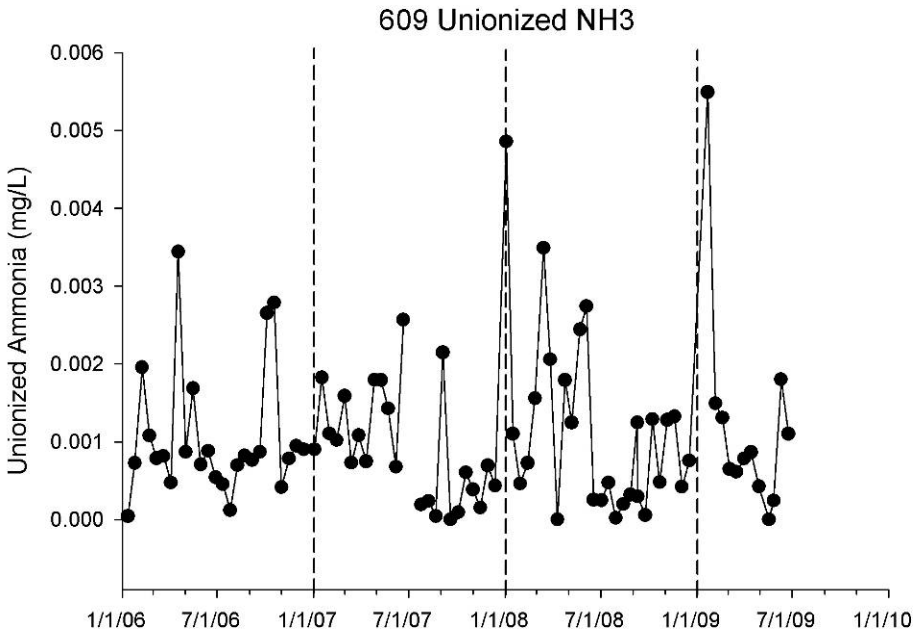

Hood Unionized Ammonia
Unionized Ammonia (mg/L)
0.020
0.015
0.010
0.005
0.000
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10


711 Unionized NH3
Unionized Ammonia (mg/L)
0.025
0.020
0.015
0.010
0.005
0.000
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10


Light 55 NHN
Total Ammonia Nitrogen (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10


609 NHN
Total Ammonia Nitrogen (mg/L)
0.4
0.3
0.2
0.1
0.0
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10


Light 55 Unionized NH3
Unionized Ammonia (mg/L)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10


609 Unionized NH3
Unionized Ammonia (mg/L)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10

Total Ammonia/um 96-h Effect Concentrations (mg/L)

	FHM	RB Trout	Delta Smelt	Acute EPA Criteria*
LC50	20.9	11.2**	11.4-12 (N=3)	3.15 - 13.3
LOEC	29.8		9	
NOEC	15.2		5	

* Acute, with salmonids present, pH 8.3-7.5, 1-h average

** Mean acute value

Un-Ionized Ammonia 96-h Effect Concentrations (mg/L)

	FHM	RB Trout	Delta Smelt	Acute EPA Criteria
LC50	0.827	0.163-1.020	0.147	**pH 7.5-8.3, T=16°C, EC=150 uS/cm:**
LOEC	1.121		0.105	0.116-0.166
NOEC	0.629		0.066	

Acute-to-Chronic Ratios

- Channel Catfish: 2.7
- Fathead minnow: 10.9
- Rainbow Trout: 14.6-23.5

US EPA **Chronic Criteria** (30-day average) for Fish Early Life Stages Present (USEPA, 1999) and respective **ammonia/um** concentrations for temperature and pH extremes measured at Hood and Grand Island (Site 711).

T (°C)	pH	EC (µS/cm)	**NH_4^+/NH_3 (mg/L)**	NH_3 (mg/L)
6.1	6.6	150	**6.57**	0.003
25.0	6.6	150	**3.13-3.56**	0.007-0.008
6.1	8.3	150	**1.52**	0.038
25.0	8.3	150	**0.73-0.83**	0.070-0.080

Delta Smelt 96h-LC50: 12 mg/L; LOEC: 9 mg/L; NOEC: 5 mg/L

US EPA **Chronic Criteria** (30-day average) for Fish Early Life Stages Present (USEPA, 1999) and respective **ammonia/um** concentrations for temperature and pH extremes measured at Hood and Grand Island (Site 711).

T (°C)	pH	EC (µS/cm)	NH_4^+/NH_3 (mg/L)	**NH_3 (mg/L)**
6.1	6.6	150	6.57	**0.003**
25.0	6.6	150	3.13-3.56	**0.007-0.008**
6.1	8.3	150	1.52	**0.038**
25.0	8.3	150	0.73-0.83	**0.070-0.080**

Delta Smelt 96h-LC50: 0.147 mg/L; LOEC: 0.105 mg/L; NOEC: 0.066 mg/L

Conclusions I

- Measured ammonia/um concentration maxima in the Delta are *15x (total) and 5x (un-ionized) below 96-h LOEC* concentrations of 40-50 d old delta smelt
- US EPA *acute* criteria (when converted to un-ionized NH_3) are *not protective at high pH (8.3)*
- US EPA *chronic* criteria *may not be protective* depending on pH, T, EC

Delta Smelt Exposures to SRWTP Effluent and NH_4Cl

- 48-h acclimation period
- 7-d exposure
- daily water exchange
- T=16-17^{o}C
- NH_4Cl or effluent (24-h composites) diluted with Sacramento River water (Garcia Bend)
- pH and ammonia measurements 3 x daily

Effluent Test I (2008)

Percent survival of 55-d old delta smelt larvae; shaded cells indicate significant ($p<0.05$) reduction in survival compared to the hatchery water control.

Treatment	Survival (%)	
	mean	se
Sacramento River at Garcia Bend (SRGB)	66.3	8.8
SRGB + 0.25 mg/L NH_3/NH_4^+ from NH_4Cl	62.5	8.0
SRGB + 0.50 mg/L NH_3/NH_4^+ from NH_4Cl	64.1	11.4
SRGB + 1.00 mg/L NH_3/NH_4^+ from NH_4Cl	64.2	8.3
SRGB + 2.00 mg/L NH_3/NH_4^+ from NH_4Cl	72.3	5.2
SRGB + 4.00 mg/L NH_3/NH_4^+ from NH_4Cl	61.2	7.1
SRGB + 0.25 mg/L NH_3/NH_4^+ from SRWTP	81.4	3.7
SRGB + 0.50 mg/L NH_3/NH_4^+ from SRWTP	45.8	4.2
SRGB + 1.00 mg/L NH_3/NH_4^+ from SRWTP	62.6	4.3
SRGB + 2.00 mg/L NH_3/NH_4^+ from SRWTP	64.9	10.1
Low EC Control[1]	81.3	7.1
Hatchery Water Control	91.7	3.4

[1] The Low EC Control consisted of hatchery water diluted with distilled water to match SRGB conductivity.

Effluent Test III (2009)

Percent survival of 47-d old delta smelt larvae.

Treatment	96-hr Survival (%)		7-day Survival (%)	
	mean	se	mean	se
Sacramento R. at Garcia Bend	92.0	3.4	73.5	10.6
2.00 mg/L NH_3-N: NH_4Cl	91.5	3.4	73.9	5.1
4.00 mg/L NH_3-N: NH_4Cl	91.5	3.4	65.3	5.7
6.00 mg/L NH_3-N: NH_4Cl	95.8	2.4	77.1	4.0
8.00 mg/L NH_3-N: NH_4Cl	76.5	9.1	32.4	9.7
2.00 mg/L NH_3-N: SRWTP	95.8	2.4	75.0	5.9
4.00 mg/L NH_3-N: SRWTP	85.5	7.0	41.5	10.2
6.00 mg/L NH_3-N: SRWTP	81.1	7.8	36.0*	9.0
8.00 mg/L NH_3-N: SRWTP	33.5*	12.1	6.3*	4.0
Low EC Control	95.8	4.2	85.2	7.1
Hatchery Water Control	95.6	2.5	82.4	9.9
Hatchery Water - No Antibiotics	83.7	9.0	81.6	11.0

Shaded cells indicate treatments with significantly lower survival than the Sacramento River at Garcia Bend dilution water control.

*significantly lower than the corresponding treatment containing NH_4Cl (two-tailed test).

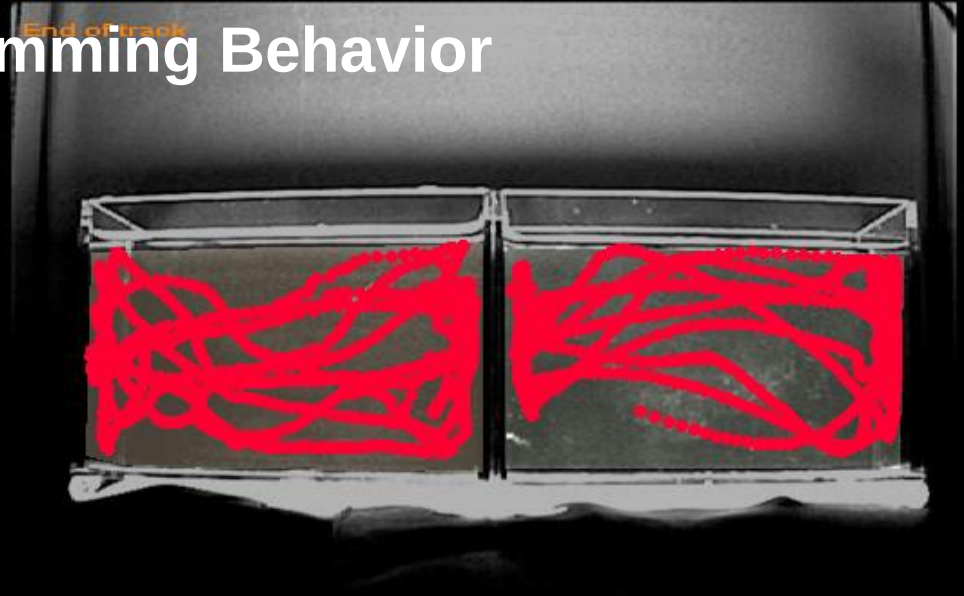
7-Day Effect Concentrations (mg/L) For Larval Delta Smelt (47 d)

	NH_4^+/NH_3	NH_4^+/NH_3 (Effluent)	NH_3	NH_3 (Effluent)	% Effluent
LC50	7.45	5.40	0.113	0.090	25.7
LOEC	7.71	3.92	0.116	0.081	18.3
NOEC	5.66	1.96	0.091	0.039	9

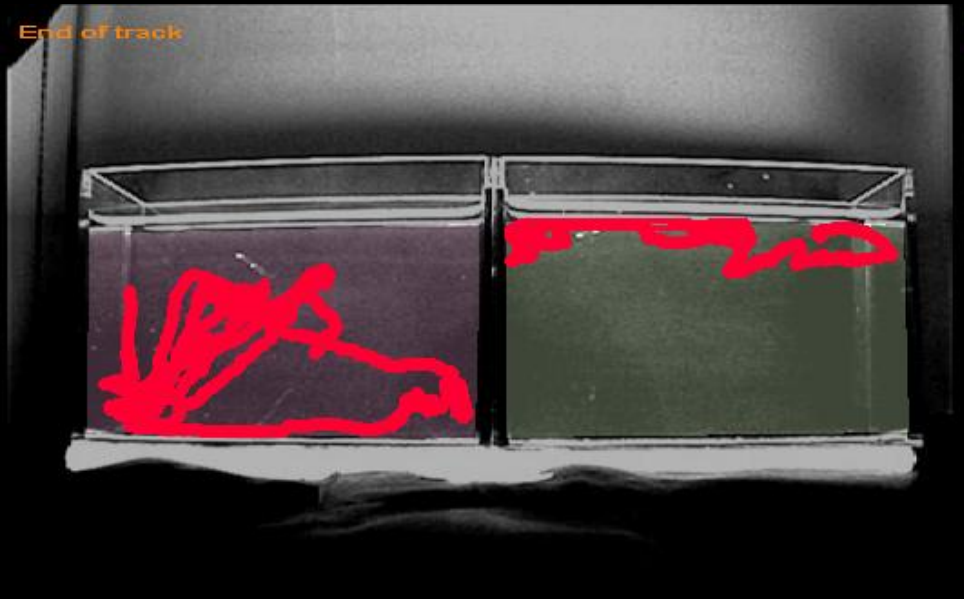
Ammonia in effluent approx. 30-40% more toxic than ammonia/um alone.

Delta Smelt Swimming Behavior

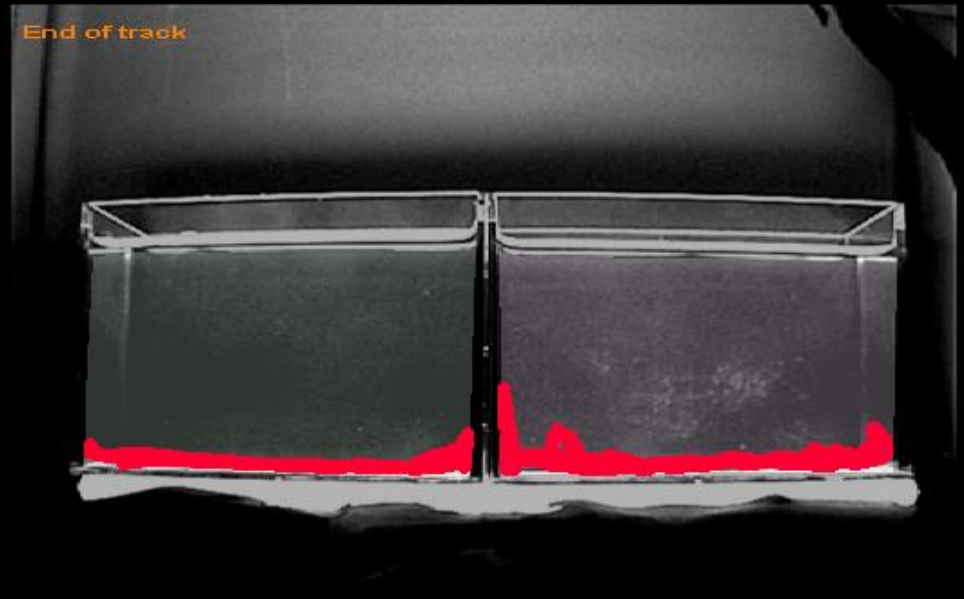
Garcia Bend



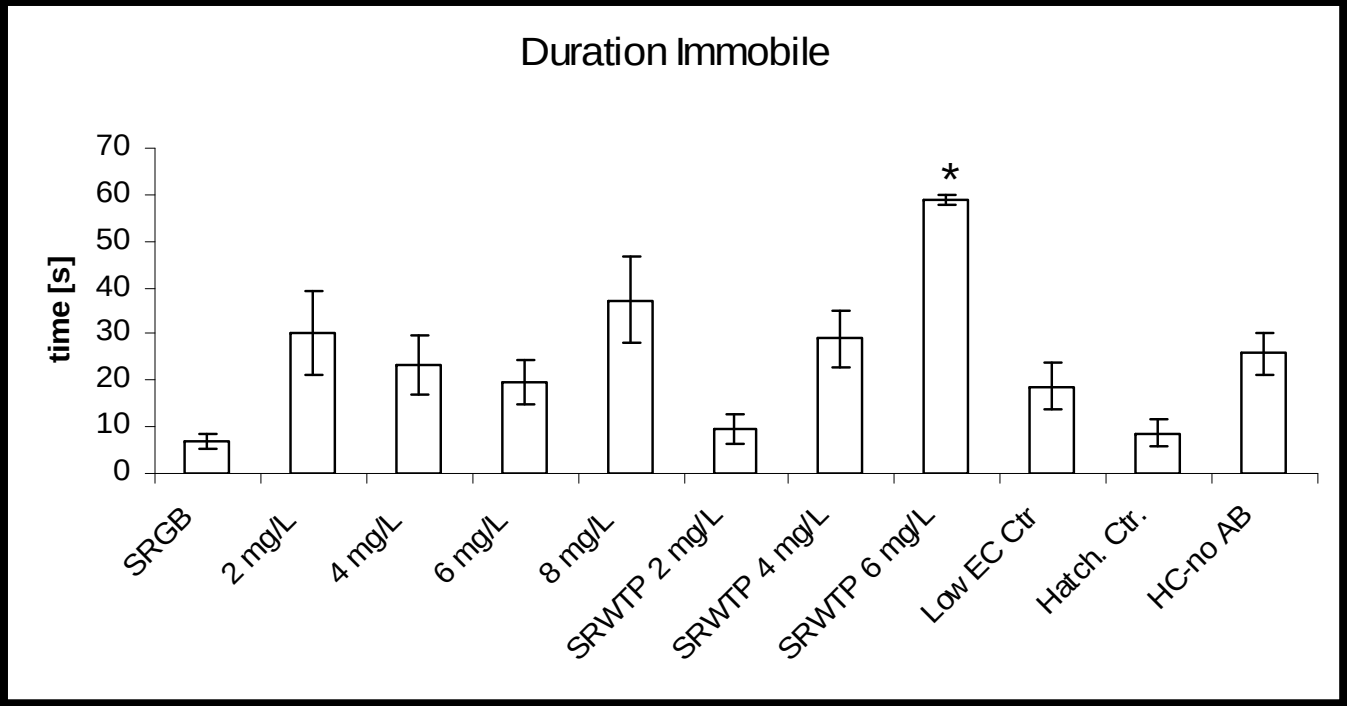
2 mg/L SRWTP

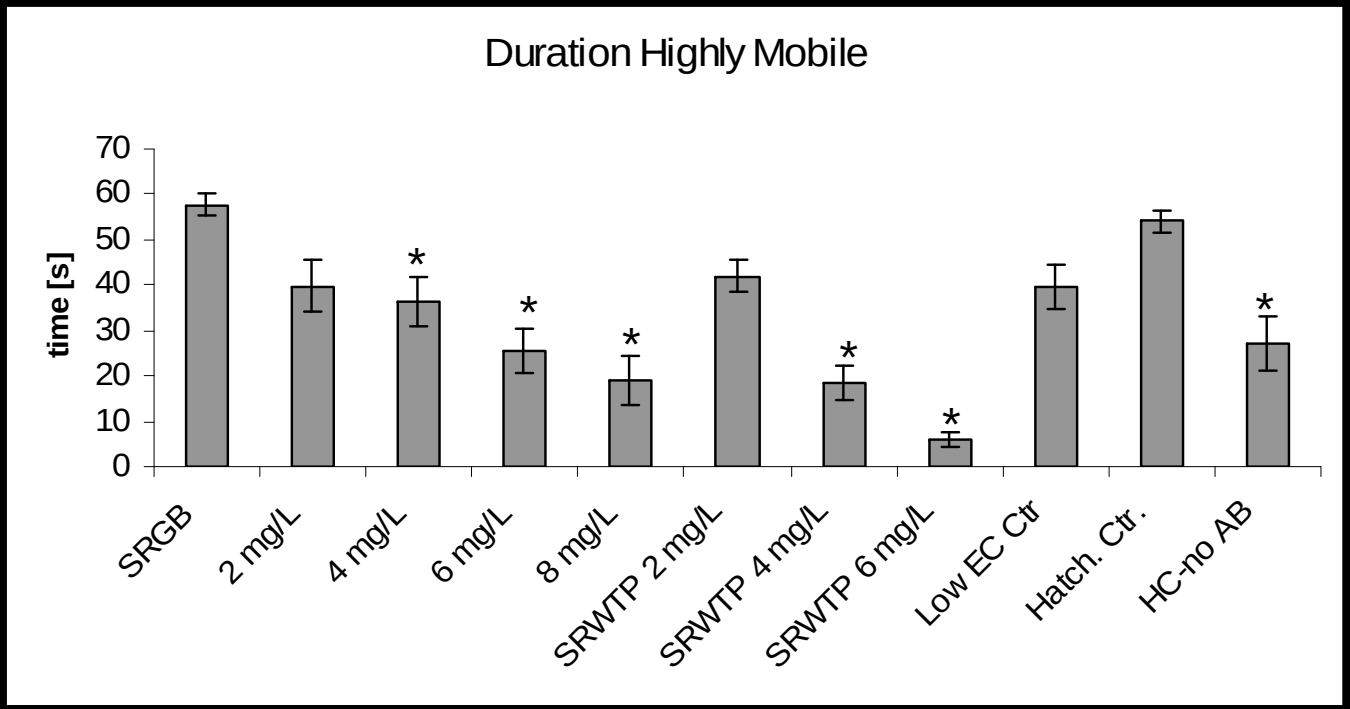


4 mg/L SRWTP



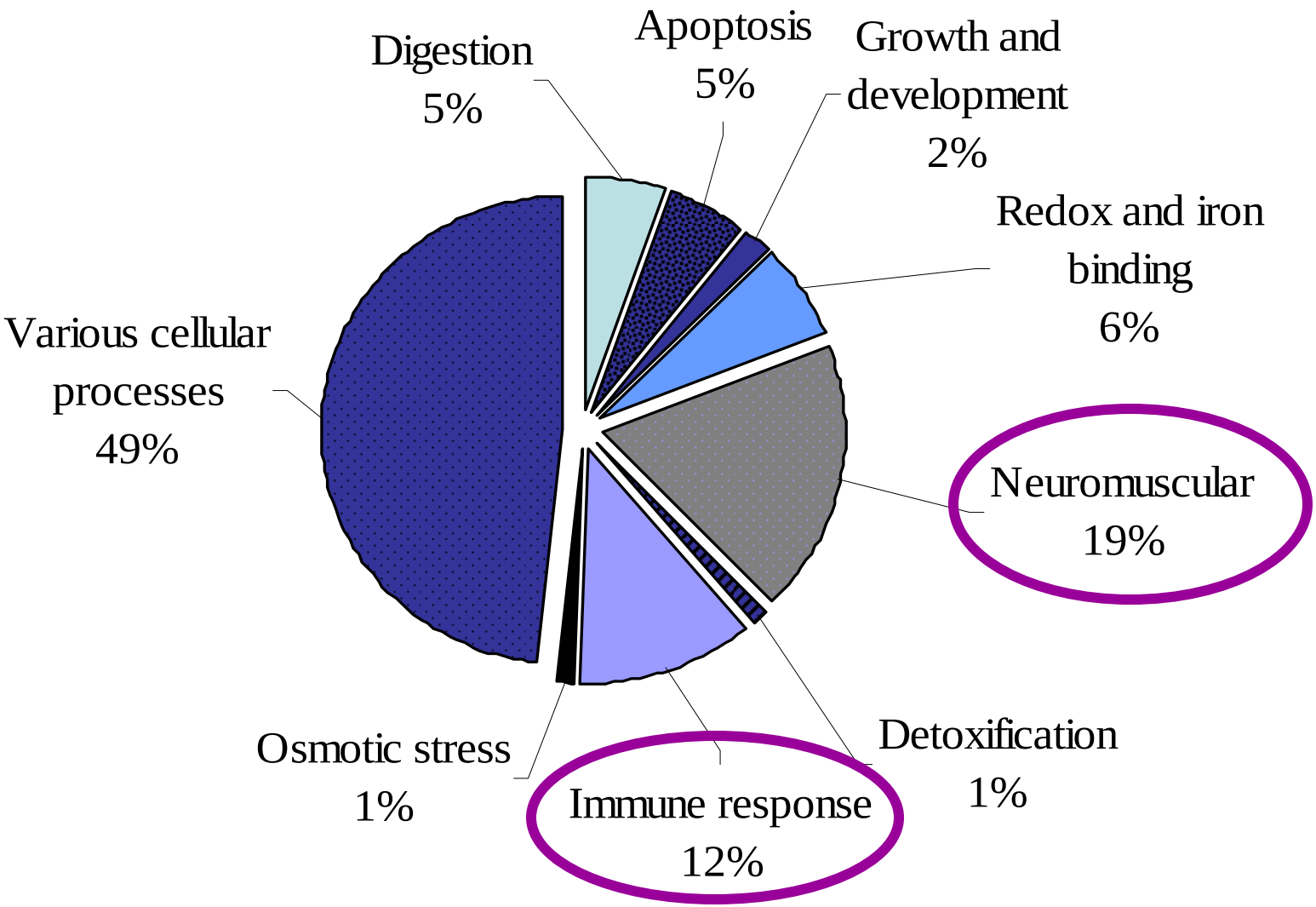
6 mg/L SRWTP





*** sign. different from SRGB**

Functional Classification Of Genes Responding To Esfenvalerate Exposure (0.0625 & 0.125 µg.L^{-1}) In Larval Delta Smelt.



Connon et al. (in press) BMC Genomics

Conclusions II

- SRWTP effluent did not affect 7-d survival of 55-d old delta smelt at concentrations *up to 2 mg/L* total ammonia/um.
- SRWTP *effluent was approx. 30-40% more toxic* than ammonia/um alone.
- US EPA *acute and chronic* criteria for ammonia/um, especially from effluent, *may not be protective* for delta smelt depending on pH, T, and EC.
- Swimming behavior can be a sensitive sublethal endpoint for effluent/ammonia/um effects.
- Biomarkers can help identify effluent/ammonia/um related effects in the field.