

A Comparative Analysis of Sonic Defences in Bombycoidea Caterpillars

Veronica L. Bura¹, Akito Y. Kawahara², Jayne E. Yack^{1*}

¹Department of Biology, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario, K1S 5B6, Canada

²Florida Museum of Natural History, University of Florida, Gainesville, Florida, 32611, USA

*Corresponding author: Dr. Jayne E. Yack, Department of Biology, Carleton University, 1125 Colonel By Drive, Ottawa, ON, Canada, K1S 5B6; Email: jayneyack@cunet.carleton.ca; Tel: 613 520 2600 (Ext. 3887)

Supplementary Table 1

Summary of all species examined for defensive behaviours between 2005-2014.

Taxonomic Group ^a			Collection Data			Sound Production	
Family	Subfamily	Species	No. of specimens (No. of broods)	Food plant	Collection location	Y/N	Type
Bombycidae	Bombycinae	<i>Bombyx mori</i> Linnaeus	10	<i>Morus rubra</i>	Ottawa, ON (Pet store)	No	n/a
	Apatelodinae	<i>Hygrochroa torrefacta</i> Smith	28	<i>Prunus</i> sp.	Arizona	No	n/a
		<i>Olceclostera angelica</i> (Grote)	50+ (2)	<i>Fraxinus</i> sp., <i>Syringa</i> sp.	Chaffey's Lock (QUBS), ON	No	n/a
Saturniidae	Ceratocampinae	<i>Anisota virginiensis</i> (Drury)	70+ (2)	<i>Quercus</i> sp.	Chaffey's Lock (QUBS), ON	No	n/a
		<i>Citheronia lobesis</i> Rothschild	2	<i>Cochlospermum vitifolium</i>	Costa Rica, Guanacaste	Yes	Chirping
		<i>Citheronia splendens</i> (Druce)	50+	<i>Rhus</i> sp.	Arizona	No	n/a
		<i>Dryocampa rubicunda</i> (Fabricius)	85+ (2)	<i>Acer saccharum</i>	Ottawa (Mer Bleue), ON & PEI	No	n/a
		<i>Eacles imperialis</i> (Drury)	50+ (2)	<i>Pinus</i> sp., <i>Picea</i> sp.	Chaffey's Lock (QUBS), ON	No	n/a
		<i>Eacles ormondei</i> Schaus	1	<i>Tapirira mexicana</i>	Costa Rica	No	n/a
		<i>Eacles oslari</i> Rothschild	5	<i>Quercus alba</i>	Arizona	No	n/a
		<i>Schausiella santarosensis</i> Lemaire	3	<i>Hymenaea courbaril</i>	Costa Rica	Yes	Chirping
	Hemilucinae	<i>Automeris postalbida</i> Schaus	1	<i>Acalypha diversifolia</i>	Costa Rica	No	n/a
		<i>Automeris io</i> (Fabricius)	80+ (3)	<i>Betula papyrifera</i> , <i>Acer</i> sp., <i>Populus</i> sp.	Chaffey's Lock (QUBS), ON & PEI	No	n/a
		<i>Automeris phrynon</i> Druce	1	<i>Terminalia catappa</i>	Costa Rica	No	n/a
		<i>Automeris cecrops pamina</i> Neumoegen	10+	<i>Quercus</i> sp.	Arizona	No	n/a
	Saturniinae	<i>Actias luna</i>	100+ (3)	<i>Betula papyrifera</i>	Chaffey's Lock	Yes	Clicking

		(Linnaeus)			(QUBS), & Ottawa (Mer Bleue), ON		
		<i>Antheraea pernyi</i> (Guérin-Ménéville)	2	<i>Quercus</i> sp.	Italy	Yes	Clicking
		<i>Antheraea polyphemus</i> (Cramer)	200+ (3)	<i>Quercus rubra</i> , <i>Betula papyrifera</i> , <i>Acer saccharum</i>	Chaffey's Lock (QUBS), & Ottawa (Mer Bleue), ON & PEI & Massachusetts	Yes	Clicking
		<i>Antheraea polyphemus oculea</i> (Neumoegen)	45	<i>Quercus</i> sp.	Arizona	Yes	Clicking
		<i>Attacus atlas</i> (Linnaeus)	8	<i>Citrus</i> sp.	South East Asia	No	n/a
		<i>Callosamia promethea</i> (Drury)	34 (3)	<i>Betula</i> sp.	Chaffey's Lock (QUBS), ON & PEI	Yes	Clicking
		<i>Calosaturnia mendocino</i> (Behrens)	4	<i>Arctostaphylos</i> sp. or <i>Arbutus menziesii</i>	California	Yes	Chirping
		<i>Eupackardia calleta</i> (Westwood)	2	<i>Prunus domestica</i>	Arizona	No	n/a
		<i>Hyalophora cecropia</i> (Linnaeus)	20+	<i>Betula papyrifera</i>	Chaffey's Lock (QUBS)	No	n/a
		<i>Hyalophora columbia</i> (SI Smith)	20+	<i>Betula</i> sp.	Arizona	No	n/a
		<i>Hyalophora columbia gloveri</i> (Strecker)	6	<i>Prunus domestica</i>	Arizona	No	n/a
		<i>Hyalophora euryalus</i> (Boisduval)	2	<i>Prunus</i> sp.	Arizona	No	n/a
		<i>Rhodinia fugax</i> * (Butler)	n/a	n/a	n/a	Yes	Whistle
		<i>Saturnia pyri</i> (Denis & Schifferrmüller)	52 (2)	<i>Populus</i> sp.	Denmark & Switzerland	Yes	Chirping
Sphingidae	Sphinginae	<i>Acherontia atropos</i> (Linnaeus)	5	<i>Solanum</i> sp.	Africa	Yes	Clicking
		<i>Ceratonia undulosa</i> (Walker)	20	<i>Fraxinus</i> sp.	Chaffey's Lock (QUBS), ON	No	n/a
		<i>Manduca albiplaga</i> (Walker)	1	<i>Annona rensoniana</i>	Costa Rica	No	n/a
		<i>Manduca florestan</i> (Stoll)	1	plant 19080 (<i>Bignoniaceae</i>)	Costa Rica	No	n/a
		<i>Manduca pellenia</i> (Herrich-Schaffer)	1	<i>Cestrum megalophyllum</i>	Costa Rica	Yes	Clicking
		<i>Manduca sexta</i> (Linnaeus)	60+ (3)	<i>Solanum lycopersicum</i> , <i>Datura inoxia</i> , <i>Nicotiana tabacum</i> , Artificial diet	Dalhousie University, NS & Mercier (supplier), QC & Windsor (supplier), ON	Yes	Clicking
		<i>Sphinx chersis</i> (Hubner)	1	<i>Fraxinus</i> sp.	Ottawa, ON	No	n/a
		<i>Sphinx drupiferarum</i> Abbot & Smith	16	<i>Prunus</i> sp. (plum)	PEI	No	n/a
		<i>Sphinx kalmiae</i> Abbot & Smith	20	<i>Fraxinus</i> sp.	PEI	No	n/a

		<i>Sphinx poecila</i> Stephens	18	<i>Vaccinium</i> sp.	PEI	No	n/a
	Smerinthinae	<i>Adhemarius ypsilon</i> (Rothschild & Jordan)	1	<i>Ocotea atirrensis</i>	Costa Rica	No	n/a
		<i>Amorpha juglandis</i> (Abbot & Smith)	18 (2)	<i>Ostyra</i> sp., <i>Alnus</i> sp., <i>Juglans</i> sp., <i>Fagus</i> sp.	Chaffey's Lock (QUBS), ON	Yes	Whistle
		<i>Mimas tiliae</i> (Linnaeus)	3	<i>Alnus</i> sp.	Europe	No	n/a
		<i>Pachysphinx modesta</i> (Harris)	8	<i>Populus tremuloides</i>	PEI	No	n/a
		<i>Paonias excaecata</i> (Abbot & Smith)	14 (2)	<i>Betula</i> sp.	Chaffey's Lock (QUBS), ON & PEI	No	n/a
		<i>Paonias myops</i> (Abbot & Smith)	20	<i>Prunus</i> sp. (cherry)	Chaffey's Lock (QUBS), ON	No	n/a
		<i>Phyllosphingia dissimilis</i> * (Bremer)	n/a	n/a	n/a	Yes	Whistle
		<i>Smerinthus cerisyi</i> Kirby	10	<i>Populus tremuloides</i>	Ottawa (Mer Bleue), ON	No	n/a
		<i>Smerinthus jamaicensis</i> (Drury)	5	<i>Populus tremuloides</i>	Ottawa (Mer Bleue), ON	No	n/a
	Macroglossinae	<i>Amphion floridensis</i> Clark	130+ (2)	<i>Vitis</i> sp.	Florida	Yes	Vocalization
		<i>Darapsa choerilus</i> (Cramer)	5	<i>Viburnum</i> sp.	PEI	No	n/a
		<i>Darapsa myron</i> (Cramer)	50+ (2)	<i>Vitis</i> sp.	Ottawa, ON & Chaffey's Lock (QUBS), ON	No	n/a
		<i>Deidamia inscriptum</i> (Harris)	1	<i>Vitis</i> sp.	Chaffey's Lock (QUBS), ON	No	n/a
		<i>Eumorpha satellitia</i> (Linnaeus)	2	<i>Vitis tiliifolia</i>	Costa Rica	Yes	Clicking
		<i>Hyles euphorbiae</i> (Linnaeus)	3	<i>Euphorbia</i> sp.	Ottawa	No	n/a
		<i>Hyles lineata</i> (Fabricius)	5	<i>Oenothera</i> sp.	Arizona	No	n/a
		<i>Nyceryx magna</i> (Felder)	1	<i>Pentagonia donnell-smithii</i>	Costa Rica	Yes	Vocalization
		<i>Pachygonidia drucei</i> (Rothschild & Jordan)	1	<i>Doliocarpus multiflorus</i>	Costa Rica	Yes	Vocalization
		<i>Sphecodina abbottii</i> (Swainson)	3	<i>Vitis</i> sp.	Ottawa, ON	Yes	Vocalization
		<i>Xylophanes anubus</i> (Cramer)	1	<i>Psychotria panamensis</i>	Costa Rica	No	n/a
		<i>Xylophanes tyndarus</i> (Boisduval)	1	<i>Faramea occidentalis</i>	Costa Rica	No	n/a
		<i>Xylophanes falco</i> (Walker)	4	<i>Bouvardia glaberrima</i>	Arizona	No	n/a
OUTGROUPS							
Lasiocampidae	Macromphalinae	<i>Euglyphis amathuria</i> DHJ02	1	<i>Cinnamomum brenesii</i>	Costa Rica	No	n/a

Noctuidae	Catocalinae	<i>Acanthodica sinuilinea</i> DHJ02	1	<i>Heteropterys obovata</i>	Costa Rica	No	n/a
Notodontidae	Dudusinae	<i>Crinodes besckei</i>	1	<i>Gouania</i> sp.	Costa Rica	No	n/a
	Dicranurinae	<i>Lirimiris fascis</i>	1	<i>Mortoniodendron guatemalense</i>	Costa Rica	No	n/a
		<i>Lirimiris guatemalensis</i>	1	<i>Guazuma ulmifolia</i>	Costa Rica	No	n/a
Nymphalidae	Morphinae	<i>Antirrhea lindigii</i> Felder	1	<i>Geonoma ferruginea</i>	Costa Rica	No	n/a
		<i>Morpho amathonte</i> Deyrolle	1	<i>Lonchocarpus oliganthus</i>	Costa Rica	No	n/a
	Nymphalinae	<i>Smyrna blomfieldia</i> (Fabricius)	1	<i>Urera caracasana</i>	Costa Rica	No	n/a
	Danainae	<i>Danaus</i> sp.	1	<i>Solandra grandiflora</i>	Costa Rica	No	n/a
Hesperiidae	Eudaminae	<i>Astraptes creteus crana</i> Evans	1	<i>Styrax argenteus</i>	Costa Rica	No	n/a

^a “Taxa names were obtained from the Natural History Museum, London, U.K. Lepindex website. Beccaloni, G. et al., *Natural History Museum - The Global Lepidoptera Names Index*. (2005) Available at: <http://www.nhm.ac.uk/our-science/data/lepindex/>. (Accessed: 15th July 2015)”

* Information on *Rhodinia fugax* is from the literature and non-lab created videos. Information on *Phyllosphingia dissimilis* is from the literature only.

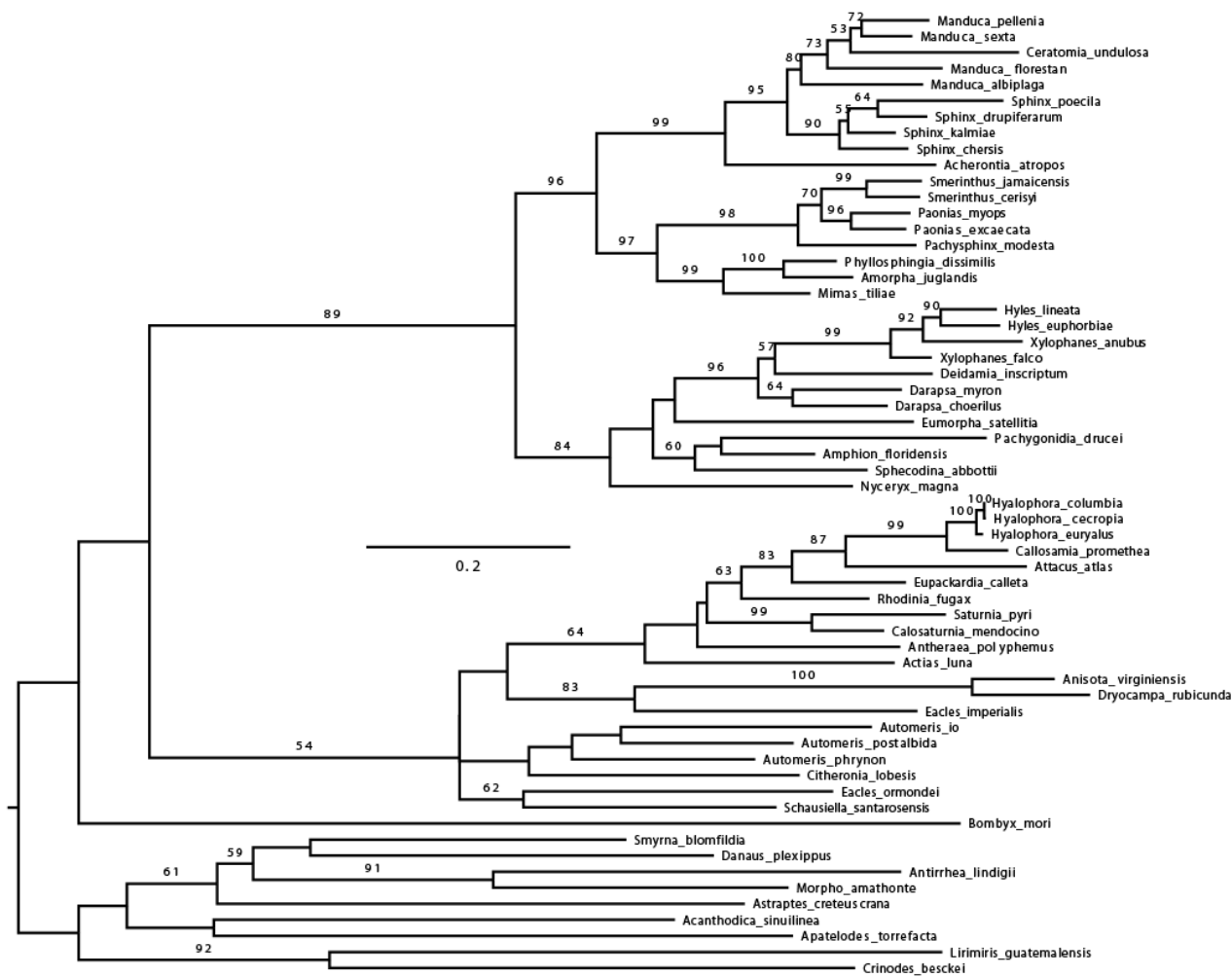
Supplementary Table 2

Taxa and their GenBank accession numbers for each locus used to construct the ML tree in this study.

Family	Genus/species	CAD	COI	DDC	EF1	WG
Saturniidae	<i>Actias luna</i>	*	GU087182	*	AF015069	*
Saturniidae	<i>Anisota virginensis</i>	*	GU087657	*	*	*
Saturniidae	<i>Antheraea pernyi</i>	*	EU532613	AY461438	FJ788508	*
Saturniidae	<i>Antheraea polyphemus</i>	EU032645	GU438053	AF373953	AF373927	EU033059
Saturniidae	<i>Attacus atlas</i>	EU032631	AB533579	EU032768	AF015066	EU033049
Saturniidae	<i>Automeris io</i>	EU032648	GU088608	EU032784	*	EU033062
Saturniidae	<i>Automeris phrynon</i>	*	GU146236	*	*	*
Saturniidae	<i>Automeris postalbida</i>	*	JQ529319	*	*	*
Saturniidae	<i>Callosamia promethea</i>	*	*	AF015052	AF015073	*
Saturniidae	<i>Ceratomia undulosa</i>	*	GU438133	*	*	*
Saturniidae	<i>Citheronia lobesis</i>	*	JQ570223	*	*	*
Saturniidae	<i>Dryocampa rubicunda</i>	*	GU087259	*	AF234564	*
Saturniidae	<i>Eacles ormondei</i>	*	JQ579310	*	*	*
Saturniidae	<i>Eupackardia calleta</i>	*	*	AF015054	AF015075	*
Saturniidae	<i>Hyalophora cecropia</i>	EU032685	KM287185	EU032818	AF015077	EU033090
Saturniidae	<i>Hyalophora columbia</i>	*	KM287192	*	*	*
Saturniidae	<i>Hyalophora euryalus</i>	EU032687	HM867376	AF015057	AF015078	*
Saturniidae	<i>Rhodinia fugax</i>	*	GU663933	AF015061	*	*
Saturniidae	<i>Calosaturnia mendocino</i>	*	*	EU032878	AF373945	EU033146
Saturniidae	<i>Saturnia pyri</i>	*	JN278459	*	DQ077816	*
Saturniidae	<i>Schausiella santarosensis</i>	*	DQ266740	*	*	*
Sphingidae	<i>Acherontia atropos</i>	EU479012		EU479122	EU479232	EU479446
Sphingidae	<i>Amorpha juglandis</i>	EU479021	GU088582	EU479131	EU479241	EU479455
Sphingidae	<i>Amphion floridensis</i>	*	JN677742	*	EU479244	EU479458
Sphingidae	<i>Darapsa myron</i>	EU479045	KP720048	EU479155	EU479266	EU479480
Sphingidae	<i>Deidamia inscriptum</i>	EU479046	KP720047	EU479156	*	EU479481
Sphingidae	<i>Eumorpha satellitia</i>	*	HQ581557	*	KP720269	KM456038
Sphingidae	<i>Hyles euphorbiae</i>	*	HQ955341	*	*	FN393414

Sphingidae	<i>Hyles lineata</i>	EU032688	JN678058	EU479176	EU479288	EU033092
Sphingidae	<i>Manduca albiplaga</i>	KC893229	GU152246	*	KC893193	KC893213
Sphingidae	<i>Manduca florestan</i>	*	JQ572523	EU479186	EU479298	EU479511
Sphingidae	<i>Manduca pellenia</i>	KC893240	DQ276326	*	KC893201	KC893216
Sphingidae	<i>Manduca sexta</i>	EU032707	HQ581428	U03909	AF234571	EU033109
Sphingidae	<i>Mimas tiliae</i>	EU479079	KP720098	EU479192	EU479304	EU479517
Sphingidae	<i>Nyceryx magna</i>	*	DQ276382	EU479196	EU479310	EU479523
Sphingidae	<i>Pachygonidia drucei</i>	*	DQ276419	*	*	*
Sphingidae	<i>Pachysphinx modesta</i>	*	JN678337	*	AF234573	*
Sphingidae	<i>Paonias excaecata</i>	*	GU090083	*	AF234572	*
Sphingidae	<i>Paonias myops</i>	*	GU091309	EU479202	AF234574	EU033131
Sphingidae	<i>Phyllosphinxia dissimilis</i>	EU479095	JN678367	EU479207	EU479320	EU479533
Sphingidae	<i>Smerinthus cerisyi</i>	*	HM862530	AF234595	AF234576	*
Sphingidae	<i>Smerinthus jamaicensis</i>	*	JN678502	*	*	*
Sphingidae	<i>Sphecodina abbottii</i>	EU479106	GU089266	EU479218	AF234575	EU479544
Sphingidae	<i>Sphinx chersis</i>	*	GU438647	AF234596	AF234577	*
Sphingidae	<i>Sphinx drupiferarum</i>	*	HM867045	*	*	*
Sphingidae	<i>Sphinx kalmiae</i>	EU479111	GU091429	EU479223	EU479336	EU479549
Sphingidae	<i>Sphinx poecila</i>	*	GU092657	*	*	*
Sphingidae	<i>Xylophanes anubus</i>	KP719988	DQ276577	*	*	KP720004
Sphingidae	<i>Xylophanes falco</i>	*	*	KP720009	AF234580	*
Apatelodidae	<i>Apatelodes torrefacta</i>	EU032647	GU089655	EU032783	*	EU033061
Bombycidae	<i>Bombyx mori</i>	EU032656	AB649182	AF372836	NM001044045	EU033069
Erebinae	<i>Acanthodica sinuilinea</i>	*	JQ523982	*	*	*
Hesperiidae	<i>Astraptus creteus crana</i>	*	JF777604	*	*	*
Notodontidae	<i>Lirimiris guatemalensis</i>	JQ784619	GU158132	*	*	JQ786889
Notodontidae	<i>Crinodes besckei</i>	JQ784377	GU332885	JQ785738	*	JQ786709
Nymphalidae	<i>Smyrna blomfieldia</i>	*	JQ548137	*	AY788816	AY788576
Nymphalidae	<i>Danaus plexippus</i>	*	GU659709	*	KJ496142	JQ786769
Nymphalidae	<i>Antirrhoea lindigii</i>	*	GU156905	*	*	*
Nymphalidae	<i>Morpho amathonte</i>	*	JQ536411	*	*	JN696117

Supplementary Figure 1: Supplementary Figure x. RAxML maximum likelihood tree showing branch lengths and outgroups. Bootstrap values >50% are shown above branches.



Supplementary Movie 1 (Caption)

Defensive sounds in caterpillars belonging to the silk and hawk moths (Bombycoidea). Videoclips show four different sound producing mechanisms (clicking, chirping, whistling and vocalizing) following simulated predator attacks.

Supplementary Movie 2 (Caption)

Close up video of mouthparts during ‘vocalization’ sound production in the Abbott’s sphinx (*Sphecodina abbottii*). The first part of the video is played in real time, and the second part is slowed down to show how mouth-parts are held wide open during sound production.