

Freshwater Mussel (Bivalvia: Unionidae) Investigation for Petroleum Spill Response in the Ochlockonee River Drainage Tributaries: Quincy Creek and Little River, Florida.

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Objectives:

1. Determine if Federally listed freshwater mussels inhabit the area impacted by the petroleum spill event.
2. Determine if any freshwater mussels exhibited an acute response (mortality) to the petroleum spill event.
3. Determine fate and transport of the petroleum spill by examining receiving creek sediments and mussel tissue at selected sites after the spill event.
4. Determine if subsequent sampling of sediment and mussel tissue are necessary to assess extent of area affected by the spill event.

Hypotheses:

1. Ho: There are no Federally listed freshwater mussels in the vicinity of the petroleum spill.
2. Ho: There are no detectable mortalities of freshwater mussels as a result of the petroleum spill.
3. Ho: Detectable petroleum hydrocarbon residues will be present from the point of spill in Quincy Creek to a wetland approximately 5 miles downstream, but residues will not be detectable downstream of the wetland or in Little River.

Justification/Need:

On 24 June 2002, at approximately 4:00 am (EST) roughly 4,000 gallons of unleaded gasoline and 500 gallons of diesel fuel were spilled from a single vehicle, tanker truck accident, onto the soil north of Quincy Creek (QC), Gadsden County, Florida. The petroleum hydrocarbons ran into a stormwater drain, which empties directly into QC at State Road 267. Immediate acute responses of high magnitude was evident for fish, reptiles, amphibians, and some bird and mammal species; however, unidentified freshwater mussels were detected and were reported as living (unconfirmed, Pers. Comm. C.E. Gunter, Advanced Environmental Technologies, LLC).

At the current time it is unknown if unionid mussels, including Federally protected species, inhabit QC. The extent of the area affected by the spill event is unknown. Of particular concern is whether the spill-introduced contamination will reach the historical habitat for endangered mussel species in the downstream Little River (LR). It is essential to document trust resources affected by this spill. Additionally, this study will document the fate and transport of petroleum hydrocarbons in river sediments and in mussel tissue to better evaluate impacts from future spills.

Background:

Records from scientific collectors and museum specimens indicate that QC historically supported a native freshwater mussel community, however, no species currently afforded Federal protection have been documented from this tributary (unpubl. data, J.D. Williams, U.S. Geological Survey, Gainesville, Florida). QC is a tributary to LR in the Ochlockonee River drainage basin of Florida and Georgia. Currently, QC receives several tributaries prior to entering an wetland created by beaver dams. After QC waters flow through the wetland, the channel reforms and then joins LR. LR has supported mussel populations including the Federally endangered shinyrayed pocketbook (*Lampsilis subangulata*) and has been reported to be one of the few known locations for the endemic, Federally endangered, Ochlockonee moccasinshell (*Medionidus simpsonianus*). While recent status surveys failed to document Federally protected species downstream of the junction of QC and LR (unpubl. data, J.D. Williams), populations may still exist within this area.

Petroleum hydrocarbons are composed of a combination of thousands of various hydrocarbon compounds (Hoffman et al. 1995). Hydrocarbons are molecules consisting of carbon and hydrogen atoms. Hydrocarbons in petroleum hydrocarbons can be lumped into to major classes, aliphatic (straight chain) and aromatic (closed ring structures) molecules (Hoffman et al. 1995). These two major classes of molecules behave very differently in the aquatic environment. The lighter aliphatic molecules tend to be more volatile (tend to evaporate) than the heavier aromatic molecules often referred to as polycyclic aromatic hydrocarbons (PAHs). The more persistent PAHs have a tendency to partition (accumulate) in the sediments, organic particulates and organisms, but not to be found in the water column (Beyer et al. 1996). Organisms associated the sediment environment are particularly susceptible to accumulating aromatic hydrocarbons, particularly soft-bodied obligate filter feeders. For this reason, bivalve (mussel) species have been used as sentinels of environmental exposure to monitor petroleum hydrocarbons in the aquatic environment, often accumulating PAH concentrations 10 to 100,000 times greater than found in the water column (Beyer et al. 1996, Heit et al. 1980).

The effects of PAHs on freshwater mussels are poorly understood (Keller et al. 1998). While freshwater mussels may be able to temporarily close their valves for periods of time and avoid impacts from initial exposure to petroleum hydrocarbons in the water column, they are more susceptible to chronic effects. Freshwater mussels are benthic organisms and are known to bioaccumulate a wide variety of toxicants that are brought in via filtering to obtain oxygen from the water column or contaminated organic particulates for food. Biological accumulation of petroleum hydrocarbons has been shown to vary

with mussel reproductive state (Beyer et al. 1996) and may ultimately result in chronic effects that limit reproduction or result in eventual death.

In one case study, many adult unionid species were reported to have died one month after a spill of ~ 30,000 gallons of No. 2 diesel fuel in a small Indiana creek (Keller et al. 1998). Initial survivorship of early life stages of these unionids was unknown. Sediments from sites within the Indiana creek where the diesel fuel spill occurred were used in toxicity testing with larval (glochidia) and juvenile mussels. Results indicated that 1 year after the spill, petroleum hydrocarbons were present at low concentrations in the creek sediments (minimum detection limit of 1ppb). Affected creek sediments used in toxicity tests 23 months after the spill event did not produce an acute response in juvenile mussels.

Methods:

Panama City Field Office will conduct tactile surveys (following accepted procedures to locate rare species, see Obermeyer, 1998; Blalock-Herod, 2000) to determine if freshwater mussels, including Federally listed species, inhabit QC and LR (see next paragraph). Any mussels encountered will be identified to species in the field, examined for mortalities (valves with fresh tissue, or valves still “in position” in the creek sediments but without tissue) or obvious indicators of stress (e.g., gaping valves), enumerated, recorded, and released. Area searched and time spent searching will be recorded.

Sediments and mussel tissues will be sampled to determine the fate and transport of petroleum hydrocarbons from the spill mentioned under “justification”. If possible, sediments will be removed from a terrestrial site where the initial spill occurred in an effort to determine the PAH “fingerprint” of the petroleum hydrocarbons released. This fingerprint will serve to uniquely identify hydrocarbons from this spill as opposed to hydrocarbons from other non-point sources (e.g., road runoff).

Aquatic sediments and mussel tissues will be sampled approximately 100 m upstream of the spill entry in QC and 500 m upstream of the junction of QC and LR (in LR) to provide additional background data concerning previously existing petroleum hydrocarbons present within these reference areas. Additional sediment and tissue samples will be collected sites: A) 100 m downstream of the spill entry into QC, B) just above the wetland (~ 4 miles downstream of the spill), C) just below the wetland, and D) at LR below the mouth of QC.

Sampling of mussels and sediment, including precautions minimizing cross contamination of samples, will be performed according to modified standard operating procedures (PCFO-EC-SOP-001 and PCFO-EC SOP 004) described below. Sediment samples will be collected using a petite ponar stainless steel grab. Five individual grabs will be taken at each sampling area. One 200 ml subsample will be taken from each grab and combined to form one site sample. Sediment samples will be placed into certified clean amber bottles and placed on ice immediately after sampling.

Up to five native non-listed freshwater mussels (same species, statistically the same size in shell length and whole wet weight) may be retained for tissue analysis described below. In the absence of native mussels from the collection sites, the non-indigenous Asian clam, *Corbicula fluminea*, will be used for contaminants analysis.

Tissues for contaminants analysis will be removed in the field and placed into certified clean amber bottles and placed on immediately ice. All samples (tissues and sediments) will be kept below 5°C until shipment for analysis. Samples will be sent to an analytical laboratory selected by USFWS, Patuxent, Maryland (Geochemical & Environmental Research Group) for PAH fingerprinting analyses within 48 hours of the sampling time. A literature search will be conducted to review PAH effect levels values for freshwater mussels and will be compared to the lab results.

Additional monitoring of sediments and tissues will be suggested if Federally listed freshwater mussels are located in QC or if petroleum hydrocarbons from the spill are detected in the sediments or mussel tissues in LR.

Proposed Timeline:

Mussel surveys and sediment and tissue sampling will be conducted concurrently, approximately 1 month after the initial spill event provided that the sites are safe to enter. Surveys and samples will be completed in a two-day time period. Samples will be sent overnight to the lab and processed immediately. Results from the lab are expected no more than 90 days from receipt of the samples, however, they are expect much sooner due to QA/QC hold times for such samples. A draft technical summary will be completed and available for review four weeks after receipt of the analytical lab report.

Products:

A technical summary will be produced to outline initial results: mussel species richness at selected sites, documented mortalities or stress in mussels related to petroleum hydrocarbons from this spill, and chemical analyses of sediments and tissues from control and affected sites. A recommendation will be made to continue or terminate monitoring of sediments and tissues for petroleum hydrocarbons related to this spill. A standard operating procedure will be developed for use by the Panama City Field Office for response to a spill of this type. Subsequent journal publications will discuss the fate and transport of petroleum hydrocarbons in stream and wetland systems and freshwater mussels.

Literature Cited:

- Blalock-Herod, H.N. 2000. Community ecology of three freshwater mussel species (Bivalvia: Unionidae) from the New River, Suwannee drainage, Florida. Unpublished Master's thesis, University of Florida, Gainesville, Florida. 72 pp.
- Beyer, W.N., Heinz, G.H., Redmon-Norwood, A.W. 1996. Environmental Contaminants in Wildlife. CRC Press, Boca Raton, FL.
- Heit, M., C.S. Klusek, and K.M. Miller. 1980. Trace element, radionuclide, and polynuclear aromatic hydrocarbon concentrations in Unionidae mussels from northern Lake George. *Environmental Science and Technology* 14(4):465-468.
- Hoffman, D.J., Rattner, B.A., Burton, G.A., Cairnes, J., 1995. Handbook of Ecotoxicology. CRC Press, Boca Raton, FL.
- Keller, A.E., D.S. Ruessler, and C.M. Chaffee. 1998. Testing the toxicity of sediments contaminated with diesel fuel using glochidia and juvenile mussels (Bivalvia: Unionidae). *Aquatic Ecosystem Health and Management*. 1998:37-47.
- Obermeyer, B.K. 1998. A comparison of quadrats versus timed snorkel searches for assessing freshwater mussels. *American Midland Naturalist* 139:331-339.

Date: Wed, 10 Jul 2002 08:31:14 -0500
From: Holly_Black-Herod@fws.gov
Subject: Re: Request - Study Plan Review
To: Dick Neves <mussel@vt.edu>
X-Mailer: Lotus Notes Release 5.0.6a January 17, 2001
X-MIMETrack: Serialize by Router on FWOHUB1/FWS/DOI(Release 5.0.9a |January 7, 2002) at 07/10/2002 07:48:04 AM
Dick,

I haven't completed a full lit search yet. However, I have found a few more papers. They mainly discuss the accumulation potential and the use as monitors. It is starting to look like we need to conduct some research to look at sub-lethal and chronic effects of petroleum products to adult and juvenile mussels. Anyway, the references are below. Good Luck.

Unionids

Birdsall, K., J.J. Kukor, and M.A. Cheney. 2001. Uptake of polycyclic aromatic hydrocarbon compounds by the gills of the bivalve mollusk *Elliptio complanata*. *Environmental Toxicology and Chemistry* 20(2):309-316.

Marine bivalves

Peven, C.S., A.D. Uhler, and F.J. Querzoli. 1996. Caged mussels and semipermeable membrane devices as indicators of organic contaminant uptake in Dorchester and Duxbury Bays, Massachusetts. *Environmental Toxicology and Chemistry* 15(2):144-149.

Baussant, T., S.Sanni, G. Jonsson, A. Skadssheim, and J.F. Borseth. 2001. Bioaccumulation of polycyclic aromatic compounds: 1. bioconcentration in two marine species and in semipermeable membrane devices during chronic exposure to dispersed crude oil. *Environmental Toxicology and Chemistry* 20(6):1175-1184.

Baumard, P., H. Budzinski, and P. Garrigues. 1998. Polycyclic aromatic hydrocarbons in sediments and mussels of the western Mediterranean Sea. *Environmental Toxicology and Chemistry* 17(5):765-776.

Boehm, P.D., P.J. Mankiewicz, R. Hartung, J.M. Neff, D.S. Page, E.S. Gilfillan, J.E. O'Reilly, and K.R. Parker. 1996. Characterization of mussel beds with residual oil and the risk to foraging wildlife 4 years after the EXXON VALDEZ oil spill. *Environmental Toxicology and Chemistry* 15(8):1289-1303.

Date: Wed, 10 Jul 2002 12:55:16 -0500
From: Holly_Blalock-Herod@fws.gov
Subject: PAH and mussels
To: mussel@vt.edu
X-Mailer: Lotus Notes Release 5.0.6a January 17, 2001

I did a search today, so I thought I would forward the results along.
Below are 55 articles that may or may not be helpful with your liquid
asphalt problem. I believe all are for marine bivalves. - holly

07/10/02 09:54 Subject: Search Results from Cambridge Scientific
Abstracts

(www.csa.com)

Wed Jul 10 10:54:20 2002

Cambridge Scientific Abstracts

Database: ASFA: Aquatic Sciences and Fisheries Abstracts

Query: KW=(mussel AND hydrocarbon)

Your Comments:

TI: Title

Persistence of oiling in mussel beds after the Exxon Valdez oil spill.

AU: Author Carls, MG; Babcock, MM; Harris, PM; Irvine, GV; Cusick, JA; Rice, SD

SO: Source Marine Environmental Research [Mar. Environ. Res.], vol. 51, no.

2, pp. 167-190, 2001

TI: Title

Cluster analysis of the levels of aliphatic hydrocarbons found in
bioindicators from the Galician shore

AU: Author Simal Gandara, J; Hermida Ameijeiras, A; Lopez Hernandez, J; Simal
Lozano, J

SO: Source Ciencia y Tecnologia Alimentaria [Cienc. Tecnol Aliment.], vol. 2,
no. 5, pp. 244-247, Jul 2000

TI: Title

Changes in immune parameters of natural mussel *Mytilus edulis*
populations following a major oil spill ('Sea Empress', Wales, UK).

AU: Author Dyrinda, EA; Law, RJ; Dyrinda, PEJ; Kelly, CA; Pipe, RK; Ratcliffe, NA

SO: Source Marine ecology progress series. Oldendorf [Mar. Ecol. Prog. Ser.],
vol. 206, pp. 155-170, 2000

TI: Title

Impact of the Sea Empress oil spill on lysosomal stability in mussel blood cells.

AU: Author Fernley, PW; Moore, MN*; Lowe, DM; Donkin, P; Evans, S

SO: Source Marine environmental research. London [Mar. Environ. Res.], vol.
50, no. 1-5, pp. 451-455, 2000

TI: Title

Evidence for and against the presence of polynuclear aromatic
hydrocarbon and 2,3,7,8-tetrachloro-p-dioxin binding proteins in
the marine mussels, *Bathymodiolus* and *Modiolus modiolus*

AU: Author Willett, KL*

SO: Source Aquatic Toxicology [Aquat. Toxicol.], vol. 48, no. 1, pp. 51-64, 1 Feb 2000

TI: Title

Influence of parasitism in controlling the health, reproduction and PAH body burden of petroleum seep mussels

AU: Author Powell, EN; Barber, RD; Kennicutt, MC II; Ford, SE

SO: Source Deep-Sea Research (Part 1, Oceanographic Research Papers) [Deep-Sea Res. (1 Oceanogr. Res. Pap.)], vol. 46, no. 12, pp. 2053-2078, 1 Dec 1999

TI: Title

Levels and trends of PCBs, chlorinated pesticides and petroleum hydrocarbons in mussels from the NW Mediterranean coast: Comparison of concentrations in 1973/1974 and 1988/1989

AU: Author Villeneuve, J-P; Carvalho, FP; Fowler, SW; Cattini, C

SO: Source Science of the Total Environment [Sci. Total Environ.], vol. 237-238, no. 1-3, pp. 57-65, 30 Sep 1999

TI: Title

Relationship Between Kinetics of Benzo(a)pyrene Bioaccumulation and DNA Binding in the Mussel *Mytilus galloprovincialis*

AU: Author Akcha, F; Burgeot, T; Venier, P; Narbonne, JF

SO: Source Bulletin of Environmental Contamination and Toxicology [Bull. Environ. Contam. Toxicol.], vol. 62, no. 4, pp. 455-462, Apr 1999

TI: Title

Polycyclic aromatic hydrocarbons in recent sediments and mussels (*Mytilus edulis*) from the western Baltic Sea: occurrence, bioavailability and seasonal variations

AU: Author Baumard, P; Budzinski, H; Garrigues, P; Dizer, H; Hansen, PD

SO: Source Marine Environmental Research [Mar. Environ. Res.], vol. 47, no. 1, pp. 17-47, 1999

TI: Title

Influence of climate change on interannual variation in contaminant body burden in Gulf of Mexico oysters

AU: Author Kim, Y; Powell, EN*; Wade, TL; Presley, BJ; Brooks, JM

SO: Source Marine Environmental Research [Mar. Environ. Res.], vol. 48, no. 4-5, pp. 459-488, 1999

TI: Title

Lack of physiological responses to hydrocarbon accumulation by *Mytilus trossulus* after 3-4 years chronic exposure to spilled Exxon Valdez crude oil in Prince William Sound

AU: Author Thomas, RE; Brodersen, C; Carls, MG; Babcock, M; Rice, SD

SO: Source Comparative Biochemistry and Physiology, C [Comp. Biochem. Physiol., C], vol. 122C, no. 1, pp. 153-163, 1999

TI: Title

Bioaccumulation of PAHs in the zebra mussel at Times Beach, Buffalo, New York

AU: Author Roper, JM; Cherry, DS; Simmers, JW; Tatem, HE

SO: Source Environmental Monitoring and Assessment [Environ. Monit. Assess.],

vol. 46, no. 3, pp. 267-277, Jul 1997

TI: Title

Restoration of oiled mussel beds in Prince William Sound, Alaska,
five years after the Exxon Valdez oil spill

AU: Author Babcock, MM; Harris, PM; Rice, SD

SO: Source Journal of Shellfish Research, vol. 16, no. 1, p. 258, Jun 1997

TI: Title

Redox cycling of aromatic hydrocarbon quinones catalysed by
digestive gland microsomes of the common mussel (*Mytilus edulis* L.)

AU: Author Sjolin, AM; Livingstone, DR

SO: Source Aquatic Toxicology [Aquat. Toxicol.], vol. 38, no. 1-3, pp. 83-99, May 1997

TI: Title

Very long-chain aliphatic hydrocarbons in lipids of mussels
(*Mytilus edulis*) suspended in the water column near petroleum
operations off Sable Island, Nova Scotia, Canada

AU: Author Zhou, S; Ackman, RG*; Parsons, J

SO: Source Marine Biology [Mar. Biol.], vol. 126, no. 3, pp. 499-507, 1996

TI: Title

Application of 'mussel watch' concept in preliminary survey of
hydrocarbon in coastal waters in the vicinity of Jeddah, Saudi Arabia.

AU: Author Ghazi, SJ

SO: Source J. King Abdulaziz Univ. (Mar. Sci.) Spec. Issue, vol. 7, pp. 41-57, 1996

TI: Title

Effects of the Aegean Sea oil spill on biotransformation enzymes,
oxidative stress and DNA-adducts in digestive gland of the mussel (*Mytilus edulis* L.)

AU: Author Sole, M; Porte, C; Biosca, X; Mitchelmore, CL; Chipman, JK;

Livingstone, DR*; Albaiges, J

SO: Source Comparative Biochemistry and Physiology, C [Comp. Biochem.

Physiol., C], vol. 113C, no. 2, pp. 257-265, Feb 1996

TI: Title

Persistence of oiling in mussel beds three and four years after
the Exxon Valdez oil spill

AU: Author Babcock, MM; Irvine, GV; Harris, PM; Cusick, JA; Rice, SD

SO: Source PROCEEDINGS OF THE EXXON VALDEZ OIL SPILL SYMPOSIUM.,

AFS, BETHESDA, MD (USA), 1996, pp. 286-297, American Fisheries Society

Symposium [AM. FISH. SOC. SYMP.], vol. 18

TI: Title

Physiological ecology of a mussel with methanotrophic
endosymbionts at three hydrocarbon seep sites in the Gulf of Mexico

AU: Author Nix, ER; Fisher, CR*; Vodenichar, J; Scott, KM

SO: Source Marine biology. Berlin, Heidelberg [MAR. BIOL.], vol. 122, no. 4,
pp. 605-617, 1995

TI: Title

Lysosomes as cellular markers of environmental pollution: Time-
and dose-dependent responses of the digestive lysosomal system of
mussels after petroleum hydrocarbon exposure

- AU: Author Cajaraville, MP; Abascal, I; Etxeberria, M; Marigomez, I
SO: Source Environmental Toxicology and Water Quality [ENVIRON. TOXICOL. WATER QUAL.], vol. 10, no. 1, pp. 1-8, 1995
TI: Title
Levels and long-term trends of polychlorinated biphenyls and DDT's in mussels collected from the eastern Adriatic coastal waters
- AU: Author Picer, M; Picer, N
SO: Source Water Research [WATER RES.], vol. 29, no. 12, pp. 2707-2719, 1995
TI: Title
Evaluation of the performance of a multiresidue gas chromatographic method for the determination of aliphatic hydrocarbons in mussels of Galicia (N.W. Spain)
- AU: Author Hermida-Ameijeiras, A; Simal-Gandara, J; Lopez-Hernandez, J; Simal-Lozano, J*
SO: Source Water Research [WATER RES.], vol. 29, no. 9, pp. 2118-2124, 1995
TI: Title
Shoreline impacts in the Gulf of Alaska region following the Exxon Valdez oil spill
- AU: Author Gilfillan, ES; Suchanek, TH; Boehm, PD; Harner, EJ; Page, DS; Sloan, NA
SO: Source EXXON VALDEZ OIL SPILL: FATE AND EFFECTS IN ALASKAN WATERS., ASTM, PHILADELPHIA, PA (USA), 1995, pp. 444-481
TI: Title
Shoreline ecology program for Prince William Sound, Alaska, following the Exxon Valdez oil spill: Part 1 -- study design and methods
- AU: Author Page, DS; Gilfillan, ES; Boehm, PD; Harner, EJ
SO: Source EXXON VALDEZ OIL SPILL: FATE AND EFFECTS IN ALASKAN WATERS., ASTM, PHILADELPHIA, PA (USA), 1995, pp. 263-295
TI: Title
Benzo(a)pyrene hydroxylase activity in the marine mussel *Mytilus galloprovincialis*: A potential marker of contamination by polycyclic aromatic hydrocarbon-type compounds
- AU: Author Michel, X; Salauen, J-P; Galgani, E; Narbonne, J-F
SO: Source Marine environmental research. London [MAR. ENVIRON. RES.], vol. 38, no. 4, pp. 257-273, 1994
TI: Title
Polynuclear aromatic hydrocarbon contaminants in oysters from the Gulf of Mexico (1986-1990)
- AU: Author Jackson, TJ; Wade, TL; McDonald, TJ; Wilkinson, DL; Brooks, JM
SO: Source Environmental Pollution [ENVIRON. POLLUT.], vol. 83, no. 3, pp. 291-298, 1994
TI: Title
The role of the zebra mussel, *Dreissena polymorpha*, in contaminant cycling: 1. The effect of body size and lipid content on the bioconcentration of PCBs and PAHs
- AU: Author Bruner, KA; Fisher, SW; Landrum, PF
SO: Source Journal of Great Lakes Research [J. GREAT LAKES RES.], vol. 20, no. 4, pp. 725-734, 1994

TI: Title

Effects of fluoranthene on the immunocompetence of the common marine mussel, *Mytilus edulis*

AU: Author Coles, JA; Farley, SR; Pipe, RK*

SO: Source Aquatic Toxicology [AQUAT. TOXICOL.], vol. 30, no. 4, pp. 367-379, 1994

TI: Title

Long-term effects of the water-accommodated fraction (WAF) of diesel oil on rocky shore populations maintained in experimental mesocosms

AU: Author Bokn, TL; Moy, FE; Murray, SN

SO: Source Botanica Marina [BOT. MAR.], vol. 36, no. 4, pp. 313-319, 1993

TI: Title

Hydrocarbon levels in edible fish, crabs and mussels from the marine environment of Trinidad

AU: Author Singh, JG; Chang-Yen, I; Stoute, VA; Chattergoon, L

SO: Source Marine Pollution Bulletin [MAR. POLLUT. BULL.], vol. 24, no. 5, pp. 270-272, 1992

TI: Title

Comparative effects of the water accommodated fraction of three oils on mussels--3. Quantitative histochemistry of enzymes related to the detoxication metabolism.

AU: Author Cajaraville, MP; Uranga, JA; Angulo, E

SO: Source Comparative Biochemistry and Physiology, C [COMP. BIOCHEM. PHYSIOL., C.], vol. 103C, no. 2, pp. 369-377, 1992

TI: Title

International mussel watch: A global assessment of environmental levels of chemical contaminants

CA: Corporate Author International Musselwatch Comm.

SO: Source 1992, 9 pp

TI: Title

Distribution and biotransformation of aromatic compounds in coastal Mediterranean ecosystems.

AU: Author Garrigues, P; Raoux, C; Narbonne, JF; Ribera, D; Lemaire, P; Mathieu, A; Salaun, JP; Lafaurie, M

CA: Corporate Author International Atomic Energy Agency, Vienna (Austria); UNEP Mediterranean Action Plan, Athens (Greece); Minnesota Univ., St. Paul (USA). Sea Grant Program

SO: Source PROCEEDINGS OF THE FAO/UNEP/IAEA CONSULTATION ON THE ACCUMULATION AND TRANSFORMATION OF CHEMICAL CONTAMINANTS BY BIOTIC AND ABIOTIC PROCESSES IN THE MARINE ENVIRONMENT (LA SPEZIA, ITALY, 24-28 SEPTEMBER 1990)., UNEP, ATHENS (GREECE), 1991, pp. 209-223, MAP

technical reports series. Athens [MAP TECH. REP. SER.], no. 59

TI: Title

Preparation and use in a diagnosis of monoclonal antibodies specific for neoplastic hemocytes of *Mytilus*

AU: Author Noeel, D; Boulo, V; Elston, R; Mialhe, E; DePauw, N; Joyce, J(comps)
SO: Source AQUACULTURE AND THE ENVIRONMENT., 1991, pp. 232-233, Special
Publication, European Aquaculture Society [SPEC. PUBL. EUR.AQUACULT. SOC.],
no. 14

TI: Title

Sublethal biological effects monitoring in the region of Sullom
Voe, Shetland, June 1989.

AU: Author Widdows, J; Donkin, P; Evans, SV; Salkeld, PN; Willows, R

SO: Source SHETLAND OIL TERMINAL ENVIRONMENTAL ADVISORY GROUP,
ABERDEEN (UK) , 1990, 16 pp

TI: Title

Sublethal biological effects monitoring in the region of Sullom Voe, Shetland, July
1988.

AU: Author Widdows, J; Dixon, D; Donkin, P; Evans, SV; McFadzen, I; Page, D;
Salkeld, PN; Worrall, CM

SO: Source SHETLAND OIL TERMINAL ENVIRONMENTAL ADVISORY GROUP,
ABERDEEN (UK) , 1989, 21 pp

TI: Title

An evaluation of the performance of five types of sediment toxicity tests.

AU: Author Long, ER; Buchman, MF

CA: Corporate Author Marine Technology Soc., Washington, DC (USA); Institute of
Electrical and Electronics Engineers, New York, NY (USA)

SO: Source OCEANS '89: THE GLOBAL OCEAN. VOLUME 2: OCEAN
POLLUTION., 1989, pp. 603-607, OCEANS '89.

TI: Title

Polynuclear aromatic hydrocarbon levels in shellfish, overview of
1989 mussel watch field season.

AU: Author Peven, CS; Steinhauer, WG

SO: Source Journal of Shellfish Research [J. SHELLFISH RES.], vol. 8, no. 2, p. 487,
1989

TI: Title

Hydrocarbons in mussels around the Cape Peninsula, South Africa.

AU: Author Mason, RP

SO: Source South African Journal of Marine Science/Suid-Afrikaanse Tydskrif
vir [S. AFR. J. MAR. SCI./S.-AFR. TYDSKR. SEEWET.], vol. 7, pp. 139-151, 1988

TI: Title

A comparison of fluorescence and GC for the determination of
petroleum hydrocarbons in mussels.

AU: Author Mason, RP

SO: Source Marine Pollution Bulletin [MAR. POLLUT. BULL.], vol. 18, no. 10,
pp. 528-533, 1987

TI: Title

Effects of polycyclic aromatic hydrocarbons on molluscan lysosomes
and endoplasmic reticulum.

AU: Author Nott, JA; Moore, MN

SO: Source Histochemical Journal [HISTOCHEM. J.], vol. 19, no. 6-7, pp. 357-368, 1987

TI: Title

The Mussel Watch concept.

AU: Author Goldberg, ED

CA: Corporate Author USSR State Comm. for Hydrometeorol. and Control Natural Environment (USSR)

SO: Source INTEGRATED GLOBAL OCEAN MONITORING. PROCEEDINGS OF THE 1st INTERNATIONAL SYMPOSIUM, TALLINN, USSR, OCTOBER 2-10, 1983. VOLUME 1., 1986, pp. 71-82

TI: Title

Determination of chlorinated hydrocarbons in coastal waters using a moored in situ sampler and transplanted live mussels.

AU: Author Green, DR; Stull, JK; Heesen, TC

SO: Source Marine Pollution Bulletin [MAR. POLLUT. BULL.], vol. 17, no. 7, pp. 324-329, 1986

TI: Title

Cellular responses in the mussel *Mytilus edulis* following exposure to diesel oil emulsions: Reproductive and nutrient storage cells.

AU: Author Lowe, DM; Pipe, RK

SO: Source RESPONSES OF MARINE ORGANISMS TO POLLUTANTS., 1985, pp. 234-237, Marine environmental research. London [MAR. ENVIRON. RES.], vol. 17, no. 2-4

TI: Title

Application of steam distillation in the determination of petroleum hydrocarbons in water and mussels (*Mytilus edulis*) from dosing experiments with crude oil.

AU: Author Donkin, P; Evans, SV

SO: Source Analytica Chimica Acta [ANAL. CHIM. ACTA.], vol. 156, pp. 207-219, 1984

TI: Title

Hydrocarbons in water, sediment and mussels from the southern Baltic Sea.

AU: Author Law, R; Andrulowicz, E

SO: Source Marine Pollution Bulletin [MAR. POLLUT. BULL.], vol. 14, no. 8, pp. 289-293, 1983

TI: Title

Biogenic and Pollutant Aliphatic Hydrocarbons in *Mytilus edulis* from the North Sea.

AU: Author Rowland, SJ; Volkman, JK

SO: Source Marine environmental research. London [MAR. ENVIRON. RES.], vol. 7, no. 2, pp. 117-130, 1982

TI: Title

Sublethal biological effects monitoring in the region of Sullom Voe, Shetland, July 1982. Preliminary report to the Shetland Oil Terminal Environmental Advisory Group.

AU: Author Widdows, J; Donkin, P; Livingstone, DR; Lowe, D; Moore, MN; Pipe, R; Salkeld, PN; Worrall, C

SO: Source SHETLAND OIL TERMINAL ENVIRONMENTAL ADVISORY GROUP, (UK), 1982, 34 pp

TI: Title

- The Eleni V Oil Spill: Return to Normal Conditions.
AU: AuthorBlackman, RAA; Law, RJ
SO: SourceMarine Pollution Bulletin [MAR. POLLUT. BULL.], vol. 12, no. 4,
pp. 126-130, 1981
TI: Title
Levels of hydrocarbons in mussels, *Mytilus edulis*, and surface
sediments from Danish coastal areas
- AU: AuthorJensen,K.
SO: SourceBull. Environ. Contam. Toxicol., 26(2), 202-206, (1981)
TI: Title
(Evaluation of Total Hydrocarbons in Mussels by
Spectrofluorimetry. Pollution Control on the Littoral after the
Bohlen Wreck.).
- AU: AuthorMarchand, M
SO: SourceRevue internationale d'oceanographie medicale. Nice [REV. INT.
OCEANOGR. MED.], no. 62, pp. 3-14, 1981
TI: Title
Aspects of petroleum hydrocarbon metabolism in marine animals.
- AU: Author Mironov, OG
SO: Source14. EUROPEAN MARINE BIOLOGICAL SYMPOSIUM ON
PROTECTION OF LIFE IN
THE SEA., 1980, pp. 292-296, Helgolander Meeresuntersuchungen.
Hamburg [HELGOL. MEERESUNTERS.], vol. 33
TI: Title
The Eleni V oil spill: fate and effects of the oil over the first
twelve months. Part 2. Biological effects
- AU: AuthorBlackman,R.A.A.; Law,R.J.
SO: SourceMar. Pollut. Bull., 11(8), 217-220, (1980)
TI: Title
Interlaboratory comparison of determinations of trace level
hydrocarbons in mussels
- AU: Author Wise,S.A.; Chesler,S.N.; Guenther,F.R.; Hertz,H.S.; Hilpert,L.R.;
May,W.E.; Parris,R.M.
SO: SourceAnal. Chem., 52(12), 1828-1833, (1980)
TI: Title
Hydrocarbon uptake and loss by the mussel *Mytilus edulis*.
- AU: Author Fossato, VU; Canzonier, WJ
SO: SourceMarine biology. Berlin, Heidelberg [Mar. Biol.], vol. 36, no. 3,
pp. 243-250, 1976