Tandem Enyne Allene−Radical Cyclization: Low-Temperature Approaches to Benz[*e*]indene and Indene Compounds

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In an effort to lower the temperatures required to prepare multicyclic compounds using the tandem enediyne−radical cyclization, we have developed the tandem enyne allene−radical cyclization which proceeds at temperatures as low as 37 °C. The reactions were carried out using three different methods for the preparation of the enyne allenes. The first method involved the [3,3] sigmatropic rearrangement of an enediyne followed by a tandem enyne allene−radical cyclization. This reaction could be effected either by thermolysis (150 °C) or by $AgBF_4$ rearrangement followed by heating at 75 °C. A second technique utilized a [2,3] sigmatropic shift of an enediyne at −78 °C followed by tandem cyclization at 37 or 75 °C depending on the substrate. The final method involved the base-catalyzed isomerization of propargyl sulfones which yielded enyne allenes that underwent cyclization at 37 °C. These three sequences provide a method for the synthesis of ring systems using conditions that may be compatible with the sensitive functionality needed during the synthesis of complex natural products.

Introduction

In recent years, the enediyne antitumor antibiotics[1] have been widely investigated due to their unique mechanism of DNA-cleavage and their unusual structures. Moreover, the emergence of these naturally occurring, biologically active compounds has sparked extensive investigations in the chemistry of conjugated enediynes,[1−3] enyne allenes[1,4,5] and enyne ketenes.[1,6] While considerable effort has been devoted to the DNA-cleaving ability of the biradical intermediates that arise from these compound families by a cycloaromatization reaction,[1−6] less attention has been focused on utilizing these highly reactive intermediates in subsequent radical cyclizations.[1ab,7,8]

Previously, we have reported that benz[*e*]indene derivatives can be synthesized in excellent yields *via* a tandem enediyne−radical cyclization of aromatic enediynes (Figure 1).[7] With this strategy, aromatic enediyne **1** can be converted into benz[*e*]indene derivative **2** in very high yield. The corresponding nonaromatic enediynes also undergo a similar cyclization to provide indene derivatives;[7c] however, the yields are only moderate. The allylic enediyne alcohol **3**, for instance, provides indan system **4** in 54% yield when heated in 1,2-dichlorobenzene at 230 °C in the presence of 1,4-cyclohexadiene. Moreover, we have demonstrated that both radicals formed in the Bergman cyclization of enediyne substrates can be utilized in subsequent radical cyclizations. The thermolysis of enediyne compound **5** carrying two radical-

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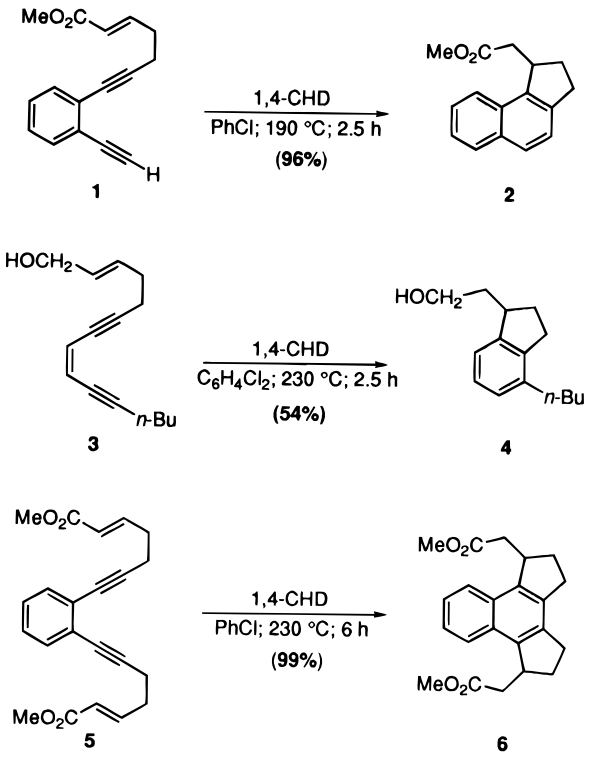


Figure 1.

accepting tethers leads to the simultaneous formation of three rings providing the tetracyclic naphthalene system **6** in 99% yield (Figure 1). Both the tandem enediyne–radical cyclization and the tandem enediyne–bis-radical cyclization methodologies require very high temperatures (*ca.* 170–230 °C); thus applications toward the synthesis of more complex systems have proven difficult. In fact, efforts in our laboratory to utilize the tandem enediyne–radical cyclization strategy for the synthesis of steroidal systems have resulted in decomposition of the precursor enediynes.[9]

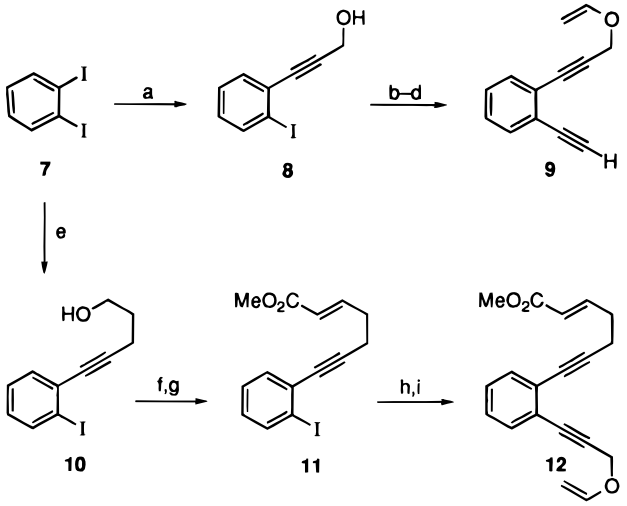
In contrast to the high-temperature tandem enediyne–radical cyclization that uses the Bergman cyclization as the initial ring-closing step, the combination of an enyne allene cyclization[4] (Myers cyclization) with a subsequent radical cyclization would allow the construction of the same benz[*e*]indene framework under much milder conditions, since the Myers cyclization typically proceeds at temperatures significantly lower than those required for the related Bergman cyclization.

In line with our efforts to lower the temperature to effect the formation of the benz[*e*]indene system, we have successfully developed the tandem enyne allene–radical cyclization strategy, using three independent synthetic methods for the preparation of the cyclization precursors. This methodology, which utilizes the enyne allene cyclization as the initial ring closure step, provides benz[*e*]indene products at temperatures as low as 37 °C.

Tandem Enyne Allene–Radical Cyclization *via* [3,3] Sigmatropic Rearrangements[10]

Synthesis of the Precursors for the Tandem Enyne Allene–Radical Cyclization *via* [3,3] Sigmatropic Rearrangements. The first method we chose for the preparation of enyne allene substrates to be used in tandem enyne allene–radical cyclizations was based on the well-precedented conversion of propargyl vinyl ethers into allenes by using a [3,3] sigmatropic rearrangement.[11] In order to utilize this strategy toward the synthesis of enyne allene substrates, various different enediyne vinyl ethers were synthesized.

Scheme 1



(a) propargyl alcohol (1.2 equiv), $Pd(PPh_3)_2Cl_2$ (0.05 equiv), CuI (0.1 equiv), NEt_3, THF (52%); (b) $Hg(OAc)_2$ (0.3 equiv), ethyl vinyl ether, 40 °C (72%); (c) (trimethylsilyl)acetylene (1.5 equiv), $Pd(PPh_3)_2Cl_2$ (0.05 equiv), CuI (0.1 equiv), NEt_3, THF (95%); (d) K_2CO_3 (cat.), MeOH (98%); (e) 4-pentynol (1.2 equiv), $Pd(PPh_3)_2Cl_2$ (0.05 equiv), CuI (0.1 equiv), NEt_3, THF (54%); (f) PCC, CH_2Cl_2 (78%); (g) trimethyl phosphonoacetate, LiCl, DBU, CH_3CN (85%); (h) propargyl alcohol (1.5 equiv), same as (a) (88%); (i) same as (b) (78%).

Scheme 1 outlines the synthetic approaches for the preparation of the enediyne vinyl ethers **9** and **12**, which were both synthesized from 1,2-diiodobenzene (**7**). A palladium(0)-catalyzed coupling reaction under modified Castro–Stephens conditions[12] with propargyl alcohol in the presence of bis(triphenylphosphine)palladium(II) chloride and copper(I) iodide as well as triethylamine as a base gave rise to iodoarene **8**. Compound **8** was converted into a vinyl ether using mercury(II) acetate and ethyl vinyl ether at 40 °C, followed by a second palladium(0)-catalyzed coupling reaction with (trimethylsilyl)acetylene under the same conditions as outlined above, and a desilylation with potassium carbonate in methanol,[13] to provide enediyne vinyl ether **9** in a total yield of 35% over four steps.

The synthetic sequence for the preparation of enediyne vinyl ether **12** started with a palladium(0)-catalyzed coupling reaction of 1,2-diiodobenzene with 4-pentynol (Scheme 1). Alcohol **10** arising from the coupling reaction was oxidized using pyridinium chlorochromate (PCC)[14] and the resulting aldehyde converted into the unsaturated ester **11** by a Horner–Emmons reaction under

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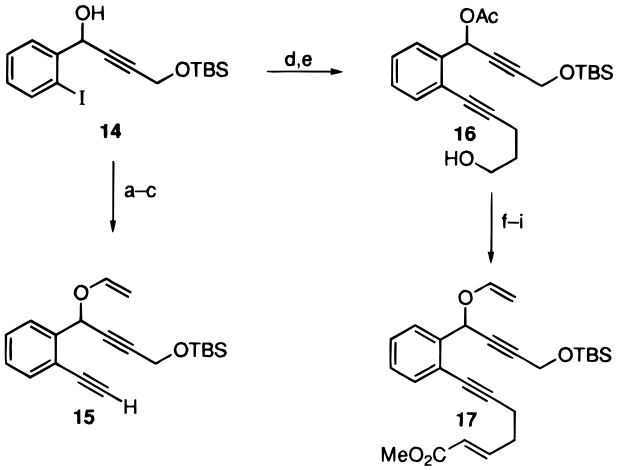
Scheme 2



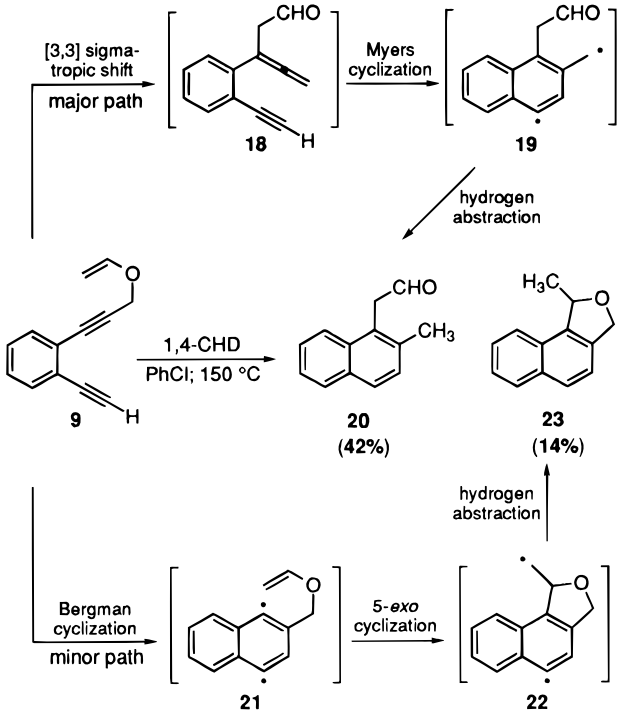
(a) (trimethylsilyl)acetylene (1.5 equiv), $Pd(PPh_3)_2Cl_2$ (0.05 equiv), CuI (0.1 equiv), NEt_3, THF (92%); (b) $Hg(OAc)_2$ (0.3 equiv), ethyl vinyl ether, 40 °C (50%); (c) K_2CO_3 (cat.), MeOH (75%); (d) Ac_2O, NEt_3, CH_2Cl_2 (72%); (e) 4-pentynol (1.2 equiv), $Pd(PPh_3)_2Cl_2$ (0.05 equiv), CuI (0.1 equiv), NEt_3, THF (32%); (f) PCC, CH_2Cl_2 (84%); (g) trimethyl phosphonoacetate, LiCl, DBU, CH_3CN (86%); (h) same as (c) (95%); (i) same as (b) (62%)

Roush−Masamune conditions[15] using trimethyl phosphonoacetate in the presence of lithium chloride and 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in acetonitrile. A subsequent palladium(0)-catalyzed coupling reaction with propargyl alcohol and conversion of the resulting alkynol into a vinyl ether completed the preparation of enediyne compound **12** in a total yield of 25% over five steps.

Alcohol **14** served as a key intermediate for the preparation of the precursor diynes **15** and **17** (Scheme 2). Alcohol **14** was prepared from 2-iodobenzyl alcohol (**13**) *via* oxidation with PCC and treatment of the resulting aldehyde with lithiated *tert*-butyldimethylsilyl propargyl ether in tetrahydrofuran (THF) at −20 °C (78%). Diyne **15** was obtained in a total yield of 35% from substrate **14** using a palladium(0)-catalyzed reaction with (trimethylsilyl)acetylene, followed by conversion of the alcohol into a vinyl ether and base-catalyzed desilylation of the (trimethylsilyl)acetylene subunit. Diyne vinyl ether **17** was obtained from intermediate **14** in a sequence of six steps (Scheme 2). The hydroxyl group of **14** was acetylated with acetic anhydride in the presence of triethylamine, followed by a palladium(0)-catalyzed coupling reaction with 4-pentynol to give alcohol **16**. Subsequent conversion of the primary alcohol into an α,β-unsaturated ester using oxidation with PCC and a Horner−Emmons reaction of the resulting aldehyde gave vinyl ether **17** (overall yield 10% from **14**).

Results of the [3,3] Sigmatropic Rearrangement-Mediated Tandem Enyne Allene−Radical Cyclization Experiments. Mild thermolysis of enediyne vinyl ether **9** at 150 °C in chlorobenzene in the presence of 1,4-cyclohexadiene (1,4-CHD) as a hydrogen atom donor produced aldehyde **20** and the tricyclic ether **23** as a 3:1 mixture in a combined yield of 56% (Scheme 3). The formation of the two products can be rationalized by two competing mechanistic pathways. The major pathway presumably involves the initial formation of enyne allene **18** *via* a [3,3] sigmatropic rearrangement followed by an

Scheme 3



enyne allene cyclization to form biradical **19** and hydrogen abstraction from 1,4-CHD to produce aldehyde **20**. The minor pathway does not involve a [3,3] sigmatropic shift, but instead proceeds through a tandem enediyne−radical cyclization to form the biradical **21**, which undergoes a 5-*exo* ring closure and hydrogen abstraction to give the tricyclic ether **23**. It is interesting that the tandem enediyne−radical cyclization proceeded at 150 °C since most of our earlier studies failed to reveal significant reactivity at this temperature.

The thermal cyclization of enediyne **12** containing a pendent olefin as a radical-accepting tether was then investigated in order to test the feasibility of the tandem enyne allene−radical cyclization strategy. When precursor **12** was heated to 150 °C in the presence of 1,4-CHD, benz[*e*]indenyl aldehyde **25** was isolated as the only characterizable product in about 20% yield (Scheme 4). Mechanistically, this aldehyde presumably arises from a [3,3] sigmatropic rearrangement of aromatic enediyne **12** to give intermediate **24** immediately followed by an enyne allene cyclization, a 5-*exo* radical cyclization of the resulting aryl radical, and hydrogen abstraction from 1,4-CHD. There was no evidence for the formation of the tetracyclic ether **27** arising from a tandem enediyne−radical cyclization. This observation is consistent with the fact that the thermal activation energy for the cyclization of *o*-arene enediynes containing two acetylenic tethers ($E_a = 34.0 \pm 0.3$ kcal/mol) is substantially higher than that for the corresponding *o*-arene enediyne with only one acetylenic tether ($E_a = 28.1 \pm 0.8$ kcal/mol), as determined in our laboratory.[7c]

In an attempt to improve the yield of this reaction and to reduce the severity of the reaction conditions, we tried to effect the sigmatropic rearrangement at a lower temperature by reacting enediyne **12** with a catalytic amount of silver(I) tetrafluoroborate ($AgBF_4$)[11] in benzene at room temperature to produce enyne allene **24**. However, **24** could not be isolated due to its slow decomposition and its propensity to undergo isomerization to the

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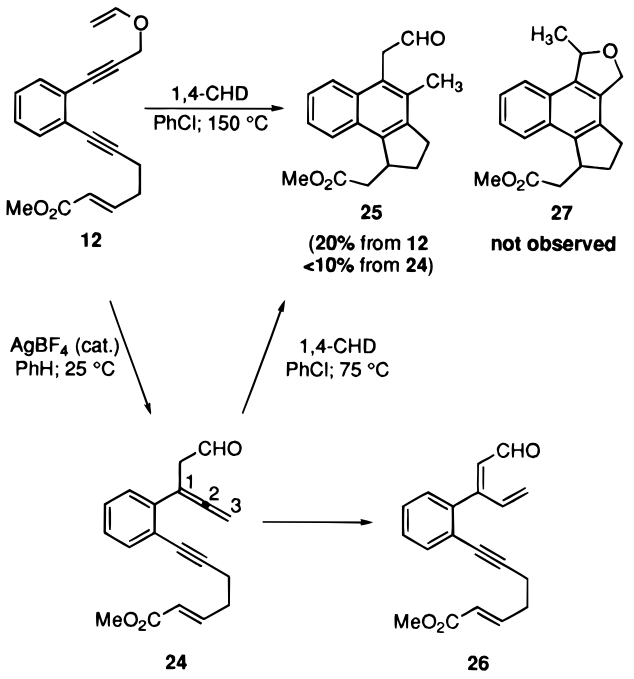
Scheme 4

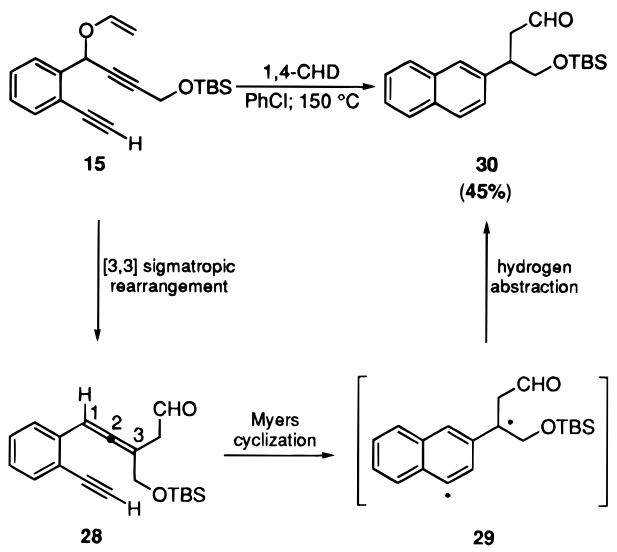


unstable α,β-unsaturated aldehyde **26**. Attempts were made to prevent the isomerization of **24** to **26** by reducing the aldehyde of **24** to the primary alcohol using sodium borohydride ($NaBH_4$). Unfortunately, the subsequent enyne allene cyclizations did not work well and produced a complex mixture of products along with a trace of the desired cyclization product. Thermolysis of the crude product **24** at 75 °C in the presence of 1,4-CHD provided only a small amount of the desired tandem enyne allene−radical cyclization product **25** in 10% yield along with aldehyde **26** and unidentified decomposition products (Scheme 4). Although the cyclization of precursor **12** provides evidence for the tandem enyne allene−radical cyclization, the modest yield of the desired benzindene **25** fails to demonstrate this method as a viable alternative to the high-temperature tandem enediyne−radical cyclization strategy.

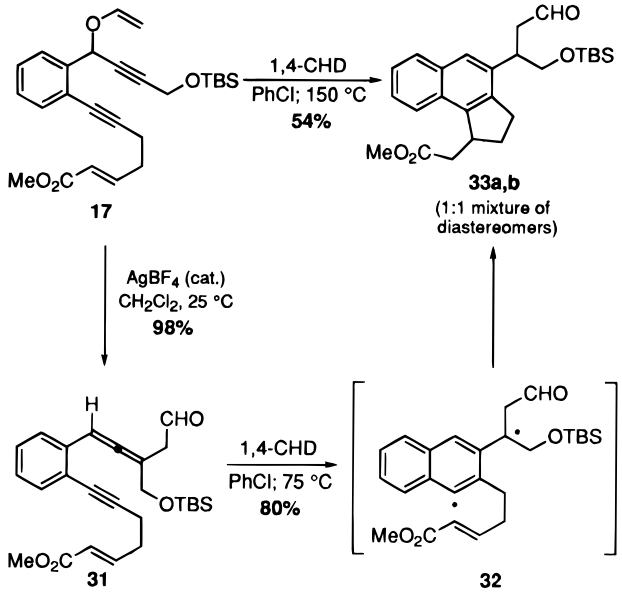
Previous work by Myers has shown that a simple alkyl substitution at the C-3 position of an allene (*cf.* Scheme 4) accelerates the enyne allene cyclization reaction.[4] The results of the enyne allene cyclization of substrate **24** and some other results in our laboratory, which will be discussed shortly, suggest that there might be an unfavorable interaction between the C-1 substituent at the allene and the *ortho* hydrogen of the aryl ring of the enyne allene; this interaction might be the origin of the low yields of the transformations described above. To test this theory, aromatic diyne **15** was prepared so that the [3,3] sigmatropic rearrangement would place the substituent in the sterically less demanding C-3 position of resulting allene **28** (Scheme 5).

When diyne **15** was heated to 150 °C in chlorobenzene in the presence of 1,4-CHD, naphthalene derivative **30** was obtained in 45% isolated yield (Scheme 5). Product **30** most likely arises from a [3,3] sigmatropic rearrangement of propargyl vinyl ether **15** followed by an enyne allene cyclization of intermediate **28** to form biradical **29**, which abstracts hydrogen from 1,4-CHD. Unfortunately, the silver(I)-catalyzed [3,3] sigmatropic shift of **15** was unsuccessful presumably due to the presence of the terminal acetylene hydrogen.

Scheme 5



Scheme 6



Due to the success of the tandem [3,3] sigmatropic rearrangement−enyne allene cyclization of **15**, attention was then focused on diyne **17** in order to test whether a pendent olefin would trap the aromatic radical generated from the enyne allene cyclization (Scheme 6). When **17** was thermolyzed at 150 °C, 2,3-dihydrobenz[*e*]indene derivatives **33a** and **33b** were isolated as a 1:1 diastereomeric ratio in a combined yield of 54% (Scheme 6). The reaction proceeds through a [3,3] sigmatropic rearrangement of **17** to give enyne allene intermediate **31**, which immediately undergoes an enyne allene cyclization to afford biradical **32**. The aryl radical within **32** then undergoes a 5-*exo* radical cyclization followed by hydrogen abstraction from 1,4-CHD to yield tricyclic compounds **33a** and **33b**.

In an effort to carry out the enyne allene−radical cyclization at lower temperature, diyne **17** was treated with a catalytic amount of $AgBF_4$ at room temperature to afford enyne allene intermediate **31** in 98% yield by a Lewis acid-catalyzed [3,3] sigmatropic rearrangement. The thermolysis of compound **31** at 75 °C in chlorobenzene in the presence of 1,4-CHD led to the formation of 2,3-dihydrobenz[*e*]indene derivatives **33a** and **33b** (1:1

ratio) in an excellent combined yield of 80% (Scheme 6). In addition to the reaction temperature being kept relatively low, the yield is improved over the one-step thermal conversion of **17** to **33**, which had to be performed at 150 °C. It is significant that dihydrobenz[*e*]-indene derivatives **33a** and **33b** were formed at 75 °C while similar compounds constructed from a tandem enediyne−radical cyclization required 190 °C or above.[7] Although the enediyne cyclizations occur in high yield, certain functional groups do not survive such high temperatures. The lower temperature employed for the enyne allene cyclization is likely to be compatible with sensitive functionality that would be required in the synthesis of a complex natural product.

These results identify the tandem enyne allene−radical cyclization as a suitable alternative to the tandem enediyne−radical cyclization methodology for the construction of molecules with a benz[*e*]indene framework. This new method is comparatively efficient, and the reaction temperatures are much more desirable for the synthetic chemist.

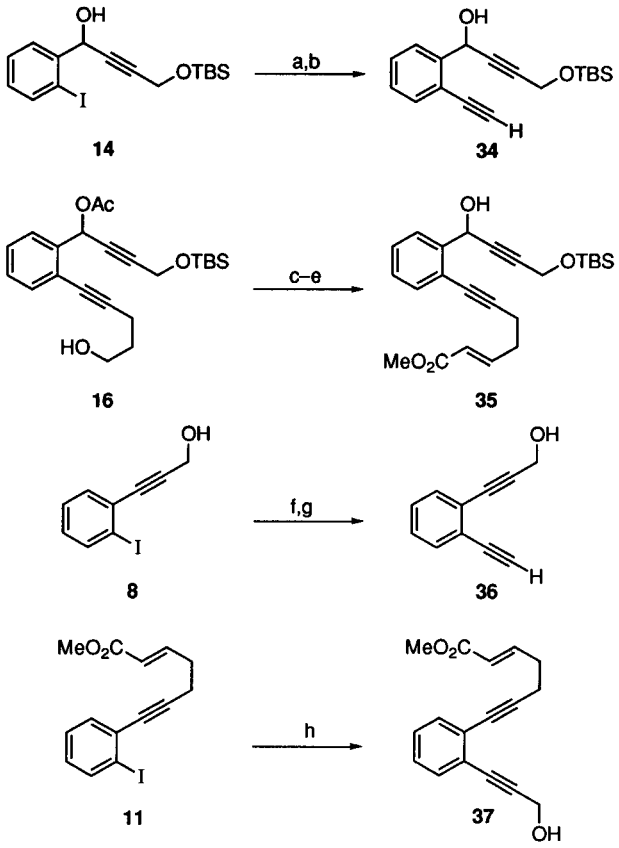
Tandem Enyne Allene−Radical Cyclization *via* [2,3] Sigmatropic Rearrangements.[16]

Synthesis of Precursors for the Tandem Enyne Allene−Radical Cyclization of Aromatic Enyne Allenes *via* [2,3] Sigmatropic Rearrangement. Enyne allenes that undergo Myers cyclization have been previously synthesized *via* a [2,3] sigmatropic rearrangement of phosphinites and sulfinates.[17] To establish if this method of allene formation would be applicable to the synthesis of suitable precursors for the tandem enyne allene−radical cyclization, a set of diyne alcohols was synthesized as outlined in Scheme 7. Due to the lability of the sulfoxides as described by Nicolaou, we chose the phosphine oxides for initial investigation.

Diyne substrate **34** was obtained in 89% yield from the iodophenyl compound **14** by a palladium(0)-catalyzed coupling reaction with (trimethylsilyl)acetylene and subsequent desilylation with potassium carbonate in methanol. Pentynol derivative **16** was oxidized using PCC and the resulting aldehyde subjected to a Horner−Emmons reaction under Roush−Masamune conditions with trimethyl phosphonoacetate in acetonitrile in the presence of lithium chloride and DBU. A subsequent base-catalyzed cleavage of the acetate provided precursor **35** in a combined yield of 59% over three steps. 3-(2-Iodophenyl)-2-propyn-1-ol (**8**) was converted to enediyne alcohol **36** in 96% yield by a palladium(0)-catalyzed coupling/desilylation sequence as described above for substrate **34**. A palladium(0)-catalyzed coupling reaction with propargyl alcohol was used to afford enediyne **37** in 88% yield from iodophenyl compound **11**.

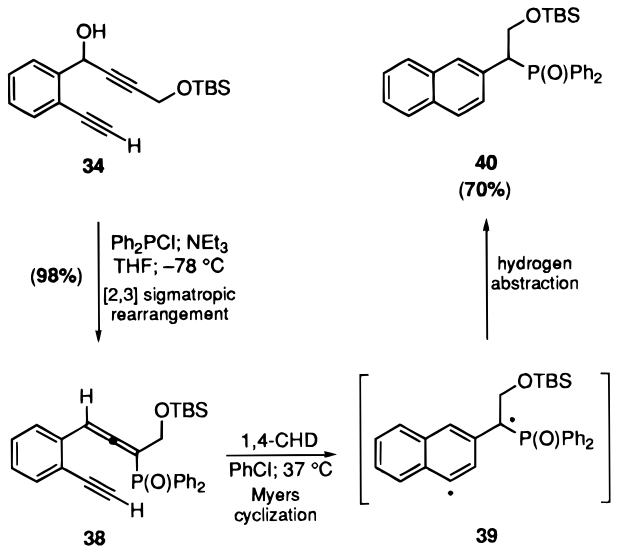
Results of the [2,3] Sigmatropic Rearrangement-Mediated Tandem Enyne Allene−Radical Cyclization Experiments Involving Aromatic Enyne Allene Substrates. In analogy to the successful cyclizations of substrates **28** and **31** in the experiments involving [3,3] sigmatropic rearrangements (*cf.* Schemes 5 and 6), the cyclization behavior of compounds **38** and **41** was investigated. Diyne alcohol **34** was treated with chlorodiphenylphosphine in THF at −78 °C in the presence of triethylamine to yield enyne allene **38** in excellent yield (Scheme 8). Heating this compound at 37 °C in the presence of 1,4-CHD as a hydrogen atom donor yielded enyne allene-cyclized product **40** in 70% yield. This

Scheme 7



(a) (trimethylsilyl)acetylene (1.5 equiv), $Pd(PPh_3)_2Cl_2$ (0.05 equiv), CuI (0.1 equiv), NEt_3, THF (92%); (b) K_2CO_3 (cat.), MeOH (97%); (c) PCC, CH_2Cl_2 (84%); (d) trimethyl phosphonoacetate, LiCl, DBU, CH_3CN (86%); (e) same as (b) (82%); (f) same as (a) (99%); (g) same as (b) (97%); (h) propargyl alcohol (1.2 equiv), $Pd(PPh_3)_2Cl_2$ (0.05 equiv), CuI (0.1 equiv), NEt_3, THF (88%).

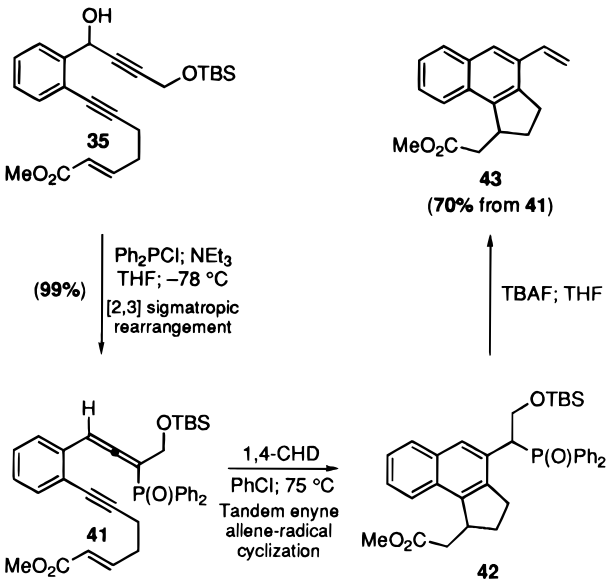
Scheme 8



(16) (a) Grissom, J. W.; Huang, D. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 2037. (b) Grissom, J. W.; Slattery, B. J. *Tetrahedron Lett.* **1994**, *35*, 5137.

(17) For examples of [2,3] sigmatropic rearrangements of propargyl diphenylphosphinites, see: (a) Nicolaou, K. C.; Skokotas, G.; Maligres, P.; Zuccarello, G.; Schweiger, E. J.; Toshima, K.; Wendeborn, S. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 1272. (b) Nicolaou, K. C.; Maligres, P.; Shin, J.; de Leon, E.; Rideout, D. *J. Am. Chem. Soc.* **1990**, *112*, 7825. (c) Nagata, R.; Yamanaka, H.; Murahashi, E.; Saito, I. *Tetrahedron Lett.* **1990**, *31*, 2907. (d) Nagata, R.; Yamanaka, H.; Okazaki, E.; Saito, I. *Tetrahedron Lett.* **1989**, *30*, 4995.

Scheme 9

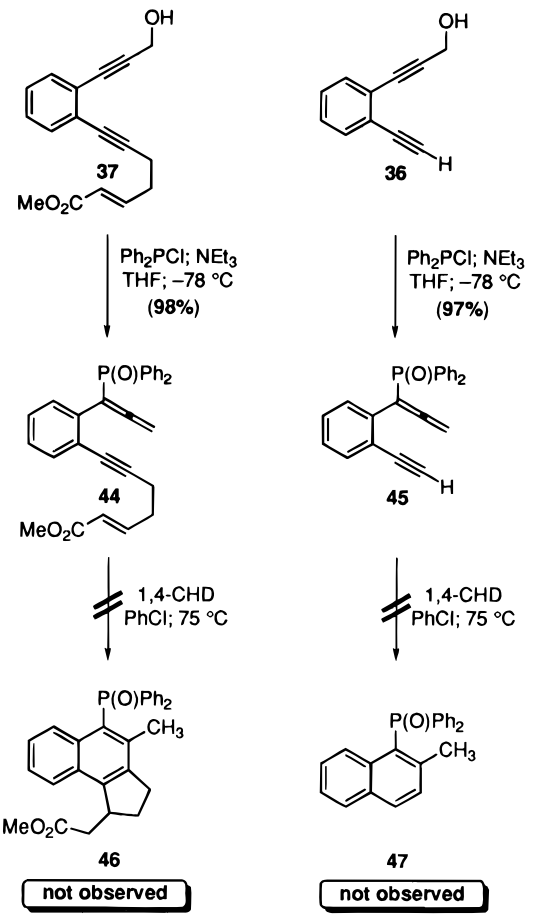


observation corresponds to the behavior of a similar substrate described by Nicolaou that has been reported to cyclize at 37 °C in a very similar yield.[17b]

Having established the feasibility of carrying an enyne allene cyclization on a substrate with a phosphine oxide substituent prepared by a [2,3] sigmatropic rearrangement of a phosphinite, the next goal was to couple this cyclization with a subsequent radical cyclization. Treatment of compound **35** with chlorodiphenylphosphine in THF at low temperature yielded enyne allene compound **41** in 99% yield (Scheme 9). Thermolysis of enyne allene **41** at 37 °C in the presence of 1,4-CHD resulted in no reaction. However, increasing the thermolysis temperature to 75 °C yielded tandem enyne allene−radical cyclization product **42**. Due to the difficulty in purifying the polar phosphine oxide **42**, this compound was subjected to a Horner−Wittig elimination to yield benz[*e*]-indene compound **43** in an overall yield of 70% from **41**. Although cyclization of **41** did occur at 50 °C, the yield obtained at this temperature was low and the product mixture more complex.

Prior to the successful outcome of the cyclization experiments with substrates **38** and **41**, both of which carry the phosphine oxide substituent at the C-3 position of the allene moiety, we had explored the cyclization behavior of the corresponding substrates **44** and **45** carrying the phosphine oxide substituent at the C-1 position of the allene functionality. These systems were investigated first since they were easily prepared in three to four steps (Scheme 7). Treatment of enediyne **37** with chlorodiphenylphosphine at low temperature resulted in a [2,3] sigmatropic shift to afford enyne allene **44** in 98% yield (Scheme 10). However, when this compound was heated to 75 °C in the presence of 1,4-CHD as a hydrogen donor, there was no evidence for tandem enyne allene−radical cyclization product **46** and only slow decomposition occurred. Attempts to effect a cyclization at higher temperatures resulted in a complex mixture of products. To test whether the problem arose during the enyne allene cyclization or the subsequent radical cyclization, the cyclization of enyne allene **45** was carried out. The expected tandem enyne allene−radical cyclization product **47** could not be detected, and the starting material slowly underwent decomposition.

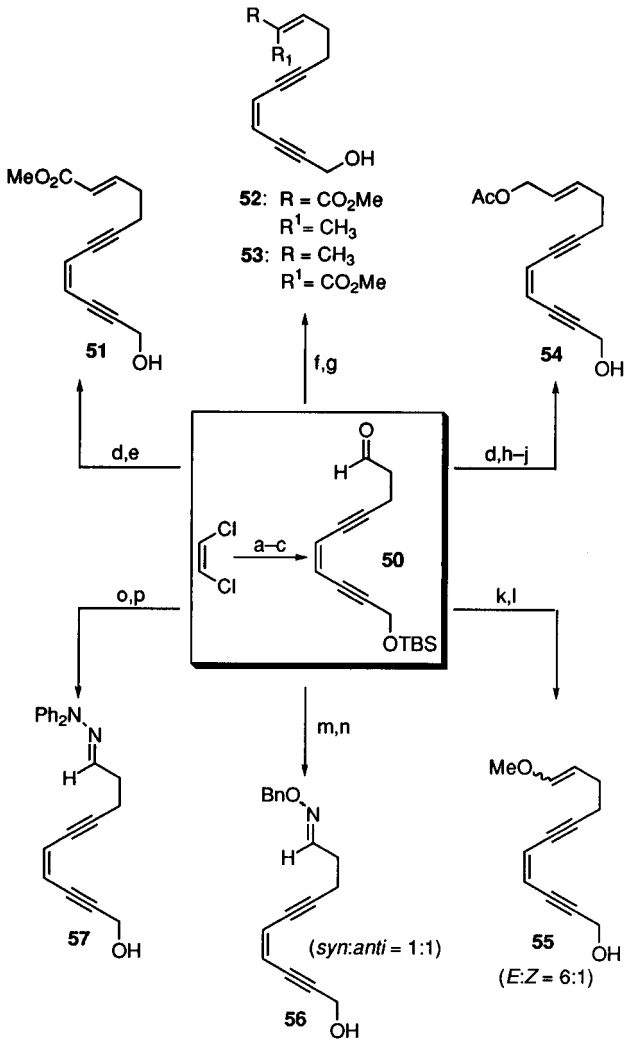
Scheme 10



These results combined with the poor reactions obtained with C-1-substituted allene **24** substantiate the assumption that an unfavorable interaction between a C-1 allene substituent and the aryl ring of the enyne allene hinders the cyclization reaction. In substrates **44** and **45** there are unfavorable steric interactions between the (diphenylphosphinyl) group and the aryl ring of the enyne allene, causing the phosphinyl group to rotate the allene out of the plane defined by the aryl group. The enyne allene would therefore no longer be coplanar and thus be unable to participate in the Myers cyclization. It is possible that a similar interaction between the C-1 allene CH_2CHO group and the aryl ring resulted in poor yields during the cyclization of [3,3]-generated enyne allene **24** to form **25** (Scheme 4). When the substituent was shifted to the C-3 allene position as in **28** and **31**, the reactions proceeded more favorably (Schemes 5 and 6). Therefore, to avoid this unfavorable steric interaction, we investigated the cyclization behavior of substrates **38** and **41** as previously described.

If an unfavorable steric interaction occurred between the C-1 allene phosphine oxide and the *ortho* hydrogen of the aromatic enyne allene, it was possible that removing that hydrogen would improve the reaction. Therefore, we then addressed the question of whether nonaromatic enyne allene precursors that carry a phosphine oxide substituent at the C-1 position of the allene would participate in a tandem enyne allene−radical cyclization. To test the feasibility of this hypothesis, a variety of enediyne alcohols were synthesized (Scheme 11). We were encouraged that this approach might be fruitful because of earlier work by Saito describing the cyclization of nonaromatic enyne allenes containing C-1 phosphine oxides.[17c]

Scheme 11

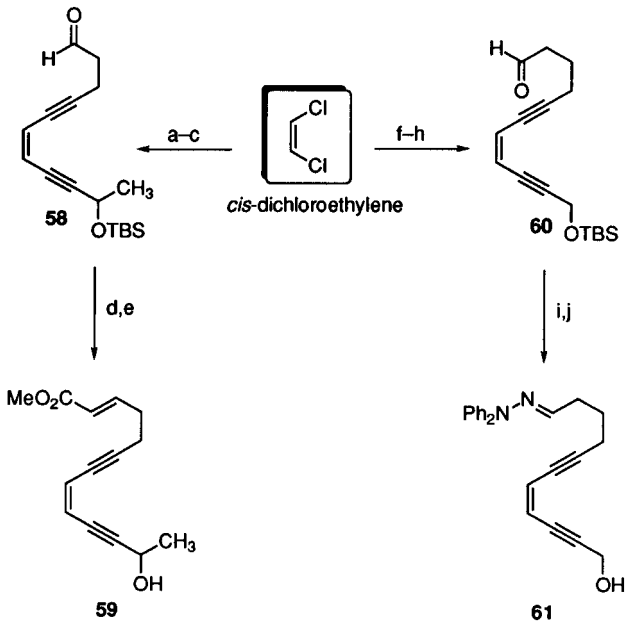


(a) 4-pentynol, $Pd(PPh_3)_4$, CuI, *n*-$BuNH_2$, PhH, 40 °C (72%); (b) 3-(*tert*-butyldimethylsilyloxy)propyne, $Pd(PPh_3)_4$, CuI, *n*-$BuNH_2$, PhH, 50 °C (85%); (c) PCC, CH_2Cl_2 (75%); (d) trimethylphosphonoacetate, DBU, LiCl, CH_3CN (86%); (e) BF_3-etherate, CH_2Cl_2 (86%); (f) trimethyl 2-methylphosphonoacetate, DBU, LiCl, CH_3CN (82%); (g) same as (e) (80% for **53**, 82% for **54**); (h) DIBAL, CH_2Cl_2, 0 °C (78%); (i) Ac_2O, NEt_3, CH_2Cl_2 (95%); (j) TBAF, THF (83%); (k) (methoxymethyl)triphenylphosphonium chloride, $(CH_3)_3COK$, THF, –78 °C (62%); (l) same as (j) (88%); (m) $BnONH_3Cl$, pyridine, CH_2Cl_2 (96%); (n) same as (j) (81%); (o) Ph_2NNH_3Cl, pyridine, CH_2Cl_2 (95%); (p) same as (j) (93%).

Synthesis of Precursors for the Tandem Enyne Allene−Radical Cyclization of Nonaromatic Enyne Allenes *via* [2,3] Sigmatropic Rearrangement. Several substrates were synthesized from easily synthesized enediyne aldehyde **50**, which was readily available from *cis*-dichloroethylene in three straightforward steps (Scheme 11). Two consecutive palladium(0)-catalyzed coupling reactions under modified Castro−Stephens conditions with 4-pentynol and 3-((*tert*-butyldimethylsilyl)-oxy)propyne followed by PCC oxidation of the resulting primary alcohol afforded enediyne aldehyde **50** in a combined yield of 46% over three steps.

The α,β-unsaturated enediyne ester **51** was obtained in 74% yield from **50** by a Horner−Emmons reaction under Roush−Masamune conditions[15] with trimethyl phosphonoacetate in the presence of lithium chloride and DBU in acetonitrile, followed by subsequent desilylation with BF_3 etherate in dichloromethane (Scheme 11). Reduction of **51** with diisobutylaluminum hydride (DIBAL)[18] in dichloromethane at 0 °C, esterification of the resulting primary alcohol with acetyl chloride and triethylamine in dichloromethane, and desilylation with tetra-*n*-butylammonium fluoride (TBAF) in THF afforded allylic acetate **54** in a total yield of 53% from **50**. Substrates **52** and **53** were prepared in a fashion similar to that of compound **51**, using trimethyl 2-methylphosphonoacetate in the Horner−Emmons reaction and separating the (*E*)- and (*Z*)-stereoisomers prior to desilylation. Thus, compound **52** (*E* isomer) was obtained in 58% from **50**, and compound **53** (*Z* isomer) was obtained in 7% from **50**. Wittig reaction[19] of aldehyde **50** with (methoxymethyl)triphenylphosphonium chloride and potassium *tert*-butoxide in THF at −78 °C and subsequent desilylation with TBAF in THF gave rise to enol ether **55** in a total yield of 55% over two steps. *O*-Benzyloxime ether **56** and diphenylhydrazone **57** were each obtained by condensing aldehyde **50** with the respective amine hydrochloride (*O*-benzylhydroxylamine hydrochloride or 1,1-diphenylhydrazine hydrochloride), followed by desilylation with TBAF in THF. With this strategy, **56** and **57** were obtained in 78% and 88% combined yields, respectively.

Scheme 12

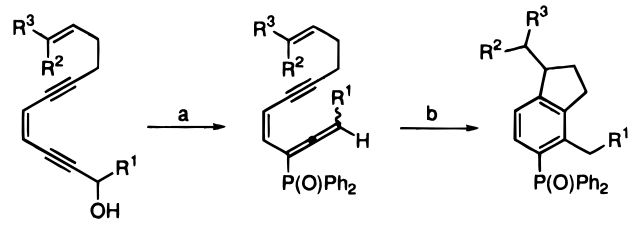


(a) 4-pentynol, $Pd(PPh_3)_4$, CuI, *n*-$BuNH_2$, PhH, 40 °C (72%); (b) 3-(*tert*-butyldimethylsilyloxy)-1-butyne, $Pd(PPh_3)_4$, CuI, *n*-$BuNH_2$, PhH, 50 °C (79%); (c) PCC, CH_2Cl_2 (77%); (d) trimethylphosphonoacetate, DBU, LiCl, CH_3CN (92%); (e) BF_3-etherate, CH_2Cl_2 (84%); (f) 5-hexynol, $Pd(PPh_3)_4$, CuI, *n*-$BuNH_2$, PhH, 40 °C (75%); (g) 3-(tert-butyldimethylsilyloxy)propyne, $Pd(PPh_3)_4$, CuI, *n*-$BuNH_2$, PhH, 50 °C (76%); (h) same as (c) (76%); (i) Ph_2NNH_3Cl, pyridine, CH_2Cl_2 (92%); (j) TBAF, THF (95%).

The synthesis of two additional precursors is illustrated in Scheme 12. The α,β-unsaturated enediyne ester **59** was prepared in a sequence similar to that of substrate **51**. Starting from *cis*-dichloroethylene, two consecutive palladium(0)-catalyzed coupling reactions with 4-pentynol and 3-((*tert*-butyldimethylsilyl)oxy)-1-butyne followed by PCC oxidation afforded aldehyde **58**, which was converted to **59** by a Horner−Emmons reaction with trimethyl phosphonoacetate and subsequent desilylation with BF_3 etherate. The overall yield of

(18) Winterfeldt, E. *Synthesis* **1975**, 617.
(19) For general reviews of the Wittig reaction, see: (a) Pommer, H.; Thieme, P. C. *Top. Curr. Chem.* **1983**, *109*, 165. (b) Bestmann, H. J.; Vostrowsky, O. *Top. Curr. Chem.* **1983**, *109*, 85. (c) Pommer, H. *Angew. Chem., Int. Ed. Engl.* **1977**, *16*, 423. (d) Maercker, A. *Org. React.* **1965**, *14*, 270.

Table 1. Tandem Enyne Allene−Radical Cyclization of Substrates 62−67



51–55, 59 62–67 68–72

(a) PPh_2Cl (1.5 equiv), NEt_3 (2.0 equiv), CH_2Cl_2, −78 °C to 0 °C; (b) 1,4-CHD (3.5 M), PhH, 37 °C, 12 h.

enediyne	enyne allene	R^1	R^2	R^3	product	yield,[a] %
51	**62**	H	H	CO_2Me	**68**	68
52	**63**	H	Me	CO_2Me	**69a,b**[b]	70
53	**64**	H	CO_2Me	Me	**69a,b**[b]	67
54	**65**	H	H	CH_2OAc	**70**	62
55[c]	**66**	H	H	OMe	**71**	55
59	**67**	Me	H	CO_2Me	**72**	52

[a] Overall yield over two steps. [b] Isolated as a 3.5:1 mixture of diastereomers. [c] *E*:*Z* = 6:1.

compound **59** in this five-step sequence from *cis*-dichloroethylene was 34%. Enediyne aldehyde **60** was obtained in a combined yield of 48% from *cis*-dichloroethylene by performing two consecutive palladium(0)-catalyzed coupling reactions with 5-hexynol and 3-((*tert*-butyldimethylsilyl)oxy)propyne followed by PCC oxidation of the intermediate enediyne alcohol. Condensing aldehyde **60** with 1,1-diphenylhydrazine hydrochloride in the presence of pyridine in dichloromethane, followed by desilylation with TBAF in THF, afforded enediyne diphenylhydrazone **61** in 87% yield over two steps.

Results of the [2,3] Sigmatropic Rearrangement-Mediated Tandem Enyne Allene−Radical Cyclization Experiments Involving Nonaromatic Enyne Allene Substrates. Given the reliability of the α,*β*-unsaturated ester as a radical acceptor in tandem enediyne or enyne allene−radical cyclizations,[7] we initially investigated enyne allene **62** (Table 1). When enediyne **51** was treated with chlorodiphenylphosphine and triethylamine in dichloromethane at −78 °C and the mixture allowed to stir at 0 °C, enyne allene **62** was formed *via* a [2,3] sigmatropic rearrangement. Unfortunately, **62** was isolated in poor yield (*ca.* 10%) due to its decomposition on silica gel and alumina. Therefore, the subsequent cyclization was performed without the purification of **62** immediately following the sigmatropic shift. Upon mild thermolysis of crude enyne allene **62** in anhydrous benzene at 37 °C in the presence of a large concentration of 1,4-CHD (c = 3.5 M) for 12 h, 2,3-dihydroindene derivative **68** was isolated in 68% overall yield from enediyne **51**.

Encouraged by the successful tandem enyne allene−radical cyclization of **62**, enyne allene **63** generated from a [2,3] sigmatropic shift of **52** was thermolyzed at 37 °C in the presence of 1,4-CHD (3.5 M) to provide 2,3-dihydroindenes **69a** and **69b** as a 3.5:1 diastereomeric mixture in 70% overall yield from **52** (Table 1). When the similar reaction sequence was applied to **53** (*Z* isomer of **52**), the 2,3-dihydroindenes **69a** and **69b** were obtained as an identical 3.5:1 diastereomeric mixture in 67% overall yield from **53**. The fact that the diastereoselectivities observed in both reactions are identical with previous results observed in the tandem enediyne−radical cyclizations and the comparable tributyltin hydride-mediated radical cyclizations[7h] reveals that the current reaction likely proceeds through a radical intermediate and the geometry of the olefin within the α,*β*-unsaturated ester has no effect on either diastereoselectivity or yield of the radical cyclization.

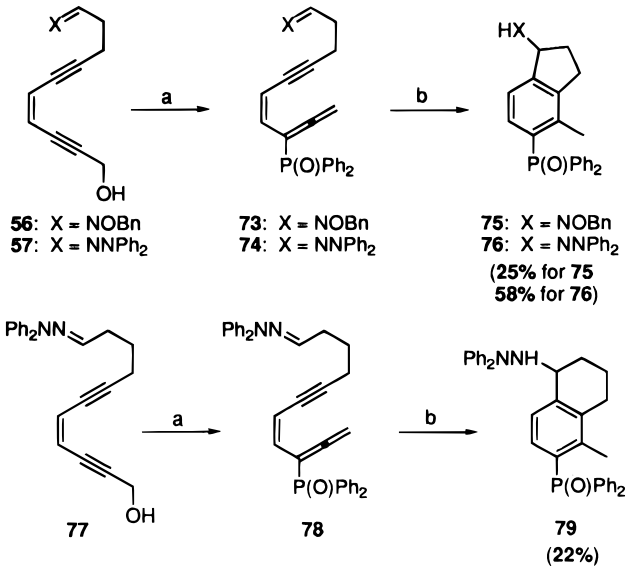
In order to test this methodology with other radical acceptors and to determine the scope of the reaction, both allylic acetate **54** and enol ether **55** were investigated. Treatment of **54** and **55** with chlorodiphenylphosphine followed by thermolysis of the corresponding enyne allenes **65** and **66** at physiological temperature (37 °C) in the presence of 1,4-CHD (3.5 M) produced the 2,3-dihydroindenes **70** and **71** in 55% and 62% overall yields, respectively. It should be pointed out that the tandem enyne allene−radical cyclization of **66** bearing a methyl vinyl ether in the radical acceptor side chain occurred smoothly at 37 °C, while the enol ether functionality in a nonaromatic enediyne similar to substrate **55** did not survive at all in the tandem enediyne−radical cyclization at high temperature.[7d,h]

Finally, enediyne **59** was chosen to explore how a simple alkyl substituent at the C-3 position of the resulting allene would affect the enyne allene cyclization. When enediyne **59** was treated with chlorodiphenylphosphine and triethylamine at −78 °C and the mixture allowed to stir at 0 °C, enyne allene **67** was formed as the major product along with an impurity (*ca.* 15% based on ^{1}H NMR). Subsequent thermolysis of crude enyne allene **67** at 37 °C in the presence of 1,4-CHD (3.5 M) afforded 2,3-dihydroindene **72** in 52% overall yield from **59** and 12% of a minor product which was identical to the impurity formed in the [2,3] sigmatropic shift and which appeared to be nonrearranged phosphite of **59** on the basis of ^{1}H NMR data. It is possible that the C-3 methyl group sterically impedes the [2,3] sigmatropic shift and the phosphine oxide simply undergoes oxidation. Additional substituent studies were not carried out.

While carbon−carbon double bonds are established as radical acceptors in the 5-*exo* ring closure mode, *O*-benzyloxime ethers as well as *N*,*N*-diphenylhydrazones have only recently emerged as suitable carbon−nitrogen radical acceptors in 5-*exo* and 6-*exo* radical ring closure reactions.[7dh,20,21] Cyclization reactions onto these accep-

(20) For the use of oxime ethers in radical cyclization reactions, see: (a) Chiara, J. L.; Marco-Contelles, J.; Khiar, N.; Gallego, P.; Destabel, C.; Bernabé, M. *J. Org. Chem.* **1995**, *60*, 6010. (b) Marco-Contelles, J.; Destabel, C.; Chiara, J. L.; Bernabé, M. *Tetrahedron: Asymmetry* **1995**, *6*, 1547. (c) Keck, G. E.; McHardy, S. F.; Murry, J. A. *J. Am. Chem. Soc.* **1995**, *117*, 7289. (d) Santagostino, M.; Kilburn, J. D. *Tetrahedron Lett.* **1995**, *36*, 1365. (e) Kiguchi, T.; Tajiri, K.; Ninimiya, I.; Naito, T.; Hiramatsu, H. *Tetrahedron Lett.* **1995**, *36*, 253. (f) Booth, S. E.; Jenkins, P. R.; Swain, C. J.; Sweeney, J. B. *J. Chem. Soc., Perkin Trans. 1* **1994**, 3499. (g) Naito, T.; Tajiri, K.; Harimoto, T.; Ninomiya, I.; Kiguchi, T. *Tetrahedron Lett.* **1994**, *35*, 2205. (h) Ingall, A. H.; Moore, P. R.; Roberts, S. M. *J. Chem. Soc., Chem. Commun.* **1994**, 83. (i) Pattenden, G.; Schultz, D. J. *Tetrahedron Lett.* **1993**, *34*, 6787. (j) Marco-Contelles, J.; Ruiz, P.; Martínez, L.; Martínez-Grau, A. *Tetrahedron* **1993**, *49*, 6669. (k) Simpkins, N. S.; Stokes, S.; Whittle, A. J. *J. Chem. Soc., Perkin Trans. 1* **1992**, 2471. (l) Marco-Contelles, J.; Ruiz, P.; Sánchez, B.; Jimeno, M. L. *Tetrahedron Lett.* **1992**, *33*, 5261. (m) Hatem, J.; Henriet-Bernard, C.; Grimaldi, J.; Maurin, R. *Tetrahedron Lett.* **1992**, *33*, 1057. (n) Marco-Contelles, J.; Pozuelo, C.; Jimeno, M. L.; Martínez, L.; Martínez-Grau, A. *J. Org. Chem.* **1992**, *57*, 2625. (o) Booth, S. E.; Jenkins, P. R.; Swain, C. J. *J. Chem. Soc., Chem. Commun.* **1991**, 1248. (p) Marco-Contelles, J.; Martínez, L.; Martínez-Grau, A. *Tetrahedron: Asymmetry* **1991**, *2*, 961. (q) Marco-Contelles, J.; Martínez-Grau, A.; Bernabe, M.; Martin, N.; Seoane, C. *Synlett* **1991**, 165. (r) Enholm, E. J.; Burroff, J. A.; Jaramillo, L. M. *Tetrahedron Lett.* **1990**, *31*, 3727. (s) Parker, K. A.; Spero, D. M.; Van Epp, J. *J. Org. Chem.* **1988**, *53*, 4628. (t) Bartlett, P. A.; McLaren, K. L.; Ting, P. C. *J. Am. Chem. Soc.* **1988**, *110*, 1633. (u) Hart, D. J.; Seely, F. L. *J. Am. Chem. Soc.* **1988**, *110*, 1631. (v) Corey, E. J.; Pyne, S. G. *Tetrahedron Lett.* **1983**, *24*, 2821.

Scheme 13



(a) PPh_2Cl (1.5 equiv), NEt_3 (2.0 equiv), CH_2Cl_2, –78 °C to 0 °C, 1 h; (b) 1,4-CHD (3.5 M), PhH, 37 °C, 12 h.

tors would offer the advantage of forming a ring structure that bears a heteroatom at the position of the ring closure rather than a carbon. Since numerous important natural products contain nitrogen functionalities, a successful radical cyclization onto oxime ethers or hydrazones could provide access to these compounds and thus broaden the applicability of the tandem enyne allene−radical cyclization methodology. The nitrogen could also serve as a handle to introduce additional functionalization at this position. To test the feasibility of these radical acceptors in the tandem enyne allene−radical cyclization methodology, enediyne substrates **56** and **57** were investigated (Scheme 13). While the treatment of oxime ether **56** with chlorodiphenylphosphine and triethylamine in dichloromethane and subsequent mild thermolysis in benzene at 37 °C provided the corresponding indene derivative **75** in only moderate yield (25%), the formation of indenyl diphenylhydrazine **76** from enediyne **57** proceeded much more efficiently in a yield of 58%. It is unclear why the hydrazone is a superior acceptor to the oxime ether.

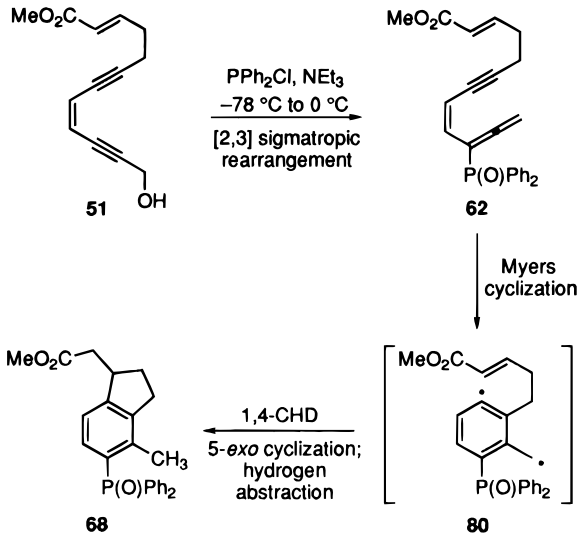
Since all biologically active steroids contain several six-six fused rings, it would be useful to utilize the current methodology to construct this ring system. To study whether a six-membered ring could be prepared using the tandem enyne allene−radical cyclization, diphenylhydrazone **77** was subjected to the cyclization conditions at 37 °C; however, tetraline derivative **79** could only be isolated in a moderate yield of 22% (Scheme 13).

The mechanism of the overall transformation is outlined in Scheme 14. Enyne allene **62**, generated from a [2,3] sigmatropic rearrangement of corresponding enediyne **51**, undergoes an enyne allene cyclization (Myers cyclization) to form biradical **80**. Subsequent 5-*exo* (6-*exo*) radical cyclization of aryl radical **80** followed by hydrogen abstraction from 1,4-CHD furnish indan derivative **68**. The mechanism of cyclization is the same as that for the enyne allenes generated from the [3,3] sigmatropic shift reaction (**17** → **33a,b**; Scheme 6).

The experiments involving nonaromatic enyne allene substrates bearing a phosphine oxide substituent at the

(21) For the use of diphenylhydrazones in radical cyclization reactions, see: (a) Sturino, C. F.; Fallis, A. G. *J. Org. Chem.* **1994**, *59*, 6514. (b) Sturino, C. F.; Fallis, A. G. *J. Am. Chem. Soc.* **1994**, *116*, 7447.

Scheme 14



C-1 position of the allene moiety show that the tandem enyne allene−radical cyclization (**62** → **68**) represents a useful tool for the construction of indan derivatives from simple enediyne precursors that are readily available from commercially available *cis*-dichloroethylene. The corresponding aromatic enyne allene substrate does not participate in a tandem enyne allene−radical cyclization (**37** → **46**) presumably due to an unfavorable steric interaction between the large C-1 phosphine oxide substituent on the allene and the adjacent aromatic hydrogen atom. Aromatic enyne allene compounds that carry a phosphine oxide substituent at the C-3 position of the allene unit undergo a tandem enyne allene−radical cyclization (**35** → **42**) and provide the respective benz[*e*]-indene derivatives in good yields; however, the synthesis of the cyclization precursors is rather lengthy.

Tandem Enyne Allene−Radical Cyclization *via* Base-Catalyzed Isomerization of Enediyne Sulfones[22]

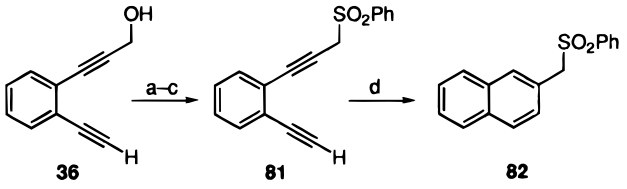
Although the previously discussed method appears to be a very efficient method for the construction of multicyclic compounds, it requires the use of a phosphine oxide substituent for the successful conversion of the starting enyne allene substrates. This phosphorous substituent, however, is not easily converted into useful functionality for the synthetic chemist if a further elaboration of the target molecules were desired. Therefore, we directed our effort toward the use of the more versatile phenylsulfonyl group in the tandem enyne allene−radical cyclization methodology.

Nicolaou,[23cd] Wu,[23a] and Shibuya[23e] have reported that base-catalyzed isomerization of an enediyne sulfone leads to an enyne allene sulfone which undergoes cyclization at 25−37 °C. To explore the feasibility of this mode of enyne allene formation and cyclization for aromatic

(22) Grissom, J. W.; Klingberg, D. *Tetrahedron Lett.* **1995**, *36*, 6607.

(23) (a) Wu, M.-J.; Lin, C.-F.; Wu, J.-S.; Chen, H.-T. *Tetrahedron Lett.* **1994**, *35*, 1879. (b) Toshima, K.; Ohta, K.; Ohtsuka, A.; Matsumura, S.; Nakata, M. *J. Chem. Soc., Chem. Commun.* **1993**, 1406. (c) Nicolaou, K. C.; Wendeborn, S.; Maligres, P.; Isshiki, K.; Zein, N.; Ellestad, G. *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 418. (d) Nicolaou, K. C.; Skokotas, G.; Maligres, P.; Zuccarello, G.; Schweiger, E. J.; Toshima, K.; Wendeborn, S. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 1272. (e) Sakai, Y.; Bando, Y.; Shishido, K.; Shibuya, M. *Tetrahedron Lett.* **1992**, *33*, 957.

Scheme 15



(a) MsCl, NEt_3, CH_2Cl_2 (94%); (b) 1.4 equiv of PhSH, 1.4 equiv of NaOH, THF–H_2O (94%); (c) 2.2 equiv of *m*-CPBA, CH_2Cl_2, 0 °C, 2 h (97%); (d) 5.0 equiv of NEt_3, 1,4-CHD (3.5 M), benzene, 30 °C, 12 h (68%).

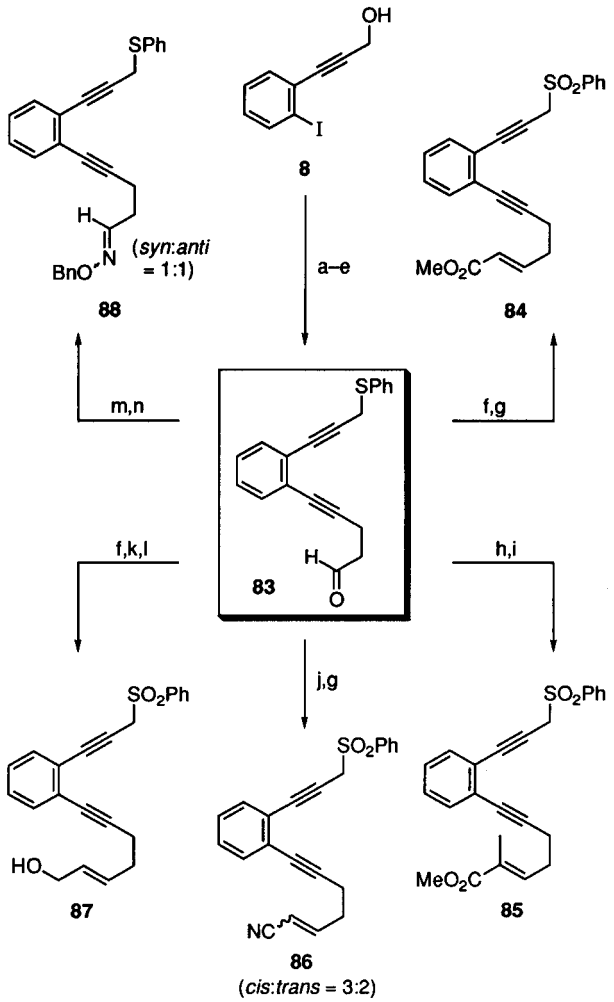
enediyne precursors, we synthesized enediyne **81** from 3-(2-ethynylphenyl)-2-propyn-1-ol (**36**) (Scheme 15). Mesylation of the alcohol with methanesulfonyl chloride and triethylamine in dichloromethane, nucleophilic exchange of the methanesulfonyl group with sodium phenyl sulfide, and oxidation of the resulting thioether with *m*-chloroperbenzoic acid (*m*-CPBA) provided enediyne sulfone **81** in an excellent yield of 86% from **36**. When enediyne sulfone **81** was heated in anhydrous benzene at 30 °C in the presence of triethylamine and a large excess of 1,4-CHD (c = 3.5 M) as a hydrogen atom donor, the simple enyne allene cyclization product **82** was isolated in 68% yield (Scheme 15).

Given the successful cyclization of substrate **81**, attention was focused on trapping the intermediate aryl radical in the enyne allene cyclization with a pendent olefin. Since the α,β-unsaturated methyl ester had been employed successfully in a variety of different tandem enediyne– and tandem enyne allene–radical cyclizations in our laboratory,[7] the cyclizations of enediyne sulfones **84**–**88** (Scheme 16) were investigated.

Synthesis of Precursors for the Tandem Enyne Allene–Radical Cyclization of Aromatic Enyne Allenes *via* Base-Catalyzed Isomerization of Enediyne Sulfones. Enediyne sulfones **84**–**88** were each synthesized in a straightforward manner from enediyne aldehyde **83**, which was prepared from 3-(2-iodophenyl)-2-propyn-1-ol (**8**) (Scheme 16). Aryl iodide **8** was subjected to a palladium(0)-catalyzed coupling reaction with 5-((*tert*-butyldimethylsilyl)oxy)-1-pentyne in the presence of bis(triphenylphosphine)palladium(II) chloride and copper(I) iodide as well as triethylamine in THF. Subsequent conversion of the primary alcohol into the phenyl sulfide *via* the methanesulfonate, desilylation with acetic acid in a THF–water mixture,[24] and Swern oxidation[25] cleanly afforded key intermediate **83** in a total yield of 75% over five steps. The desilylation step had to be performed with a 3:1 mixture of acetic acid and water; the use of lower acetic acid concentrations was ineffective. Attempts to effect the deprotection with tetra-*n*-butylammonium fluoride in THF resulted in decomposition of starting material.

The α,β-unsaturated enediyne ester **84** was obtained from aldehyde **83** in 69% by a Horner–Emmons reaction under Roush–Masamune conditions[15] with trimethyl phosphonoacetate and subsequent *m*-CPBA oxidation in dichloromethane at 0 °C. Following the same procedure using trimethyl 2-methylphosphonoacetate in the Horner–Emmons reaction, enediyne sulfone **85** was prepared in 44% total yield. Unsaturated enediyne nitrile **86** was

Scheme 16



(a) 5-(*tert*-butyldimethylsilyloxy)-1-pentyne, $(Ph_3P)_2PdCl_2$, CuI, NEt_3, THF (98%); (b) MsCl, NEt_3, CH_2Cl_2 (94%); (c) PhSH, NaOH, THF–H_2O (97%); (d) HOAc, THF, H_2O (91%); (e) oxalyl chloride, DMSO, NEt_3, –78 °C (92%); (f) trimethyl phosphonoacetate, DBU, LiCl, CH_3CN (82%); (g) *m*-CPBA, CH_2Cl_2, 0 °C (84%); (h) trimethyl 2-methylphosphonoacetate, DBU, LiCl, CH_3CN (62%); (i) same as (g) (71%); (j) $(EtO)_2P(O)CH_2CN$, $(CH_3)_3COK$, THF (76%); (k) DIBAL, CH_2Cl_2, 0 °C (72%); (l) *m*-CPBA, CH_2Cl_2, –78 °C to 0 °C (46%); (m) $PhCH_2ONH_3Cl$, pyridine, CH_2Cl_2 (94%); (n) same as (l) (84%).

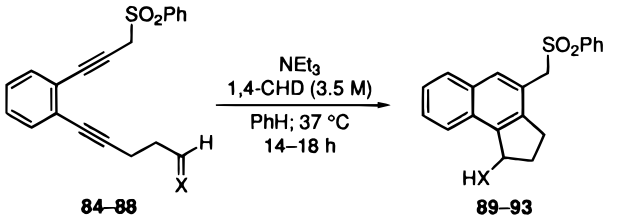
obtained in 55% as a 3:2 mixture of *cis*/*trans* isomers from **83** by a Horner–Emmons reaction with diethyl (cyanomethyl)phosphonate[26] and potassium *tert*-butoxide in THF followed by subsequent oxidation with *m*-CPBA. Horner–Emmons reaction of aldehyde **83** with trimethyl phosphonoacetate, subsequent reduction of the α,β-unsaturated enediyne ester with diisobutylaluminum hydride (DIBAL), and oxidation with *m*-CPBA at –78 °C provided allylic enediyne alcohol **87** in a moderate yield of 27% over three steps. To guarantee good yields in all Horner–Emmons reactions of intermediate **83**, the reaction mixtures had to be worked up immediately after the reagents were added. *O*-Benzyloxime ether **88** was

(24) Corey, E. J.; Venkateswarlu, A. *J. Am. Chem. Soc.* **1972**, *94*, 6190.

(25) Mancuso, A. J.; Huang, S.-L.; Swern, D. *J. Org. Chem.* **1978**, *43*, 2480.

(26) For general reviews of the Horner–Emmons reaction, see: (a) Maryanoff, B. E.; Reitz, A. B. *Chem. Rev.* **1989**, *89*, 863. (b) Wadsworth, W. S., Jr. *Org. React.* **1977**, *25*, 73. (c) Boutagy, J.; Thomas, R. *Chem. Rev.* **1974**, *74*, 87. For Wittig reactions or Horner–Emmons reactions that employ cyano-substituted phosphoranes or cyanomethyl-substituted phosphonates, see: (d) Ullas, G. V.; Chu, C. K.; Ahn, M. K.; Kosugi, Y. *J. Org. Chem.* **1988**, *53*, 2413. (e) Piechucki, C. *Synthesis* **1974**, 869. (f) Tronchet, J. M. J.; Baehler, B.; Eder, H.; Le-Hong, N.; Perret, F.; Poncet, J.; Zumwald, J.-B. *Helv. Chim. Acta* **1973**, *56*, 1310. (g) Bose, A. K.; Dahill, R. T., Jr. *J. Org. Chem.* **1965**, *30*, 505. (h) Schiemenz, G. P.; Engelhard, H. *Chem. Ber.* **1961**, *94*, 578.

Table 2. Tandem Enyne Allene−Radical Cyclization of Substrates 84−88



enediyne	X	product	yield, %
84	$CHCO_2Me$	**89**	76
85	$C(Me)CO_2Me$	**90**[c]	78
86[a]	CHCN	**91**	72
87	$CHCH_2OH$	**92**	68
88[b]	$NOCH_2Ph$	**93**	71

[a] Prepared as a 3:2 mixture of *cis*/*trans* isomers. [b] Prepared as a 1:1 mixture of *syn*/*anti* isomers. [c] Isolated as a 3.5:1 mixture of diastereomers.

prepared in 79% yield as a 1:1 mixture of *syn*/*anti* isomers by condensing enediyne aldehyde **83** with *O*-benzylhydroxylamine and subsequent low-temperature *m*-CPBA oxidation. To our delight, the low-temperature oxidation led to the selective oxidation of the sulfide over the oxime carbon−nitrogen bond and provided the desired sulfone product in a good 84% yield. When the extremely mild oxidation agent tetra-*n*-propylammonium perruthenate (TPAP) was used as described by Kende for the selective oxidation of sulfides to sulfones,[27] the desired sulfone **88** was not formed and decomposition was observed.

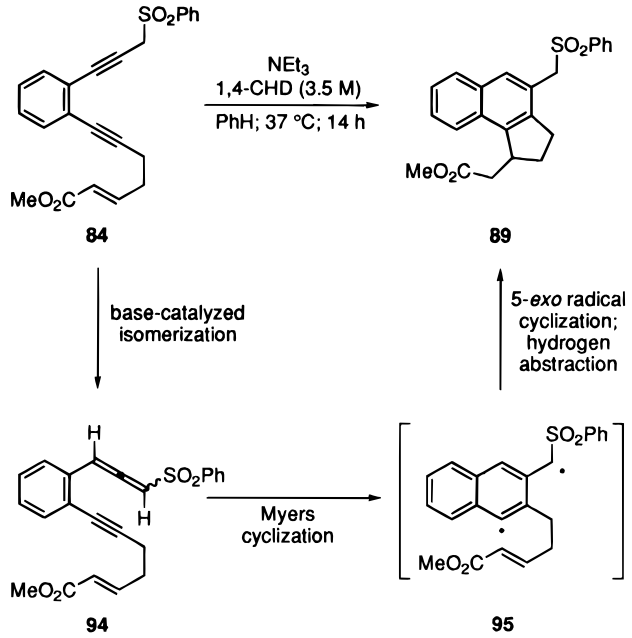
Although the substrates described in the previous paragraph could all be synthesized in a straightforward fashion, the general use of this synthetic scheme might prove rather challenging. The key steps that include both the oxidation of the sulfide to the corresponding sulfone in the presence of the oxime ether or olefin as well as the elaboration of the aldehyde in **83** in the presence of the thioether side chain involve certain compatibility problems, which limit the usefulness of the synthetic route used for the preparation of these substrates.

When **84** was heated at 37 °C for 14 h in anhydrous benzene in the presence of triethylamine and a large excess of 1,4-CHD ($c = 3.5$ mol/L), tandem enyne allene−radical cyclization product **89** was formed in 76% yield (Table 2). Notably, this product was formed both in good yield and at low temperature. Compound **84** has the sulfone group in the C-3 allene position and like the C-3 substituted enyne allenes **31** (Scheme 6) and **41** (Scheme 9) generated from the [3,3] and [2,3] sigmatropic shifts, respectively, this allene substitution pattern is important to the success of the reaction.

To test the generality of this reaction, enediyne sulfones **85**−**88** (Scheme 16) were each subjected to the same reaction conditions. Treatment of enediyne sulfone **85** under these conditions resulted in the formation of the corresponding tandem enyne allene−radical cyclization product **90** in 78% yield (Table 2). It is noteworthy that product **90** was isolated as a 3.5:1 mixture of diastereomers. This result is identical with previous results observed both in tandem enediyne− and tandem enyne allene−radical cyclizations as well as the comparable

(27) (a) Guertin, K. R.; Kende, A. *Tetrahedron Lett.* **1993**, *34*, 5369. (b) For a review of the oxidizing agent tetra-*n*-propylammonium perruthenate (TPAP), see: Ley, S. V.; Norman, J.; Griffith, W. P.; Marsden, S. P. *Synthesis* **1994**, 639.

Scheme 17



tributyltin hydride-mediated radical cyclization.[7g] This observation suggests that all these transformations presumably proceed through a common radical intermediate, while the geometry of the olefin within the α,β-unsaturated ester has no effect on the diastereomeric outcome of the radical cyclization (*vide supra*).

To test the use of other radical acceptors in this reaction, enediyne sulfones **86**−**88** containing an α,β-unsaturated nitrile, a simple alkene, and an oxime ether,[20] respectively, were subjected to the standard reaction conditions to furnish 2,3-dihydrobenz[*e*]indene derivatives **91** (72%), **92** (68%), and **93** (71%) in good yields (Table 2). It is noteworthy that the elimination of *O*-benzylhydroxylamine that was observed in the respective high-temperature tandem enediyne−radical cyclization[7d] did not occur due to the low temperature employed in the present reaction.

The mechanism of the overall transformation is outlined in Scheme 17 for enediyne substrate **84**. Enyne allene **94** generated from a base-catalyzed isomerization of corresponding enediyne **84** undergoes an enyne allene cyclization (Myers cyclization) to form biradical **95**. Subsequent 5-*exo* radical cyclization of the aryl radical in intermediate **95** followed by hydrogen atom abstraction from 1,4-CHD furnished 2,3-dihydrobenz[*e*]indene derivative **89**. This mechanism is similar to the cyclization of the enyne allenes generated from the [3,3] and [2,3] sigmatropic shifts (Schemes 6 and 14, respectively).

With these experiments, we have extended the tandem enyne allene−radical cyclization to enediyne sulfone substrates. The cyclization precusors can be readily synthesized from commercially available starting materials. The tandem enyne allene−radical cyclization of aromatic enediyne sulfones occurs at physiological temperature (*ca.* 37 °C), and the 2,3-dihydrobenz[*e*]indene derivatives are formed in good overall yields. The sulfones formed in these tandem enyne allene−radical cyclizations provide the opportunity for further elaboration, since sulfones exhibit a high synthetic versatility. In particular, due to the mild reaction conditions, this methodology should be tolerant of a variety of functionality and should be applicable to the synthesis of complex

hetero- and carbocycles. This method is comparable to the low-temperature tandem nonaromatic enyne allene−radical cyclizations of phosphine oxides described previously. On the other hand, the synthesis of similar compounds *via* a tandem enediyne−radical cyclization requires temperatures in excess of 220 °C.[7]

Conclusion

In an effort to lower the temperatures required to prepare multicyclic compounds using the tandem enediyne−radical cyclization, we have developed the tandem enyne allene−radical cyclization which proceeds at lower temperatures. These reactions utilized three different methods for the preparation of the enyne allenes including a [3,3] sigmatropic shift, a [2,3] sigmatropic shift, and a base-catalyzed isomerization of a propargyl sulfone. Many of these cyclizations occur at temperatures as low as 37 °C. Given the low temperatures and the ease of preparation of many of the cyclization substrates, we expect that the tandem enyne allene−radical cyclization will prove to be a useful method for the preparation of various biologically active carbocycles and heterocycles. Further studies utilizing the present compounds for DNA cleavage and drug delivery are in progress.

Experimental Section[28]

Preparation of 3-(2-Iodophenyl)-2-propyn-1-ol (8). 1,2-Diiodobenzene (**7**) (0.396 mL, 1.000 g, 3.03 mmol) was dissolved in 30 mL of THF. After the addition of triethylamine (1.267 mL, 0.920 g, 9.09 mmol) and bis(triphenylphosphine)-palladium(II) chloride (0.064 g, 0.09 mmol), the reaction mixture was stirred for 10 min. Then copper(I) iodide (0.058 g, 0.30 mmol) was added and the reaction mixture stirred for an additional 10 min, before propargyl alcohol (0.265 mL, 0.255 g, 4.55 mmol) was added in one portion *via* syringe. The reaction was allowed to stir at room temperature overnight. The solvent was removed *in vacuo* and the residue filtered through silica gel using a 1:1 mixture of hexanes/diethyl ether. Purification by radial chromatography with an 85:15 mixture of hexanes/diethyl ether yielded 0.407 g (52%) of **8** as a pale yellow oil: TLC R_f 0.26 (3:1 hexanes/ethyl acetate); IR (neat) ν 3345 (br), 3057, 2913, 2861, 2238 cm^{-1}; ^{1}H NMR δ 2.14 (1H, s, br), 4.54 (2H, s), 6.97 (1H, ddd, J = 9.3, 8.1, 1.7 Hz), 7.26 (1H, ddd, J = 8.8, 7.5, 1.2 Hz), 7.42 (1H, dd, J = 7.8, 1.7 Hz), 7.81 (1H, ddd, J = 8.1, 1.2, 0.5 Hz); ^{13}C NMR δ 138.6, 132.7, 129.6, 129.0, 127.8, 100.7, 91.0, 87.6, 51.6; HRMS (EI) calcd for C_9H_7IO (M^+) 257.9541, found 257.9565.

Preparation of 2-Ethynyl-1-(3-(vinyloxy)-1-propynyl)-benzene (9). A mixture of **8** (0.300 g, 1.16 mmol) and mercury(II) acetate (0.112 g, 0.350 mmol) in ethyl vinyl ether (15 mL) was heated to reflux under nitrogen for 2 d. The reaction mixture was filtered through Florisil using a 1:1 mixture of hexanes/ethyl acetate. Removal of the solvent followed by column chromatography of the residue (90:9:1 hexanes/ethyl acetate/triethylamine) gave 2-iodo-1-[3-(vinyloxy)-1-propynyl]benzene as a yellow oil (0.237 g, 72%): TLC R_f 0.49 (5:1 hexanes/ethyl acetate); IR (neat) ν 2235, 1620, 1186, 754 cm^{-1}; ^{1}H NMR δ 7.81 (dd, J = 8.1, 1.2 Hz, 1H), 7.44 (dd, J = 7.5, 1.8 Hz, 1H), 7.27 (td, J = 7.5, 1.8 Hz, 1H), 6.98 (td, J = 7.5, 1.8 Hz, 1H), 6.52 (dd, J = 14.1, 6.6 Hz, 1H), 4.66 (s, 2H), 4.42 (dd, J = 14.1, 2.4 Hz, 1H), 4.17 (dd, J = 6.6, 2.4 Hz, 1H); ^{13}C NMR δ 150.4, 138.7, 133.0, 129.8, 128.8, 127.7, 100.7, 88.7, 88.6, 87.4, 56.5; HRMS (EI) m/z calcd for $C_{11}H_9IO$ (M^+) 283.9697, found 283.9668.

2-Iodo-1-[3-(vinyloxy)-1-propynyl]benzene (0.094 g, 0.330 mmol) was subjected to palladium coupling conditions similar to those for the preparation of **8** using triethylamine (0.140 mL, 1.00 mmol), bis(triphenylphosphine)palladium(II) chloride (0.012 g, 0.017 mmol), copper(I) iodide (0.006 g, 0.030 mmol), and (trimethylsilyl)acetylene (0.070 mL, 0.500 mmol) in THF (30 mL). The reaction mixture was stirred at room temperature for 6 h. The mixture was then concentrated and filtered through Florisil (2:1, hexanes/ethyl acetate). The solvent was removed *in vacuo* to give a brown oil, which was dissolved in methanol (5 mL) and treated with a catalytic amount of potassium carbonate (≈ 5 mg) at room temperature for 8 h. The reaction mixture was filtered through Florisil (2:1, hexanes/ethyl acetate). Removal of the solvent followed by column chromatography of the residue (94:5:1 hexanes/ethyl acetate/triethylamine) afforded **9** as a pale yellow oil (0.056 g, 93% over two steps): TLC R_f 0.52 (5:1, hexanes/ethyl acetate); IR (neat) ν 3302, 2249, 2133, 1638, 1186 cm^{-1}; ^{1}H NMR δ 7.48−7.36 (m, 2H), 7.28−7.18 (m, 2H), 6.48 (dd, J = 14.4, 6.6 Hz, 1H), 4.61 (s, 2H), 4.36 (dd, J = 14.4, 2.4 Hz, 1H), 4.11 (dd, J = 6.6, 2.4 Hz, 1H), 3.26 (s, 1H); ^{13}C NMR δ 150.4, 132,5, 132.2, 128.5, 128.3, 125.3, 124.7, 88.5, 87.7, 85.2, 81.8, 81.2, 56.6; HRMS (EI) calcd for $C_{13}H_{10}O$ (M^+) 182.0732, found 182.0725.

Preparation of 5-(2-Iodophenyl)-4-pentyn-1-ol (10). 1,2-Diiodobenzene (**7**) (0.396 mL, 1.000 g, 3.03 mmol) was subjected to coupling conditions similar to those for the preparation of **8** using triethylamine (1.470 mL, 0.920 g, 9.10 mmol), bis(triphenylphosphine)palladium(II) chloride (0.064 g, 0.09 mmol), copper(I) iodide (0.057 g, 0.30 mmol), and 4-pentynol (0.419 mL, 0.379 g, 4.50 mmol) in THF (30 mL). Purification by radial chromatography with an 85:15 mixture of hexanes/diethyl ether yielded 0.486 g (56%) of **10** as a pale yellow oil: TLC R_f 0.25 (2:1 hexanes/ethyl acetate); IR (neat) ν 3374 (br), 3059, 2947, 2230 cm^{-1}; ^{1}H NMR δ 1.52 (1H, s, br, OH), 1.89 (2H, quintet, J = 6.3 Hz), 2.59 (2H, t, J = 6.3 Hz), 3.87 (2H, t, J = 6.3 Hz), 6.94 (1H, td, J = 7.5, 1.5 Hz), 7.24 (1H, td, J = 7.5, 1.5 Hz), 7.38 (1H, dd, J = 7.8, 1.5 Hz), 7.79 (1H, dd, J = 7.8, 1.5 Hz); ^{13}C NMR δ 138.6, 132.5, 130.2, 128.9, 127.7, 101.0, 93.6, 83.4, 61.7, 31.0, 16.1; HRMS (EI) calcd for $C_{11}H_{11}IO$ (M^+) 285.9853, found 285.9849.

Preparation of Methyl 7-(2-Iodophenyl)hept-2-en-6-ynoate (11). To a stirred solution of **10** (1.50 g, 5.24 mmol) in dichloromethane (150 mL) was added pyridinium chlorochromate (1.36 g, 6.30 mmol). The reaction mixture was stirred overnight at room temperature, upon which the alcohol was consumed as monitored by TLC. The solvent was removed *in vacuo*, and the residue was filtered through silica gel using a 2:1 mixture of hexanes/ethyl acetate. The filtrate was concentrated, and the residue was subjected to radial chromatography (9:1 hexanes/ethyl acetate) to give 5-(2-iodophenyl)-4-pentynal as a light yellow oil (1.16 g, 78%): TLC R_f 0.34 (5:1 hexanes/ethyl acetate); IR (neat) ν 3059, 2107, 1723, 1473, 756 cm^{-1}; ^{1}H NMR δ 9.82 (t, J = 1.2 Hz, 1H), 7.75 (dd, J = 7.5, 1.5 Hz, 1H), 7.36 (dd, J = 7.5, 1.5 Hz, 1H), 7.20 (td, J = 7.5, 1.5 Hz, 1H), 6.90 (td, J = 7.5, 1.5 Hz, 1H), 2.72 (td, J = 7.2, 1.2 Hz, 2H), 2.55 (t, J = 7.2 Hz, 2H); ^{13}C NMR δ 202.0, 138.6, 132.6, 130.4, 129.1, 127.3, 101.5, 94.1, 83.5, 43.1, 21.4; HRMS (EI) calcd for $C_{11}H_9IO$ (M^+) 283.9697, found 283.9695.

To a stirred mixture of trimethyl phosphonoacetate (0.340 mL, 2.10 mmol) and lithium chloride (0.120 g, 2.83 mmol) in acetonitrile (10 mL) was added 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) (0.320 mL, 2.14 mmol) at room temperature under nitrogen. The reaction mixture was stirred at room temperature for 30 min. 5-(2-Iodophenyl)-4-pentynal (0.400 g, 1.41 mmol), dissolved in acetonitrile (10 mL), was then added dropwise *via* syringe into the reaction mixture. The reaction mixture was stirred at room temperature overnight, upon which the aldehyde was consumed as monitored by TLC. The reaction mixture was extracted with diethyl ether/water. The organic phase was dried over magnesium sulfate, filtered, and concentrated *in vacuo*. Purification of the product was achieved by radial chromatography (95:5 hexanes/ethyl acetate) to afford **11** as a yellow oil (0.408 g, 85%): TLC R_f 0.45 (5:1 hexanes/ethyl acetate); IR (neat) ν 2255, 1733, 1659, 1273 cm^{-1}; ^{1}H NMR δ 7.79 (dd, J = 7.8, 1.2 Hz, 1H), 7.37 (dd, J = 7.8, 1.2 Hz, 1H), 7.23 (td, J = 7.8, 1.2 Hz, 1H), 7.10 (dt, J = 15.6, 6.6 Hz, 1H), 6.93 (td, J = 7.8, 1.2 Hz, 1H), 5.96 (dt, J = 15.6, 1.5 Hz, 1H), 3.71 (s, 3H), 2.65−2.48 (m, 4H); ^{13}C NMR δ 166.7, 146.8, 138.5, 132.4, 129.9, 128.9, 127.6, 122.2, 100.8,

(28) General experimental techniques are described in ref 7d.

92.4, 83.8, 51.4, 31.0, 18.5; HRMS (EI) calcd for $C_{14}H_{13}IO_2$ (M^+) 339.9959, found 339.9962.

Preparation of Methyl 7-[2-(3-(Vinyloxy)-1-propynyl)-phenyl]hept-2-en-6-ynoate (12). Ester **11** (0.290 g, 0.850 mmol) was subjected to reaction conditions similar to those for the preparation of **8** using triethylamine (0.370 mL, 26.5 mmol), bis(triphenylphosphine)palladium(II) chloride (0.031 g, 0.044 mmol), copper(I) iodide (0.017 g, 0.089 mmol), and propargyl alcohol (0.077 mL, 1.32 mmol). The reaction mixture was stirred at 50 °C overnight under nitrogen. The mixture was passed through silica gel (1:2 hexanes/ethyl acetate), and the solvent was removed *in vacuo*. Purification by radial chromatography (5:1 hexanes/ethyl acetate) provided methyl 7-[2-(3-hydroxy-1-propynyl)phenyl]hept-2-en-6-ynoate as a yellow oil (0.202 g, 88%): TLC R_f 0.18 (2:1 hexanes/ethyl acetate); IR (neat) ν 3430, 2249, 1721, 1659 cm^{-1}; ^1H NMR δ 7.40−7.30 (m, 2H), 7.22−7.09 (m, 3H), 5.94 (dt, J = 15.6, 1.5 Hz, 1H), 4.50 (s, 2H), 3.69 (s, 3H), 3.28 (bs, 1H), 2.62−2.42 (m, 4H); ^{13}C NMR δ 167.4, 147.6, 132.1, 131.8, 127.9, 127.4, 125.8, 125.1, 121.8, 92.2, 91.3, 83.6, 80.4, 51.6, 51.2, 31.0, 18.5; HRMS (EI) calcd for $C_{17}H_{16}O_3$ (M^+) 268.1099, found 268.1099.

Compound **12** was prepared by the same ethylenation used for the preparation of **9** using 7-[2-(3-hydroxy-1-propynyl)-phenyl]hept-2-en-6-ynoate (0.140 g, 0.520 mmol) and mercury(II) acetate (0.051 g, 0.160 mmol) in ethyl vinyl ether (10 mL) (reflux 2 d). The reaction mixture was passed through Florisil using a 2:1 mixture of hexanes/ethyl acetate. The solvent was removed *in vacuo*, and purification was achieved by column chromatography (90:9:1 hexanes/ethyl acetate/triethylamine) to give **12** as a light yellow oil (0.120 g, 78%, two conformers, 2:1 ratio): TLC R_f 0.55 (2:1 hexanes/ethyl acetate); IR (neat) ν 2255, 1725, 1661, 1626, 1273 cm^{-1}; ^1H NMR δ 7.45−7.33 (m, 2H), 7.26−7.15 (m, 2H), 7.05 (dt, J = 15.6, 6.6 Hz, 1H), 6.52 (dd, J = 14.1, 6.6 Hz, $^1/_3$H), 6.50 (dd, J = 14.1, 6.6 Hz, $^2/_3$H), 5.93 (dt, J = 15.6, 1.5 Hz, 1H), 4.65 (s, 2H), 4.39 (dd, J = 14.1, 2.7 Hz, $^1/_3$H), 4.38 (dd, J = 14.1, 2.7 Hz, $^2/_3$H), 4.15 (dd, J = 6.6, 2.7 Hz, $^1/_3$H), 4.13 (dd, J = 6.6, 2.7 Hz, $^2/_3$H), 3.71 (s, 2H), 3.69 (s, 1H), 2.80−2.45 (m, 4H); ^{13}C NMR δ 166.8, 150.5, 147.0, 132.1, 132.0, 131.9, 131.8, 128.3, 127.5, 126.1, 124.7, 122.0, 92.6, 88.4, 87.1, 85.8, 80.1, 56.7, 51.8, 51.5, 33.3, 31.3, 18.6; HRMS (EI) calcd for $C_{19}H_{18}O_3$ (M^+) 294.1256, found 294.1251.

Preparation of 4-((*tert*-Butyldimethylsilyl)oxy)-1-(2-iodophenyl)-2-butyn-1-ol (14). 2-Iodobenzyl alcohol (**13**) (10.0 g, 43.0 mol) was subjected to PCC oxidation conditions (PCC, 11.1 g, 51.6 mmol) similar to those for the preparation of **11**. After the reaction was complete, the solvent was removed *in vacuo* and the residue was filtered through silica gel using a 2:1 mixture of hexanes/ethyl acetate to give 2-iodobenzaldehyde as a colorless crystalline solid (9.67g, 97%): TLC R_f 0.55 (3:1 hexanes/ethyl acetate); IR (neat) ν 1696, 1200, 754 cm^{-1}; ^1H NMR δ 10.01 (d, J = 0.6 Hz, 1H), 7.91−7.80 (m, 2H), 7.44−7.20 (m, 2H); ^{13}C NMR δ 195.6, 140.5, 135.4, 135.0, 130.1, 128.6, 100.7; HRMS (EI) calcd for C_7H_5IO (M^+) 231.9384, found 231.9390.

To a stirred solution of *tert*-butyldimethylsilyl propargyl ether (2.20 g, 13.0 mmol) in THF (10 mL) at −20 °C (sodium chloride/ice bath) was added *n*-butyllithium (2.5 M solution in hexanes) (5.20 mL, 13.0 mmol) *via* syringe. After 30 min, 2-iodobenzaldehyde (2.00 g, 8.60 mmol), dissolved in THF (15 mL), was added *via* syringe into the reaction mixture. The mixture was allowed to warm to room temperature and stirred overnight. The reaction was quenched with a saturated aqueous sodium chloride solution followed by removal of THF *in vacuo* to give a residue which was extracted with dichloromethane. The organic layer was dried over magnesium sulfate, filtered, and evaporated. Purification by radial chromatography (95:5 hexanes/ethyl acetate) afforded **14** as a colorless oil (2.77g, 80%): TLC R_f 0.50 (3:1 hexanes/ethyl acetate); IR (neat) ν 3391, 2343, 1084, 837 cm^{-1}; ^1H NMR δ 7.80 (dd, J = 7.8, 1.2 Hz, 1H), 7.72 (dd, J = 7.8, 1.8 Hz, 1H), 7.36 (td, J = 7.5, 1.2 Hz, 1H), 6.99 (td, J = 7.5, 1.8 Hz, 1H), 5.68−5.62 (m, 1H), 4.36 (d, J = 1.8 Hz, 2H), 2.67 (d, J = 4.8 Hz, 1H), 0.87 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H); ^{13}C NMR δ 142.4, 139.6, 130.0, 128.6, 128.1, 97.9, 85.6, 83.6, 68.4, 51.8, 25.7, 18.2, −5.2, −5.2; HRMS (EI) calcd for $C_{12}H_{14}IO_2Si$ (M^+ − C_4H_9) 344.9806, found 344.9795.

Preparation of 4-((*tert*-butyldimethylsilyl)oxy)-1-(2-ethynylphenyl)-2-butynyl 1-Vinyl Ether (15). Alcohol **14** (0.530 g, 1.32 mmol) was subjected to palladium coupling reaction conditions similar to those for the preparation of **8** using triethylamine (0.550 mL, 3.96 mmol), bis(triphenylphosphine)palladium(II) chloride (0.046 g, 0.066 mmol), copper(I) iodide (0.025 g, 0.130 mmol), and (trimethylsilyl)acetylene (0.280 mL, 1.98 mmol). The reaction mixture was allowed to stir at room temperature under nitrogen for 12 h. The mixture was filtered through silica gel using a 2:1 mixture of hexanes/ethyl acetate and evaporated. Purification by radial chromatography (9:1 hexanes/ethyl acetate) provided 4-((*tert*-butyldimethylsilyl)oxy)-1-[[2-(trimethylsilyl)ethynyl]phenyl]-2-butyn-1-ol as a yellow oil (0.450 g, 92%): TLC R_f 0.52 (3:1 hexanes/ethyl acetate); IR (neat) ν 3455, 2158, 1252, 1084 cm^{-1}; ^1H NMR δ 7.64 (ddd, J = 7.5, 1.5, 0.6 Hz, 1H), 7.45 (ddd, J = 7.5, 1.5, 0.6 Hz, 1H), 7.33 (td, J = 7.5, 1.5 Hz, 1H), 7.24 (td, J = 7.5, 1.5 Hz, 1H), 5.86 (dt, J = 5.4, 1.8 Hz, 1H), 4.37 (d, J = 1.8 Hz, 2H), 2.81 (d, J = 5.4 Hz, 1H), 0.87 (s, 9H), 0.25 (s, 9H), 0.07 (s, 3H), 0.06 (s, 3H); ^{13}C NMR δ 142.6, 132.6, 129.0, 128.0, 126.6, 121.1, 102.2, 100.4, 85.2, 83.7, 63.1, 51.8, 25.7, 18.2, −0.2, −5.2; HRMS (EI) calcd for $C_{21}H_{32}O_2Si_2$ (M^+) 372.1940, found 372.1939.

A mixture of 4-((*tert*-butyldimethylsilyl)oxy)-1-[[2-(trimethylsilyl)ethynyl]phenyl]-2-butyn-1-ol (0.333 g, 0.900 mmol) and mercury(II) acetate (0.086 g, 0.270 mmol) in ethyl vinyl ether (25 mL) was heated to reflux under nitrogen for 2 d. The reaction mixture was passed through Florisil using a 2:1 mixture of hexanes/ethyl acetate. The solvent was removed *in vacuo*, and the residue was subjected to column chromatography (94:5:1 hexanes/ethyl acetate/triethylamine) to yield 4-((*tert*-butyldimethylsilyl)oxy)-1-[(2-(trimethylsilyl)ethynyl)-phenyl]-2-butynyl 1-vinyl ether as a yellow oil (0.180 g, 50%): TLC R_f 0.65 (5:1 hexanes/ethyl acetate); IR (neat) ν 2158, 1616, 1252, 1094 cm^{-1}; ^1H NMR δ 7.70 (ddd, J = 7.5, 1.5, 0.6 Hz, 1H), 7.46 (ddd, J = 7.5, 1.5, 0.6 Hz, 1H), 7.35 (td, J = 7.5, 1.5 Hz, 1H), 7.26 (td, J = 7.5, 1.5 Hz, 1H), 6.49 (dd, J = 14.4, 6.9 Hz, 1H), 6.00 (t, J = 1.8 Hz, 1H), 4.48 (dd, J = 14.4, 1.8 Hz, 1H), 4.39 (d, J = 1.8 Hz, 2H), 4.16 (dd, J = 6.9, 1.8 Hz, 1H), 0.88 (s, 9H), 0.25 (s, 9H), 0.08 (s, 3H), 0.08 (s, 3H); ^{13}C NMR δ 150.0, 139.6, 132.3, 129.0, 128.5, 127.4, 122.2, 101.9, 100.1, 89.9, 86.7, 81.4, 68.4, 51.7, 25.7, 18.2, −0.1, −5.2; HRMS (EI) calcd for $C_{23}H_{34}O_2Si_2$ (M^+) 398.2098, found 398.2115.

To a stirred solution of 4-((*tert*-butyldimethylsilyl)oxy)-1-[(2-(trimethylsilyl)ethynyl)phenyl]-2-butynyl 1-vinyl ether (0.090 g, 0.230 mmol) in methanol (15 mL) was added a catalytic amount of potassium carbonate. The resulting mixture was allowed to stir at room temperature for 2 h. Subsequently, the mixture was filtered through Florisil using a 3:1 mixture of hexanes/ethyl acetate. The solvent was removed *in vacuo*, and the residue was subjected to column chromatography (94:5:1 hexanes/ethyl acetate/triethylamine) to afford **15** as a yellow oil (0.056 g, 75%): TLC R_f 0.55 (5:1 hexanes/ethyl acetate); IR (neat) ν 3298, 1640, 1256, 1092 cm^{-1}; ^1H NMR δ 7.70 (dd, J = 7.5, 1.5 Hz, 1H), 7.50 (dd, J = 7.5, 1.5 Hz, 1H), 7.39 (td, J = 7.5, 1.5 Hz, 1H), 7.29 (td, J = 7.5, 1.5 Hz, 1H), 6.48 (dd, J = 14.1, 6.6 Hz, 1H), 5.99 (t, J = 1.8 Hz, 1H), 4.47 (dd, J = 14.1, 2.1 Hz, 1H), 4.37 (d, J = 1.8 Hz, 2H), 4.15 (dd, J = 6.6, 2.1 Hz, 1H), 3.33 (s, 1H), 0.87 (s, 9H), 0.07 (s, 3H), 0.07 (s, 3H); ^{13}C NMR δ 149.7, 139.9, 132.8, 129.3, 128.5, 127.4, 121.0, 90.3, 86.8, 82.5, 81.3, 80.6, 68.4, 51.7, 25.7, 18.2, −5.2; HRMS (EI) calcd for $C_{20}H_{26}O_2Si$ (M^+) 326.1702, found 326.1694.

Preparation of 5-[2-(1-Acetoxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)phenyl]-4-pentyn-1-ol (16). Alcohol **14** (2.00 g, 4.98 mmol) was dissolved in dichloromethane (25 mL); then triethylamine (3.50 mL, 25.0 mmol) and acetic anhydride (0.940 mL, 9.96 mmol) were added *via* syringe. The reaction mixture was allowed to stir at room temperature for 7 h, upon which the alcohol was consumed as monitored by TLC. The mixture was extracted with dichloromethane/water. The organic layer was dried over magnesium sulfate followed by filtration and evaporation to give a yellow oil. Purification by radial chromatography (95:5 hexanes/ethyl acetate) yielded 4-((*tert*-butyldimethylsilyl)oxy)-1-(2-iodophenyl)-2-butynyl-1-

acetate as a yellow oil (1.80 g, 82%): TLC R_f 0.64 (2:1 hexanes/ethyl acetate); IR (neat) ν 1748, 1223, 1088 cm^{-1}; ^{1}H NMR δ 7.83 (dd, J = 7.8, 1.2 Hz, 1H), 7.72 (dd, J = 7.8, 1.8 Hz, 1H), 7.37 (td, J = 7.8, 1.2 Hz, 1H), 7.02 (td, J = 7.8, 1.8, 1H), 6.52 (t, J = 1.8 Hz, 1H), 4.36 (d, J = 1.8 Hz, 2H), 2.09 (s, 3H), 0.87 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H); ^{13}C NMR δ 169.3, 139.7, 139.1, 130.5, 129.3, 128.5, 98.4, 86.7, 80.5, 69.6, 51.7, 25.7, 20.8, 18.2, −5.2; HRMS (EI) calcd for $C_{14}H_{16}IO_3Si$ ($M^+ - C_4H_9$) 386.9912, found 386.9919.

4-((*tert*-Butyldimethylsilyl)oxy)-1-(2-iodophenyl)-2-butyne-1-acetate (1.58 g, 3.56 mmol) was subjected to palladium coupling reaction conditions similar to those for the preparation of **8** using triethylamine (1.50 mL, 10.7 mmol), bis-(triphenylphosphine)palladium(II) chloride (0.125 g, 0.180 mmol), copper(I) iodide (0.068 g, 0.360 mmol), and 4-pentynol (0.500 mL, 5.37 mmol). The reaction mixture was allowed to stir at room temperature for 2 d. Then the mixture was passed through silica gel using a 1:2 mixture of hexanes/ethyl acetate and the solvent was removed *in vacuo*. Purification by radial chromatography (5:1 hexanes/ethyl acetate) provided **16** as a yellow oil (0.450 g, 32%): TLC R_f 0.20 (2:1 hexanes/ethyl acetate); IR (neat) ν 3425, 2230, 1744, 1227, 1084 cm^{-1}; ^{1}H NMR δ 7.70 (dd, J = 7.5, 1.8 Hz, 1H), 7.38 (dd, J = 7.5, 1.5 Hz, 1H), 7.31 (td, J = 7.5, 1.8 Hz, 1H), 7.26 (td, J = 7.5, 1.5 Hz, 1H), 6.87 (t, J = 1.8 Hz, 1H), 4.37 (d, J = 1.8 Hz, 2H), 3.85−3.70 (m, 2H), 2.54 (t, J = 6.6 Hz, 2H), 2.19 (bs, 1H), 2.07 (s, 3H), 1.81 (quintet, J = 6.6 Hz, 2H), 0.87 (s, 9H), 0.08 (s, 3H), 0.08 (s, 3H); ^{13}C NMR δ 169.9, 138.0, 132.1, 128.8, 128.0, 127.8, 123.2, 95.4, 86.0, 80.9, 77.8, 64.0, 61.1, 51.7, 31.0, 25.7, 20.8, 18.2, 15.8, −5.2, −5.3; HRMS (EI) calcd for $C_{19}H_{23}O_4Si$ ($M^+ - C_4H_9$) 343.1366, found 343.1370.

Preparation of Methyl 7-[2-(1-(Vinyloxy)-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl) phenyl]hept-2-en-6-ynoate (17). To a stirred solution of **16** (0.420 g, 1.05 mmol) in dichloromethane (25 mL) was added pyridinium chlorochromate (0.340 g, 1.58 mmol). The resulting mixture was stirred at room temperature overnight, upon which the reaction mixture was filtered through silica gel using a 1:1 mixture of hexanes/ethyl acetate. The solvent was removed *in vacuo*, and the residue was subjected to radial chromatography (5:1 hexanes/ethyl acetate) to afford 5-[2-(1-acetoxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)phenyl]-4-pentynal as a pale yellow oil (0.350 g, 84%): TLC R_f 0.42 (2:1 hexanes/ethyl acetate); IR (neat) ν 2230, 1746, 1732 cm^{-1}; ^{1}H NMR δ 9.80 (t, J = 0.9 Hz, 1H), 7.70 (dd, J = 7.5, 1.8 Hz, 1H), 7.37 (dd, J = 7.5, 1.5 Hz, 1H), 7.30 (td, J = 7.5, 1.8 Hz, 1H), 7.25 (td, J = 7.5, 1.5 Hz, 1H), 6.81 (t, J = 1.8 Hz, 1H), 4.36 (d, J = 1.8 Hz, 2H), 2.80−2.66 (m, 4H), 2.05 (s, 3H), 0.86 (s, 9H), 0.07 (s, 3H), 0.06 (s, 3H); ^{13}C NMR δ 200.2, 169.5, 138.0, 132.1, 128.7, 128.2, 127.8, 122.8, 93.7, 86.0, 80.9, 78.1, 63.7, 51.7, 42.3, 25.7, 20.8, 18.1, 12.6, −5.3; HRMS (EI) calcd for $C_{19}H_{21}O_4Si$ ($M^+ - C_4H_9$) 341.1209, found 341.1225.

5-[2-(1-Acetoxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)-phenyl]-4-pentynal (0.680 g, 1.70 mmol) was subjected to Horner−Emmons reaction conditions similar to those for the preparation of **11**, and the reaction was worked up similarly. Purification was achieved by radial chromatography (9:1 hexanes/ethyl acetate) to provide methyl 7-[2-(1-acetoxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)phenyl]hept-2-en-6-ynoate as a light yellow oil (0.667 g, 86%): TLC R_f 0.48 (2:1 hexanes/ethyl acetate); IR (neat) ν 2232, 1742, 1726, 1660 cm^{-1}; ^{1}H NMR δ 7.70 (dd, J = 7.5, 1.8 Hz, 1H), 7.37 (dd, J = 7.5, 1.5 Hz, 1H), 7.31 (td, J = 7.5, 1.8 Hz, 1H), 7.26 (td, J = 7.5, 1.5 Hz, 1H), 6.99 (dt, J = 15.6, 6.6 Hz, 1H), 6.82 (t, J = 1.8 Hz, 1H), 5.91 (dt, J = 15.6, 1.5 Hz, 1H), 4.36 (d, J = 1.8 Hz, 2H), 3.70 (s, 3H), 2.60−2.44 (m, 4H), 2.05 (s, 3H), 0.86 (s, 9H), 0.07 (s, 3H), 0.06 (s, 3H); ^{13}C NMR δ 169.4, 166.7, 146.8, 138.1, 132.2, 128.7, 128.1, 127.8, 122.8, 122.1, 94.1, 86.0, 80.9, 78.3, 63.8, 51.7, 51.4, 31.1, 25.7, 20.7, 18.4, 18.1, −5.3; HRMS (EI) calcd for $C_{22}H_{25}O_5Si$ ($M^+ - C_4H_9$) 397.1471, found 397.1462.

To a stirred solution of 7-[2-(1-acetoxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)phenyl]hept-2-en-6-ynoate (0.220 g, 0.480 mmol) in methanol (12 mL) was added a catalytic amount of potassium carbonate. The reaction mixture was stirred at room temperature for 6 h; then the mixture was passed through Florisil with diethyl ether and concentrated. Radial chromatography of the resulting oil (3:1 hexanes/diethyl ether) gave methyl 7-[2-(1-hydroxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)phenyl]hept-2-en-6-ynoate as a light yellow oil (0.190 g, 95%): TLC R_f 0.34 (2:1 hexanes/ethyl acetate); IR (neat) ν 3435, 2232, 1726, 1660 cm^{-1}; ^{1}H NMR δ 7.65 (dd, J = 7.5, 1.5 Hz, 1H), 7.37 (dd, J = 7.5, 1.2 Hz, 1H), 7.29 (td, J = 7.5, 1.5 Hz, 1H), 7.22 (td, J = 7.5, 1.5 Hz, 1H), 7.05 (dt, J = 15.6, 6.6 Hz, 1H), 5.95 (dt, J = 15.6, 1.5 Hz, 1H), 5.87−5.82 (m, 1H), 4.36 (d, J = 1.8 Hz, 2H), 3.72 (s, 3H), 2.93 (d, J = 5.1 Hz, 1H), 2.65−2.45 (m, 4H), 0.86 (s, 9H), 0.06 (s, 3H), 0.06 (s, 3H); ^{13}C NMR δ 167.0, 147.0, 142.0, 132.3, 128.3, 128.1, 126.7, 122.2, 121.7, 93.6, 84.9, 84.1, 79.2, 62.8, 51.8, 51.6, 31.0, 25.7, 18.6, 18.2, −5.3; HRMS (EI) calcd for $C_{20}H_{23}O_4Si$ ($M^+ - C_4H_9$) 355.1366, found 355.1366.

Compound **17** was prepared by the same ethylenation used for the preparation of **9** using 7-[2-(1-hydroxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)phenyl]hept-2-en-6-ynoate (0.190 g, 0.460 mmol) and mercury(II) acetate (0.044 g, 0.140 mmol) in ethyl vinyl ether (10 mL) (reflux 1 d) to give **17** as a colorless oil (0.132 g, 66%): TLC R_f 0.62 (2:1 hexanes/ethyl acetate); IR (neat) ν 2268, 1728, 1660, 1638, 1256 cm^{-1}; ^{1}H NMR δ 7.65 (dd, J = 7.5, 1.5 Hz, 1H), 7.37 (dd, J = 7.5, 1.2 Hz, 1H), 7.31 (td, J = 7.5, 1.5 Hz, 1H), 7.23 (td, J = 7.5, 1.5 Hz, 1H), 7.01 (dt, J = 15.6, 6.6 Hz, 1H), 6.46 (dd, J = 14.1, 6.6 Hz, 1H), 5.93 (dt, J = 15.6, 1.5 Hz, 1H), 5.92 (t, J = 1.8 Hz, 1H), 4.44 (dd, J = 14.1, 2.1 Hz, 1H), 4.36 (d, J = 1.8 Hz, 2H), 4.12 (dd, J = 6.6, 2.1 Hz, 1H), 3.71 (s, 3H), 2.63−2.46 (m, 4H), 0.85 (s, 9H), 0.06 (s, 3H), 0.06 (s, 3H); ^{13}C NMR δ 166.7, 149.8, 146.8, 139.0, 132.2, 128.4, 128.3, 127.3, 122.5, 122.2, 93.8, 90.0, 86.6, 81.4, 78.7, 68.5, 51.7, 51.4, 31.2, 25.7, 18.5, 18.2, −5.2; HRMS (EI) calcd for $C_{26}H_{34}O_4Si$ (M^+) 438.2226, found 438.2211.

Preparation of 1-(2-Hydroxyethyl)-2-methylnaphthalene (20′) and 1,3-Dihydro-1-methylbenz[*e*]isobenzofuran (23) *via* Thermal Cyclization of Enediyne 9. A solution of vinyl ether **9** (0.056 g, 0.310 mmol) in anhydrous chlorobenzene (7.3 mL) was transferred to a predried high-pressure vial. The reaction mixture was degassed by passing dry nitrogen through the solution for 20 min, and 1,4-CHD (1.70 mL, 18.0 mmol) was added *via* syringe. The reaction vial was sealed under nitrogen with a nylon screw cap and heated to 150 °C for 8 h, upon which the starting material was consumed as monitored by TLC. Removal of the solvent *in vacuo* followed by radial chromatography of the residue (pentane followed by 98:2 pentane/ethyl acetate) gave a mixture of aldehyde **20** and ether **23** as a colorless oil (0.032 g, 3:1 ratio, 56% combined yield). To a stirred solution of **20** and **23** in methanol (4 mL) was added sodium borohydride (0.013 g, 0.340 mmol). The stirring was continued for 2 h, and the reaction mixture was passed through Florisil (2:1 hexanes/ethyl acetate). The solvent was removed *in vacuo*, and the residue was subjected to radial chromatography (95:5 hexanes/ethyl acetate) to provide the reduced product of aldehyde **20** (alcohol **20′**) (0.022 g, 38% from **9**) and ether **23** (0.008 g, 14% from **9**) as colorless oils. **20′**: TLC R_f 0.22 (2:1 hexanes/ethyl acetate); IR (neat) ν 3356, 2860, 1040 cm^{-1}; ^{1}H NMR δ 8.06 (d, J = 8.1 Hz, 1H), 7.80 (dd, J = 8.1, 1.5 Hz, 1H), 7.65 (d, J = 8.1 Hz, 1H), 7.49 (ddd, J = 8.4, 6.9, 1.5 Hz, 1 H), 7.40 (ddd, J = 7.8, 6.9, 1.5 Hz, 1H), 7.30 (d, J = 8.4 Hz, 1H), 3.91 (t, J = 7.5 Hz, 2H), 3.40 (t, J = 7.5 Hz, 2H), 2.53 (s, 3H), 1.49 (bs, 1H); ^{13}C NMR δ 134.3, 132.5, 131.0, 130.5, 129.2, 128.6, 126.8, 126.1, 124.6, 123.5, 62.5, 31.8, 20.5; HRMS (EI) calcd for $C_{13}H_{14}O$ (M^+) 186.1045, found 186.1051. **23**: TLC R_f 0.65 (2:1 hexanes/ethyl acetate); IR (neat) ν 3057, 2859, 1067, 810 cm^{-1}; ^{1}H NMR δ 7.90 (dd, J = 7.5, 1.8 Hz, 1H), 7.80−7.70 (m, 2H), 7.56−7.42 (m, 2H), 7.33 (d, J = 8.1 Hz, 1H), 5.91−5.80 (m, 1H), 5.35 (dd, J = 12.3, 3.3 Hz, 1H), 5.19 (dd, J = 12.3, 1.5 Hz, 1H), 1.65 (d, J = 6.0 Hz, 3H); ^{13}C NMR δ 138.3, 135.8, 133.2, 128.8, 128.6, 128.5, 126.5, 125.3, 123.5, 119.2, 80.7, 73.1, 22.2; HRMS (EI) calcd for $C_{13}H_{12}O$ (M^+) 184.0888, found 184.0887.

Preparation of Methyl 2,3-Dihydro-5-(formylmethyl)-4-methyl-1*H*-benz[*e*]indene-1-acetate (25) *via* Tandem Enyne Allene−Radical Cyclization of Enediyne 12. A solution of vinyl ether **12** (0.050 g, 0.170 mmol) in anhydrous chlorobenzene (7.3 mL) was transferred to a predried high-pressure vial. The reaction mixture was degassed by passing

dry nitrogen through the solution for 20 min, and 1,4-CHD (1.70 mL, 18.0 mmol) was added *via* syringe. The reaction vial was sealed under nitrogen with a nylon screw cap and heated to 150 °C for 8 h, upon which the starting material was consumed as monitored by TLC. The solvent was removed *in vacuo*, and the residue was subjected to radical chromatography (95:5 hexanes/ethyl acetate) to afford **25** as a pale yellow oil (0.010 g, 20%): TLC R_f 0.42 (2:1 hexanes/ethyl acetate); IR (neat) ν 2949, 1726, 1437, 1273 cm^{-1}; ^{1}H NMR δ 9.71 (t, J = 2.1 Hz, 1H), 7.95−7.80 (m, 2H), 7.50−7.40 (m, 2H), 4.17 (d, J = 2.1 Hz, 2H), 4.22−4.10 (m, 1H), 3.72 (s, 3H), 3.19−2.96 (m, 2H), 2.77 (dd, J = 15.3, 3.3 Hz, 1H), 2.40 (s, 3H), 2.37 (dd, J = 15.3, 11.1 Hz, 2H), 2.16−2.06 (m, 1H); ^{13}C NMR δ 199.3, 173.3, 141.1, 140.6, 132.7, 132.4, 128.4, 125.7, 125.4, 124.8, 124.5, 124.2, 51.7, 44.0, 40.9, 38.7, 31.1, 30.3, 17.1; HRMS (EI) calcd for $C_{19}H_{20}O_3$ (M^+) 296.1413, found 296.1420.

Preparation of 3-[((*tert*-Butyldimethylsilyl)oxy)methyl]-3-(2-naphthyl)propanal (30) *via* Tandem [3,3] Sigmatropic Rearrangement−Enyne Allene Cyclization of Diyne 15. A solution of vinyl ether **15** (0.045 g, 0.140 mmol) was thermolyzed at 150 °C for 4.5 h in the same manner as that of **12**. Radial chromatography (9:1 hexanes/ethyl acetate) gave **30** as a pale yellow oil (0.021 g, 45%): TLC R_f 0.44 (5:1 hexanes/ethyl acetate); IR (neat) ν 1726, 1472, 1256, 1094 cm^{-1}; ^{1}H NMR δ 9.76 (t, J = 2.1 Hz, 1H), 7.81−7.75 (m, 3H), 7.65 (s, 1H), 7.50−7.40 (m, 2H), 7.34 (dd, J = 8.7, 1.8 Hz, 1H), 3.85 (dd, J = 9.9, 4.8 Hz, 1H), 3.70 (dd, J = 9.9, 8.1 Hz, 1H), 3.57 (dddd, J = 8.1, 7.2, 6.9, 4.8 Hz, 1H), 3.02 (ddd, J = 16.8, 7.2, 2.1 Hz, 1H), 2.80 (ddd, J = 16.8, 6.9, 2.1 Hz, 1H), 0.86 (s, 9H), −0.02 (s, 6H); ^{13}C NMR δ 201.8, 138.6, 133.4, 132.5, 128.3, 127.7, 127.6, 126.4, 126.2, 126.2, 125.7, 67.5, 46.6, 43.0, 25.8, 18.2, −5.6; HRMS (EI) calcd for $C_{20}H_{28}O_2Si$ (M^+) 327.1780, found 327.1786.

Preparation of Methyl 2,3-Dihydro-4-[1-(((*tert*-butyldimethylsilyl)oxy)methyl)-2-formylethyl]-1*H*-benz[*e*]-indene-1-acetate (33a,b) *via* Tandem Enyne Allene−Radical Cyclization of Diyne 17. A solution of vinyl ether **17** (0.100 g, 0.230 mmol) was thermolyzed at 150 °C for 7 h in the same manner as that of **12**. Radial chromatography (98:2 hexanes/ethyl acetate) gave **33a** and **33b** as pale yellow oils (1:1 diasteromeric ratio, 54% combined yield). **33a** (0.026 g): TLC R_f 0.48 (2:1 hexanes/ethyl acetate); IR (neat) ν 2953, 1730, 1437, 1256, 1101 cm^{-1}; ^{1}H NMR δ 9.77 (t, J = 2.1 Hz, 1H), 7.85−7.74 (m, 2H), 7.49 (s, 1H), 7.48−7.36 (m, 2H), 4.15 (ddd, J = 11.4, 8.1, 3.0 Hz, 1H), 3.86−3.76 (m, 1H), 3.72 (s, 3H), 3.70−3.58 (m, 2H), 3.20−3.10 (m, 2H), 3.05 (ddd, J = 16.8, 6.6, 2.1 Hz, 1H), 2.84 (ddd, J = 16.8, 6.6, 2.1 Hz, 1H), 2.78 (dd, J = 15.3, 2.7 Hz, 1H), 2.37 (dd, J = 15.3, 11.1Hz, 2H), 2.20−2.08 (m, 1H), 0.85 (s, 9H), −0.03 (s, 3H), −0.04 (s, 3H); ^{13}C NMR δ 203.9, 201.7, 173.3, 141.5, 140.1, 135.9, 133.3, 128.5, 126.0, 125.2, 125.0, 123.5, 66.8, 51.7, 46.6, 40.7, 39.8, 38.6, 30.6, 30.0, 25.8, 18.3, −5.6, −5.5; HRMS (EI) calcd for $C_{26}H_{36}O_4Si$ (M^+) 440.2383, found 440.2379. **33b** (0.028 g): TLC R_f 0.48 (2:1 hexanes/ethyl acetate); IR (neat) ν 2953, 1730, 1437, 1256, 1101 cm^{-1}; ^{1}H NMR δ 9.76 (t, J = 1.8 Hz, 1H), 7.85−7.73 (m, 2H), 7.49 (s, 1H), 7.48−7.36 (m, 2H), 4.15 (ddd, J = 11.4, 8.1, 3.0 Hz, 1H), 3.88−3.77 (m, 1H), 3.72 (s, 3H), 3.70−3.58 (m, 2H), 3.30−3.10 (m, 2H), 3.05 (ddd, J = 16.8, 6.9, 1.8 Hz, 1H), 2.82 (ddd, J = 16.8, 6.9, 1.8 Hz, 1H), 2.77 (dd, J = 15.6, 2.7 Hz, 1H), 2.37 (dd, J = 15.6, 11.4 Hz, 2H), 2.20−2.08 (m, 1H), 0.86 (s, 9H), −0.02 (s, 6H); ^{13}C NMR δ 203.8, 201.6, 173.3, 141.3, 140.2, 136.0, 133.3, 128.4, 126.0, 125.1, 124.9, 123.5, 66.9, 51.7, 46.6, 40.6, 39.6, 38.6, 30.5, 30.0, 25.8, 18.2, −5.5; HRMS (EI) calcd for $C_{26}H_{36}O_4Si$ (M^+) 440.2383, found 440.2379.

Methyl 7-[2-[3-(((*tert*-Butyldimethylsilyl)oxy)methyl)-5-oxo-1,2-pentadienyl]phenyl]hept-2-en-6-ynoate (31). To a stirred solution of **17** (0.060 g, 0.140 mmol) in dichloromethane (60 mL) was added a catalytic amount of silver tetrafluoroborate at room temperature under nitrogen. The reaction mixture was allowed to stir at room temperature for 15 min, upon which the starting material was consumed as monitored by TLC. The reaction mixture was quickly passed through a small amount of Florisil using a 1:1 mixture of hexanes/ethyl acetate, and the solvent was removed *in vacuo* to provide **31** as a pale yellow oil (0.059 g, 98%): TLC R_f 0.46 (2:1 hexanes/ethyl acetate); IR (neat) ν 2236, 1954, 1726, 1660, 1260 cm^{-1}; ^{1}H NMR δ 9.72 (t, J = 2.1 Hz, 1H), 7.39 (dd, J = 7.8, 0.9 Hz, 1H), 7.34 (dd, J = 7.8, 0.9 Hz, 1H), 7.19 (td, J = 7.8, 0.9 Hz, 1H), 7.09 (td, J = 7.8, 0.9 Hz, 1H), 7.02 (dt, J = 15.6, 6.6 Hz, 1H), 6.80 (tt, J = 2.1, 2.4 Hz, 1H), 5.92 (dt, J = 15.6, 1.5 Hz, 1H), 4.27 (d, J = 2.4 Hz, 2H), 3.70 (s, 3H), 3.20−3.17 (m, 2H), 2.64−2.46 (m, 4H), 0.86 (s, 9H), 0.04 (s, 3H), 0.03 (s, 3H); ^{13}C NMR δ 203.9, 199.4, 166.7, 146.8, 135.1, 132.5, 128.0, 126.9, 126.5, 122.1, 121.6, 100.5, 94.5, 93.2, 79.6, 63.9, 51.4, 43.9, 31.3, 25.7, 18.5, 18.2, −5.5, −5.5; HRMS (EI) calcd for $C_{26}H_{34}O_4Si$ (M^+) 438.2226, found 438.2218.

Preparation of 33a,b *via* Tandem Enyne Allene−Radical Cyclization of 31. A solution of allene **31** (0.059 g, 0.135 mmol) in anhydrous chlorobenzene (7.3 mL) was transferred to a predried high-pressure vial. The reaction mixture was degassed by passing dry nitrogen through the solution for 20 min, and 1,4-CHD (1.70 mL, 18.0 mmol) was added *via* syringe. The reaction vial was sealed under nitrogen with a nylon screw cap and heated to 75 °C for 8 h, upon which the reaction was complete as monitored by TLC. The solvent was removed *in vacuo*, and the residue was subjected to radial chromatography (98:2 hexanes/ethyl acetate) to afford **33a** (0.023 g) and **33b** (0.025 g) as pale yellow oils (1:1 diasteromeric ratio, 80% combined yield).

Preparation of 4-((*tert*-Butyldimethylsilyl)oxy)-1-(2-ethynylphenyl)but-2-yn-1-ol (34). Alcohol **14** (0.505 g 1.23 mmol) was subjected to coupling conditions similar to those for the preparation of **8** using triethylamine (0.60 mL, 0.37 g, 3.7 mmol), bis(triphenylphosphine)palladium(II) chloride (0.041g, 0.06 mmol), copper(I) iodide (0.023g, 0.12 mmol), and (trimethylsilyl)acetylene (0.23 mL, 0.16 g, 1.6 mmol). The reaction was stirred for 3 h. Catalytic potassium carbonate resulted in desilylation (2 h). The resulting oil was subjected to column chromatography (80:20 hexanes/ethyl acetate) to afford product **34** as a yellow oil (0.332 g, 89%): TLC R_f 0.56 (2:1 hexanes/ethyl acetate); IR (neat) ν 3406, 3300, 2930, 1082 cm^{-1}; ^{1}H NMR δ 7.84 (dd, 1H, J = 7.5, 1.5 Hz), 7.64 (dd, 1H, J = 7.5, 1.5 Hz), 7.53 (td, 1H, J = 7.5, 1.5 Hz), 7.42 (td, 1H, J = 7.5, 1.5 Hz), 6.04 (dt, 1H, J = 5.7, 1.8 Hz), 4.52 (d, 2H, J = 1.8 Hz), 3.50 (s, 1H), 2.76 (d, 1H, J = 5.7 Hz), 1.03 (s, 9H), 0.23 (s, 6H); ^{13}C NMR δ 134.4, 132.1, 130.5, 129.5, 129.4, 127.3, 85.6, 84.5, 81.2, 74.5, 64.1, 52.0, 26.8, 19.1, −1.1; HMRS (EI) calcd for $C_{18}H_{24}O_2Si$ ($M^+ - C_4H_9$) 243.0841, found 243.0834.

Preparation of 7-[2-[4-((*tert*-Butyldimethylsilyl)oxy)-1-hydroxy-2-butynyl)phenyl]hept-2-en-6-ynoate (35). Alcohol **16** (0.316 g, 0.79 mmol) was transferred to an oven-dried, nitrogen-flushed flask and diluted with dichloromethane (17 mL). Pyridinium chlorochromate (0.510 g, 2.4 mmol) and a weight equivalent of Celite were added under vigorous stirring in a portionwise manner. After 2.5 h, the reaction mixture was filtered and concentrated. It was then purified by column chromatograghy (80:20 hexanes/ethyl acetate) to afford 5-[2-(1-acetoxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)phenyl]-4-pentynal (0.20 g, 65%) as a colorless oil: TLC R_f 0.55 (2:1 hexanes/ethyl acetate); IR (neat) ν 2932, 1746, 1732, 840 cm^{-1}; ^{1}H NMR δ 7.63 (dd, 1H, J = 7.8, 1.5 Hz), 7.16−7.31 (m, 3H), 6.74 (t, 1H, J = 1.8 Hz), 4.30 (d, 2H, J = 1.8 Hz), 2.67 (m, 4H), 1.91 (s, 3H), 0.80 (s, 9H), 0.01 (s, 3H), 0.00 (s, 3H); ^{13}C NMR δ 200.3, 169.7, 138.2, 132.4, 128.9, 128.3, 128.0, 122.9, 93.9, 86.2, 81.1, 78.3, 64.0, 52.0, 42.6, 26.0, 21.1, 18.6, 12.9, −1.1; HMRS (EI) calcd for $C_{23}H_{30}O_4Si$ ($M^+ - C_4H_9$) 341.1209, found 341.1225.

5-[2-(1-Acetoxy-4-((*tert*-butyldimethylsilyl)oxy)-2-butynyl)-phenyl]-4-pentynal (0.131 g, 0.33 mmol) was subjected to Horner−Emmons reaction conditions similar to those for the preparation of **11** using trimethyl phosphonoacetate (0.08 mL, 0.09 g, 0.5 mmol), acetonitrile (5 mL), lithium chloride (0.028 g, 0.66 mmol), and DBU (0.07 mL, 0.08 g, 0.5 mmol). The reaction was stirred 10 min; then the reaction mixture was passed through silica gel (3:2 hexanes/ethyl acetate) and subsequently concentrated. The resulting residue was subjected to silica gel chromatography (80:20 hexanes/ethyl acetate) to afford methyl 7-[2-[1-acetoxy-4-((*tert*-butyldimethylsilyl)oxy))-2-butynyl]phenyl]hept-2-en-6-ynoate (0.125g, 86%) as a slightly yellow oil: TLC R_f 0.56 (3:1 hexanes/ethyl acetate); IR (neat) ν 2953, 1742, 1726, 1435 cm^{-1}; ^{1}H NMR δ

7.70 (dd, 1H, J = 7.5, 1.5 Hz), 7.39 (dd, 1H, J = 7.5, 1.5 Hz), 7.24−7.37 (m, 2H), 7.00 (dt, 1H, J = 15.6, 6.5 Hz), 6.82 (t, 1H, J = 1.8 Hz), 5.92 (dt, 1H, J = 15.6, 1.5 Hz), 4.37 (d, 2H, J = 1.8 Hz), 3.71 (s, 3H), 2.49−2.59 (m, 4H), 2.07 (s, 3H), 0.081 (s, 9H), 0.23 (s, 3H), 0.22 (s, 3H); ^{13}C NMR δ 169.6, 165.1, 147.0, 138.2, 132.4, 128.9, 128.3, 128.0, 123.0, 122.2, 94.3, 86.2, 81.1, 78.5, 64.0, 52.0, 51.7, 31.4, 26.0, 21.1, 18.7, 18.5, −1.1; HMRS (EI) calcd for $C_{26}H_{34}O_5Si$ ($M^+ - C_4H_9$) 397.1471, found 397.1462.

7-[2-[1-Acetoxy-4-((*tert*-butyldimethylsilyl)oxy))-2-butynyl]-phenyl]hept-2-en-6-ynoate (0.132 g, 0.32 mmol) was placed in a nitrogen-flushed, oven-dried flask and dissolved in methanol (15 mL). A catalytic amount of potassium carbonate (≈5 mg) was then added under rapid stirring. After 2.5 h the reaction mixture was filtered and concentrated. The residue was purified by silica gel chromatography (3:1 hexanes/ethyl acetate) to give alcohol **35** (0.049 g, 87%) as a yellow oil: TLC R_f 0.54 (2:1 hexanes/ethyl acetate); IR (neat) ν 3435, 2953, 1724, 1660, 1080 cm^{-1}; ^{1}H NMR δ 7.57 (dd, 1H, J = 7.2, 1.4 Hz), 7.31 (dd, 1H, J = 7.2, 1.4 Hz), 7.13−7.26 (m, 2H), 6.98 (dt, 1H, J = 15.6, 5.4 Hz), 5.88 (dt, 1H, J = 15.6, 1.5 Hz), 5.78 (dt, 1H, J = 5.4, 1.8 Hz), 4.30 (d, 2H, J = 1.8 Hz), 3.66 (s, 3H), 2.75 (d, 1H, J = 5.4 Hz), 2.54 (t, 2H, J = 2.5 Hz), 2.44 (q, 2H, J = 2.5 Hz), 0.79 (s, 9H), 0.00 (s, 6H); ^{13}C NMR δ 169.1, 147.1, 142.0, 132.5, 128.5, 128.3, 126.9, 122.4, 121.9, 93.8, 85.2, 84.2, 79.4, 63.1, 52.0, 51.9, 31.3, 25.9, 18.9, 18.5, −1.1; HMRS (EI) calcd for $C_{24}H_{32}O_4Si$ (M^+) 355.1366, found 355.1366.

Preparation of 3-(2-Ethynylphenyl)-2-propyn-1-ol (36). 3-(2-Iodophenyl)-2-propyn-1-ol (**8**) (1.200 g, 4.65 mmol) was subjected to coupling conditions similar to those for the preparation of **8** using triethylamine (1.944 mL, 1.411 g, 13.95 mmol), bis(triphenylphosphine)palladium (II) chloride (0.098 g, 0.14 mmol), copper(I) iodide (0.089 g, 0.47 mmol), and (trimethylsilyl)acetylene (0.986 mL, 0.685 g, 6.98 mmol) and stirring for 15 min at room temperature. Radial chromatography with an 85:15 mixture of hexanes/diethyl ether gave 1.053 g (99%) of 3-[2-[(trimethylsilyl)ethynyl]phenyl]-2-propyn-1-ol as a pale yellow oil: TLC R_f 0.37 (3:1 hexanes/ethyl acetate); IR (neat) ν 3385 (br), 3063, 2961, 2899, 2866, 2234, 2160 cm^{-1}; ^{1}H NMR δ 0.25 (9H, s), 1.96 (1H, t, J = 6.1 Hz), 4.51 (2H, d, J = 6.1 Hz), 7.20−7.25 (2H, m), 7.38−7.45 (2H, m); ^{13}C NMR δ 132.0, 131.7, 128.2, 128.1, 125.6, 125.4, 103.3, 98.7, 91.3, 84.2, 51.6, −0.1. Anal. Calcd for $C_{14}H_{16}OSi$: C, 73.63; H, 7.06. Found: C, 73.38; H, 7.06.

3-[2-[(Trimethylsilyl)ethynyl]phenyl]-2-propyn-1-ol (0.850 g, 3.72 mmol) was subjected to the same desilylation conditions as **35** using potassium carbonate (≈5 mg) dissolved in 10 mL of methanol with stirring for 45 min. The solvent was then removed *in vacuo* and the residue passed through a short silica gel column with diethyl ether. The crude product was purified by radial chromatography with a 70:30 mixture of hexanes/diethyl ether to yield 0.564 g (97%) of **36** as a colorless crystalline solid: TLC R_f 0.20 (3:1 hexanes/ethyl acetate); IR (Nujol) ν 3273 (br), 2955, 2926, 2857, 2230, 2104 cm^{-1}; ^{1}H NMR δ 2.11 (1H, t, J = 5.7 Hz), 3.27 (1H, s), 4.48 (1H, d, J = 5.7 Hz), 7.21 (2H, m), 7.36−7.44 (2H, m); ^{13}C NMR δ 132.6, 132.1, 128.5, 128.2, 125.4, 124.4, 91.3, 83.9, 82.0, 81.1, 51.6. Anal. Calcd for $C_{11}H_8O$: C, 84.59; H, 5.16. Found: C, 84.70; H, 5.30.

Preparation of Methyl 2-(3-Hydroxy-1-propynylphenyl)hept-2-en-6-ynoate (37). Methyl 7-(2-iodophenyl)hept-2-en-6-ynoate (**11**) (0.300 g, 0.88 mmol) was transferred to a nitrogen-flushed, oven-dried flask and dissolved in triethylamine (6 mL). Tetrakis(triphenylphosphine)palladium(0) (0.021 g, 0.02 mmol) and copper(I) bromide (0.008 g, 0.03 mmol) were added under rapid stirring. After 10 min, propargyl alcohol (0.08 mL, 0.07 g, 1 mmol) was added *via* syringe and the resulting reaction mixture was heated to 50 °C for 1.5 h. The reaction mixture was then filtered and concentrated. The resulting residue was purified by silica gel chromatography (80:20 hexanes/ethyl acetate) to afford alcohol **37** (0.175 g, 74%) as a slightly yellow oil: TLC R_f 0.20 (3:1 hexanes/ethyl acetate); IR (neat) ν 3465, 1724, 1664, 1227 cm^{-1}; ^{1}H NMR δ 7.63 (dd, 1H, J = 7.8, 1.5 Hz), 7.20−7.33 (m, 3H), 7.04 (dt, 1H, J = 15.6, 5.4 Hz), 5.92 (d, 1H, J = 15.6 Hz), 4.53 (s, 2H), 3.70 (s, 3H), 2.87 (s, 1H), 2.60 (t, 2H, J = 5.4 Hz), 2.44 (q, 2H, J = 5.4 Hz); ^{13}C NMR δ 166.7, 147.0, 139.0, 132.9, 129.3, 128.1, 123.1, 101.3, 100.8, 93.0, 84.3, 77.5, 77.1, 60.8, 31.7, 30.3, 19.2.

Preparation of (4-((*tert*-Butyldimethylsilyl)oxy)-1-(2-ethynylphenyl)-1,2-butadien-3-yl)diphenylphosphine Oxide (38). Compound **34** (0.047 g, 0.57 mmol) was transferred to an oven-dried, nitrogen-flushed flask and diluted in THF (3 mL) and triethylamine (0.076 mL, 0.047 g, 0.47 mmol). The resulting solution was cooled to −78 °C in a dry ice−acetone bath. Chlorodiphenylphosphine (0.019 mL, 0.035 g, 0.16 mmol) was added *via* syringe in a dropwise fashion to a vigorously stirred reaction mixture. After 2 h, the reaction mixture was concentrated at 0 °C and immediately subjected to chromatography on deactivated silica gel (70:29:1 hexanes/ethyl acetate/triethylamine) to yield the unstable allene **38** (0.050 g, 98%) as a light yellow oil: TLC R_f 0.07 (3:1 hexanes/ethyl acetate); ^{1}H NMR δ 7.73−7.87 (m, 4H), 7.30−7.56 (m, 7H), 7.16−7.25 (m, 3H), 6.87−6.94 (dt, 1H, J = 10.5, 2.9 Hz), 4.60−4.65 (m, 2H), 3.29 (s, 1H), 0.82 (s, 9H), 0.01 (s, 3H), 0.00 (s, 3H); unstability of this compound precluded any attempts at further characterization.

Formation of (2-((*tert*-Butyldimethylsilyl)oxy)-1-(2-naphthyl)ethyl)diphenylphosphine Oxide (40) *via* Enyne Allene Cyclization of Enyne Allene 38. Compound **38** (0.050 g, 0.10 mmol) was dissolved in chlorobenzene (6.5 mL) and transferred to a pressure tube. Nitrogen was passed through the resulting solution for 10 min, after which 1,4-CHD (1.5 mL, 1.3 g, 16 mmol) was added. The pressure tube was then capped and immersed into a 37 °C oil bath for 3.5 h. The reaction mixture was concentrated, and the resulting residue was purified by silica gel chromatography (3:2 hexanes/ethyl acetate) to give the cyclized product **40** as a colorless crystalline solid (0.035 g, 70%): TLC R_f 0.40 (3:2 hexanes/ethyl acetate); IR (neat) ν 2894, 1429, 1160, 1094 cm^{-1}; ^{1}H NMR δ 7.92−7.99 (m, 1H), 7.63−7.80 (m, 5H) 7.35−7.54 (m, 7H), 7.10−7.24 (m, 4H), 4.19−4.36 (m, 2H), 3.90 (dt, 1H, J = 8.1, 5.1 Hz), 0.64 (s, 9H), −0.26 (s, 3H), −0.33 (s, 3H); ^{13}C NMR δ 125.7−131.8 (aromatic), 63.9 (d, 1C, $^2J_{PC}$ = 3.3 Hz), 50.5 (d, 1C, $^1J_{PC}$ = 65.8 Hz), 25.9, 22.9, −1.7; ^{31}P NMR δ 30.6; HMRS (EI) calcd for $C_{30}H_{35}SiPO_2$ ($M^+ - C_4H_9$) 429.1440, found 429.1450.

Preparation of Methyl 7-[2-(4-((*tert*-butyldimethylsilyl)oxy)-3-(diphenylphosphinyl)-2-butadienyl)phenyl]-hep-2-en-6-ynoate (41). This compound was prepared in a manner similar to that of **38** using alcohol **35** (0.048 g, 0.13 mmol), THF (3 mL) chlorodiphenylphosphine (0.02 mL, 0.03 g, 0.1 mmol), and triethylamine (0.06 mL, 0.04 g, 0.4 mmol) with rapid stirring for 1.5 h. Purification on deactiviated silica gel (70:29:1 hexanes/ethyl acetate/triethylamine) gave allene **41** (0.077 g, 99%) as a yellow oil: TLC R_f 0.12 (3:2 hexanes/ethyl acetate); IR (neat) ν 3405, 1925, 1724, 1485 cm^{-1}; ^{1}H NMR δ 7.83−8.04 (m, 4H), 7.36−7.71 (m, 8H), 7.10−7.28 (m, 3H), 6.87 (dt, 1H, J = 10.8, 3Hz), 6.05 (dt, 1H, J = 15.6, 1.5Hz), 4.69−4.73 (m, 2H), 3.87 (s, 3H), 2.58−2.73 (m, 4H), 0.91 (s, 9H), 0.09 (s, 3H), 0.08 (s, 3H); ^{13}C NMR δ 210.5, 166.8, 147.0, 126.8−133.9 (aromatic), 122.3, 103.8 (d, 1C, $^1J_{PC}$ = 98.3 Hz), 96.6 (d, 1C, $^3J_{PC}$ = 13.0 Hz), 93.5, 79.6, 60.7 (d, 1C, $^2J_{PC}$ = 10.8 Hz), 51.7, 31.6, 25.9, 18.8, 18.5, −1.4; ^{31}P NMR δ 27.9; HMRS (EI) calcd for $C_{36}H_{41}SiPO_4$ (M^+) 596.2512, found 596.2516.

Preparation of Methyl 1*H*-4-Vinyl-1,2-dihydrobenz[*e*]-indene-1-acetate (43) *via* Tandem Enyne Allene−Radical Cyclization of Enyne Allene 41. This reaction was similar to the thermolysis of **38** using enyne allene **41** (0.077 g, 0.13 mmol). The pressure tube was immersed in a 75 °C oil bath for 8 h, after which it was concentrated affording a yellow oil which proved to be unstable when subjected to silica gel chromatography. The residue was dissolved in THF (5 mL) and transferred to an oven-dried, nitrogen-flushed flask. To this rapidly stirred mixture was added a solution of tetra-*n*-butylammonium fluoride in THF (0.13 mL, 1 M, 0.13 mmol). After 1 h, the reaction mixture was concentrated and subjected to chromatography (9:1 hexanes/ethyl acetate) to afford dihydrobenz[*e*]indene **43** as a light yellow oil (0.024 g, 70%): TLC R_f 0.82 (3:2 hexanes/ethyl acetate); IR (neat) ν 2952, 1737, 1435, 1259 cm^{-1}; ^{1}H NMR δ 7.84 (m, 3H), 7.47 (td, 1H, J = 6.6, 1.2 Hz), 7.41 (t, 1H, J = 6.6 Hz), 6.92 (dd, 1H, J = 17.7, 11.1 Hz), 5.83 (dd, 1H, J = 17.7 1.2 Hz), 5.37 (dd, 1H, J = 11.1, 1.2 Hz), 4.14 (ddd, 1H, J = 9.3, 8.1, 3 Hz), 3.73 (s, 3H), 3.10−3.19 (m, 2H), 2.79 (dd, 1H, J = 15.6, 3 Hz), 2.33−2.43

(m, 2H), 2.15 (dd, 1H, J = 14.1, 6.0 Hz); ^{13}C NMR δ 173.4, 141.5, 139.4, 135.3, 133.4, 133.0, 129.4, 129.0, 126.3, 125.3, 124.2, 123.7, 115.9, 51.9, 40.6, 38.8, 31.0, 30.6; HMRS (EI) calcd for $C_{18}H_{18}O_2$ (M^+) 266.1307, found 266.1301.

Preparation of [1-[2-(6-(Methoxycarbonyl)hex-5-en-1-ynyl)phenyl]propadien-1-yl]diphenylphosphine Oxide (44). This compound was prepared in a manner similar to that of **38** using enediyne alcohol **37** (0.150 g, 0.56 mmol), THF (10 mL) chlorodiphenylphosphine (0.12 mL, 0.15 g, 0.7 mmol), and triethylamine (0.27 mL, 0.2 g, 1.7 mmol) with rapid stirring for 3 h. The reaction mixture was concentrated and subjected to silica gel chromatography (60:39:1 hexanes/ethyl acetate/triethylamine). Purification afforded allene **44** (0.245 g, 97%) as a light yellow oil: TLC R_f 0.05 (2:1 hexanes/ethyl acetate); IR (neat) ν 1720, 1437, 1192 cm^{-1}; ^{1}H NMR δ 8.22 (m, 1H), 7.70−7.82 (m, 4H), 7.26−7.49 (m, 7H), 7.02−7.19 (m, 3H), 5.97 (d, 1H, J = 14.4 Hz), 4.79 (d, 2H, J = 10.8 Hz), 3.70 (s, 3H) 2.63 (t, 2H, J = 5.4 Hz) 2.51 (q, 2H, J = 5.4 Hz); ^{31}P NMR δ 31.9.

Preparation of Methyl (*E*,*Z*)-12-Hydroxydodeca-2,8-diene-6,10-diynoate (51). To a stirred solution of methyl (*E*,*Z*)-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diynoate[7c] (0.700 g, 2.11 mmol) in dichloromethane (30 mL) was added boron trifluoride diethyl etherate (0.775 mL, 6.30 mmol) *via* syringe. After being stirred at room temperature under nitrogen for 30 min, the reaction mixture was quenched with water and extracted with dichloromethane (2 × 40 mL). The combined organic layers were dried over anhydrous magnesium sulfate, filtered, and evaporated. Purification by radial chromatography (3:1 hexanes/ethyl acetate) afforded **51** as a yellow oil (0.396 g, 86%): TLC R_f 0.18 (2:1 hexanes/ethyl acetate); IR (neat) ν 3435, 2212, 1721, 1659, 1287 cm^{-1}; ^{1}H NMR δ 7.08 (dt, J = 15.6, 6.6 Hz, 1H), 5.90 (dt, J = 15.6, 1.5 Hz, 1H), 5.76−5.73 (m, 2H), 4.40 (d, J = 1.2 Hz, 2H), 3.69 (s, 3H), 3.12 (bs, 1H), 2.56−2.37 (m, 4H); ^{13}C NMR δ 167.3, 147.4, 121.9, 119.8, 118.4, 96.3, 95.0, 82.2, 79.2, 51.6, 51.2, 30.9, 18.7; HRMS (EI) calcd for $C_{13}H_{14}O_3$ (M^+) 218.0943, found 218.0923.

Preparation of Methyl (*E*,*Z*)- and (*Z*,*Z*)-2-Methyl-12-hydroxydodeca-2,8-diene-6,10-diynoate (52 and 53). (*Z*)-10-((*tert*-Butyldimethylsilyl)oxy)dec-6-ene-4,8-diynal (**50**)[7c] (0.150 g, 0.543 mmol) was subjected to Horner−Emmons reaction conditions similar to those for the preparation of **11** using trimethyl 2-methylphosphonoacetate (0.160 g, 0.816 mmol), acetonitrile (4 mL), lithium chloride (0.046 g, 1.09 mmol), and DBU (0.122 mL, 0.816 mmol). The reaction mixture was stirred at rt for 10 min, quenched with water, and extracted with diethyl ether (3 × 40 mL). The combined organic layers were dried over anhydrous magnesium sulfate, filtered, and concentrated *in vacuo*. Purification of the product was achieved by radial chromatography (98:2 hexanes/ethyl acetate) to afford methyl (*E*,*Z*)-2-methyl-12-((*tert*-butyldimethylsilyl)oxy)-dodeca-2,8-diene-6,10-diynoate and methyl (*Z*,*Z*)-2-methyl-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diynoate in an 8:1 ratio as yellow oils. Methyl (*E*,*Z*)-2-methyl-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diynoate (0.138 g, 73%): TLC R_f 0.64 (2:1 hexanes/ethyl acetate); IR (neat) ν 2953, 2214, 1716, 1653, 1265 cm^{-1}; ^{1}H NMR δ 6.79−6.72 (m, 1H), 5.76−5.74 (m, 2H), 4.47 (d, J = 0.9 Hz, 2H), 3.71 (s, 3H), 2.53−2.36 (m, 4H), 1.84−1.82 (m, 3H), 0.88 (s, 9H), 0.11 (s, 6H); ^{13}C NMR δ 139.8, 128.9, 127.4, 119.8, 118.3, 96.9, 94.9, 82.1, 78.6, 52.2, 51.7, 27.9, 25.8, 19.1, 18.2, 12.5, −5.2; HRMS (EI) calcd for $C_{20}H_{30}SiO_3$ (M^+) 346.1964, found 346.1965. Methyl (*Z*,*Z*)-2-methyl-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diynoate (0.017 g, 9%): TLC R_f 0.66 (2:1 hexanes/ethyl acetate); IR (neat) ν 2953, 2212, 1719, 1649, 1254 cm^{-1}; ^{1}H NMR δ 6.04 (tq, J = 6.9, 1.5 Hz, 1H), 5.77−5.74 (m, 2H), 4.47 (d, J = 1.5 Hz, 2H), 3.70 (s, 3H), 2.74−2.64 (m, 2H), 2.49−2.43 (m, 2H), 1.89 (m, 3H), 0.88 (s, 9H), 0.11 (s, 6H); ^{13}C NMR δ 168.1, 141.0, 128.1, 120.0, 118.0, 97.5, 94.8, 82.1, 78.6, 52.3, 51.3, 28.6, 25.8, 20.6, 19.8, 18.3, −5.1; HRMS (EI) calcd for $C_{20}H_{30}SiO_3$ (M^+) 346.1964, found 346.1945.

The (*E*,*Z*) compound **52** was prepared like **51** using methyl (*E*,*Z*)-2-methyl-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diynoate (0.600 g, 1.73 mmol), dichloromethane (15 mL), and boron trifluoride diethyl etherate (0.640 mL, 5.20 mmol) with stirring for 40 min. Purification afforded **52** as a pale yellow oil (0.322 g, 80%): TLC R_f 0.19 (2:1 hexanes/ethyl acetate); IR (neat) ν 3460, 2951, 2212, 1711, 1651, 1277 cm^{-1}; ^{1}H NMR δ 6.85 (tq, J = 6.9, 1.5 Hz, 1H), 5.75−5.72 (m, 2H), 4.38 (d, J = 0.6 Hz, 2H), 3.69 (s, 3H), 2.98 (s, 1H), 2.53−2.34 (m, 4H), 1.80 (m, 3H); ^{13}C NMR δ 168.8, 140.4, 128.6, 120.0, 118.2, 97.0, 94.8, 82.2, 78.7, 51.8, 51.2, 27.5, 18.9, 12.4; HRMS (EI) calcd for $C_{14}H_{16}O_3$ (M^+) 232.1100, found 232.1101.

The (*Z*,*Z*) compound **53** was prepared like **51** using methyl (*Z*,*Z*)-2-methyl-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diynoate (0.100 g, 0.289 mmol), dichloromethane (8 mL), and boron trifluoride diethyl etherate (0.107 mL, 0.870 mmol) with stirring for 1 h. Purification afforded **53** as a pale yellow oil (0.055 g, 82%): TLC R_f 0.20 (2:1 hexanes/ethyl acetate); IR (neat) ν 3443, 2951, 2212, 1711, 1645, 1217 cm^{-1}; ^{1}H NMR δ 6.02 (tq, J = 6.9, 1.5 Hz, 1H), 5.78−5.75 (m, 2H), 4.42 (d, J = 1.5 Hz, 2H), 3.70 (s, 3H), 2.77−2.67 (m, 2H), 2.50−2.44 (m, 2H), 2.30 (s, 1H), 1.89 (m, 3H); ^{13}C NMR δ 168.3, 141.2, 128.1, 120.5, 117.9, 98.0, 94.4, 82.8, 78.5, 51.5, 51.4, 28.7, 20.5, 19.7; HRMS (EI) calcd for $C_{14}H_{16}O_3$ (M^+) 232.1100, found 232.1110.

Preparation of (*Z*,*E*)-12-Acetoxydodeca-4,10-diene-2,6-diyn-1-ol (54). To a stirred solution of methyl (*E*,*Z*)-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diynoate[7c] (1.00 g, 3.01 mmol) in dichloromethane (15 mL) at 0 °C was added diisobutylaluminum hydride (1.5 M solution in toluene, 4.00 mL, 6.00 mmol) *via* syringe. After being stirred at 0 °C under nitrogen for 20 min, the reaction mixture was quenched with potassium fluoride monohydrate (0.560 g, 5.95 mmol) and excess water followed by a dichloromethane/water extraction. The combined organic layers were dried over anhydrous magnesium sulfate, filtered, and concentrated *in vacuo*. The resulting yellow residue was subjected to radial chromatography (9:1 hexanes/ethyl acetate) to afford (*E*,*Z*)-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diyn-1-ol as a light yellow oil (0.715 g, 78%): TLC R_f 0.31 (2:1 hexanes/ethyl acetate); IR (neat) ν 3379, 2930, 2212, 1672, 1579, 1255, 1076 cm^{-1}; ^{1}H NMR δ 5.81−5.63 (m, 4H), 4.47 (d, J = 1.2 Hz, 2H), 4.09−4.05 (m, 2H), 2.48−2.40 (m, 2H), 2.32−2.23 (m, 2H), 1.79 (bs, 1H), 0.88 (s, 9H), 0.11 (s, 6H); ^{13}C NMR δ 130.5, 130.4, 120.1, 118.0, 97.6, 94.6, 82.2, 78.5, 63.4, 52.3, 31.2, 25.8, 19.8, 18.3, −5.2; HRMS (EI) calcd for $C_{18}H_{28}SiO_2$ (M^+) 304.1859, found 304.1866.

(*E*,*Z*)-12-((*tert*-Butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diyn-1-ol (0.700 g, 2.30 mmol) was dissolved in dichloromethane (15 mL); then triethylamine (1.60 mL, 11.5 mmol) and acetic anhydride (0.434 mL, 4.60 mmol) were added *via* syringe. After being stirred at room temperature overnight, the reaction mixture was diluted with water and extracted with dichloromethane (3 × 50 mL). The combined organic layers were dried over anhydrous magnesium sulfate, filtered, and concentrated *in vacuo* to give a yellow residue. Purification was achieved by radial chromatography (95:5 hexanes/ethyl acetate) to yield (*E*,*Z*)-1-acetoxy-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diyne as a pale yellow oil (0.758 g, 95%): TLC R_f 0.56 (2:1 hexanes/ethyl acetate); IR (neat) ν 2930, 2216, 1742, 1232, 1076 cm^{-1}; ^{1}H NMR δ 5.87−5.76 (m, 1H), 5.75−5.73 (m, 2H), 5.67−5.56 (m, 1H), 4.49 (dd, J = 6.3, 1.2 Hz, 2H), 4.47 (d, J = 1.2 Hz, 2H), 2.47−2.40 (m, 2H), 2.33−2.23 (m, 2H), 2.02 (s, 3H), 0.88 (s, 9H), 0.10 (s, 6H); ^{13}C NMR δ 170.7, 133.9, 125.2, 119.9, 118.1, 97.3, 94.8, 82.1, 78.6, 64.9, 52.2, 31.3, 25.8, 20.9, 19.6, 18.2, −5.2; HRMS (EI) calcd for $C_{20}H_{30}SiO_3$ (M^+) 346.1965, found 346.1945.

To a stirred solution of (*E*,*Z*)-1-acetoxy-12-((*tert*-butyldimethylsilyl)oxy)dodeca-2,8-diene-6,10-diyne (0.600 g, 1.73 mmol) in THF (10 mL) was added tetra-*n*-butylammonium fluoride (1.0 M solution in THF, 5.00 mL, 5.00 mmol) at room temperature under nitrogen. After the reaction mixture was stirred for 2 min, it was quenched with water and extracted with diethyl ether (2 × 50 mL). The combined organic layers were dried over anhydrous magnesium sulfate, filtered, and evaporated. Purification by radial chromatography (3:1 hexanes/ethyl acetate) afforded **54** as a light yellow oil (0.335 g, 83%): TLC R_f 0.15 (2:1 hexanes/ethyl acetate); IR (neat) ν 3435, 2936, 2212, 1738, 1240, 1024 cm^{-1}; ^{1}H NMR δ 5.86−5.75 (m, 1H), 5.74−5.71 (m, 2H), 5.65−5.54 (m, 1H), 4.47 (dd, J = 6.3, 1.2 Hz, 2H), 4.38 (d, J = 1.5 Hz, 2H), 2.77 (bs, 1H), 2.46−2.39 (m,

2H), 2.30−2.21 (m, 2H), 2.00 (s, 3H); ^{13}C NMR δ 171.0, 133.9, 125.1, 120.2, 117.8, 97.6, 94.4, 82.5, 78.5, 64.9, 51.2, 31.1, 20.9, 19.4; HRMS (EI) calcd for $C_{14}H_{16}O_3$ (M^+) 232.1099, found 232.1120.

Preparation of (*Z*,*E*)- and (*Z*,*Z*)-11-Methoxyundeca-4,-10-diene-2,6-diyn-1-ol (55). To a stirred solution of (methoxymethyl)triphenylphosphonium chloride (0.771 g, 2.25 mmol) in THF (20 mL) at −78 °C under nitrogen was added potassium *tert*-butoxide (0.252 g, 2.25 mmol). After being warmed to room temperature and stirred for 1 h, the reaction mixture was cooled to −78° C and (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)dec-6-ene-4,8-diynal (**50**)[7c] (0.250 g, 0.906 mmol), dissolved in THF (5 mL), was added dropwise *via* syringe. After the mixture was stirred at −78° C for 10 min, it was quenched with water and extracted with diethyl ether (3 × 40 mL). The combined organic layers were dried over anhydrous magnesium sulfate, filtered, and concentrated *in vacuo*. The residue was purified by radial chromatography (95:5 hexanes/ethyl acetate) to afford a mixture of (*E*,*Z*)- and (*Z*,*Z*)-1-methoxy-11-((*tert*-butyldimethylsilyl)oxy)undeca-1,7-diene-5,9-diyne as a pale yellow oil (0.171 g, 6:1 mixture of *E*:*Z* isomers, 62% combined yield): TLC R_f 0.64 (2:1 hexanes/ethyl acetate); IR (neat) ν 2930, 2212, 1657, 1211 cm^{-1}; ^{1}H NMR *E* isomer δ 6.34 (dt, J = 12.3, 1.2 Hz, 1H), 5.80−5.69 (m, 2H), 4.76 (dt, J = 12.3, 7.2 Hz, 1H), 4.48 (d, J = 1.5 Hz, 2H), 3.48 (s, 3H), 2.42−2.35 (m, 2H), 2.20−2.11 (m, 2H), 0.88 (s, 9H), 0.11 (s, 6H); *Z* isomer δ 5.89 (dt, J = 6.6, 1.2 Hz, 1H), 5.80−5.69 (m, 2H), 4.49−4.46 (m, 1H), 4.48 (d, J = 1.5 Hz, 2H), 3.55 (s, 3H), 2.42−2.35 (m, 2H), 2.33−2.23 (m, 2H), 0.88 (s, 9H), 0.11 (s, 6H); ^{13}C NMR δ 148.1, 146.9, 120.3, 120.1, 117.8, 117.7, 104.7, 101.0, 98.0, 94.7, 82.2, 78.4, 55.8, 52.3, 27.2, 25.8, 23.2, 21.6, 20.2, 18.2, −5.2. Anal. Calcd for $C_{18}H_{28}SiO_2$: C, 71.00; H, 9.27. Found: C, 70.80; H, 9.35.

The subsequent desilylation was carried out as described for **54** using (*E*,*Z*)/(*Z*,*Z*)-1-methoxy-11-((*tert*-butyldimethylsilyl)oxy)undeca-1,7-diene-5,9-diyne (0.125 g, 0.411 mmol), THF (20 mL), and tetra-*n*-butylammonium fluoride (1.0 M solution in THF) (1.23 mL, 1.23 mmol) to provide **55** as a light yellow oil (0.069 g, 6:1 mixture of *E*:*Z* isomers, 88% combined yield): TLC R_f 0.21 (2:1 hexanes/ethyl acetate); IR (neat) ν 3410, 2934, 2211, 1657, 1209 cm^{-1}; ^{1}H NMR *E* isomer δ 6.36 (dt, J = 12.3, 1.2 Hz, 1H), 5.82−5.71 (m, 2H), 4.86 (dt, J = 12.3, 7.2 Hz, 1H), 4.41 (d, J = 2.7 Hz, 2H), 3.50 (s, 3H), 2.50−2.37 (m, 3H), 2.20−2.11 (m, 2H); *Z* isomer δ 5.90 (dt, J = 6.6, 1.2 Hz, 1H), 5.82−5.71 (m, 2H), 4.50−4.43 (m, 1H), 4.41 (d, J = 2.7 Hz, 2H), 3.56 (s, 3H), 2.50−2.37 (m, 3H), 2.34−2.25 (m, 2H); ^{13}C NMR δ 147.9, 146.9, 120.8, 120.5, 117.7, 117.5, 104.7, 101.5, 98.3, 94.3, 82.7, 78.6, 59.5, 56.1, 51.6, 51.5, 26.8, 23.2, 21.4, 20.2; HRMS (EI) calcd for $C_{12}H_{13}O_2$ (M^+ − H) 189.0916, found 189.0930.

Preparation of (*Z*)-10-Hydroxy-*N*-(phenylmethoxy)-dec-6-ene-4,8-diyn-1-imine (56). To a stirred solution of (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)dec-6-ene-4,8-diynal (**50**)[7c] (0.320 g, 1.16 mmol) in dichloromethane (15 mL) were added *O*-benzylhydroxylamine hydrochloride (0.222 g, 1.39 mmol) and pyridine (0.112 mL, 1.39 mmol). The reaction mixture was allowed to stir at room temperature for 30 min, upon which the aldehyde had been consumed as monitored by TLC. The solvent was removed *in vacuo*, and the residue was washed through silica gel using a 3:1 mixture of hexanes/ethyl acetate. The filtrate was evaporated, and the residue was subjected to radial chromatography (98:2 hexanes/ethyl acetate) to provide (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)-*N*-(phenylmethoxy)dec-6-ene-4,8-diyn-1-imine as a pale yellow oil (0.425 g, 1:1 mixture of *E*/*Z* imine isomers, 96%): TLC R_f 0.53 (3:1 hexanes/ethyl acetate); IR (neat) ν 2930, 2216, 1256, 1076, 837 cm^{-1}; ^{1}H NMR *E* isomer δ 7.57 (t, J = 6.0 Hz, 1H), 7.37−7.25 (m, 5H), 5.79−5.75 (m, 2H), 5.05 (s, 2H), 4.50−4.48 (m, 2H), 2.66−2.40 (m, 4H), 0.90 (s, 9H), 0.12 (s, 6H); *Z* isomer δ 6.83 (t, J = 4.8 Hz, 1H), 7.37−7.25 (m, 5H), 5.79−5.75 (m, 2H), 5.11 (s, 2H), 4.50−4.48 (m, 2H), 2.66−2.40 (m, 4H), 0.90 (s, 9H), 0.12 (s, 6H); ^{13}C NMR δ 150.1, 149.4, 137.8, 137.5, 128.3, 128.2, 127.9, 127.8, 127.7, 127.6, 119.7, 119.6, 118.6, 118.5, 96.3, 96.1, 95.1, 95.0, 82.1, 82.0, 79.1, 79.0, 75.8, 75.6, 52.3, 52.2, 28.7, 25.8, 25.0, 18.3, 17.6, 16.8, −5.1; HRMS (EI) calcd for $C_{19}H_{22}NSiO_2$ (M^+ − C_4H_9) 324.1420, found 324.1436.

(*Z*)-10-((*tert*-Butyldimethylsilyl)oxy)-*N*-(phenylmethoxy)dec-6-ene-4,8-diyn-1-imine (0.360 g, 0.940 mmol) was subjected to desilylation reaction conditions similar to those for the preparation of **54** using tetra-*n*-butylammonium fluoride (1.0 M solution in THF, 2.82 mL, 2.82 mmol). Purification by radial chromatography (3:1 hexanes/ethyl acetate) afforded **56** as a pale yellow oil (0.203 g, 1:1 mixture of *E*/*Z* imine isomers, 81%): TLC R_f 0.12 (3:1 hexanes/ethyl acetate); IR (neat) ν 3406, 2924, 2214, 1635, 1020, 748 cm^{-1}; ^{1}H NMR *E* isomer δ 7.66 (t, J = 6.0 Hz, 1H), 7.37−7.25 (m, 5H), 5.80−5.76 (m, 2H), 5.07 (s, 2H), 4.31 (d, J = 1.8 Hz, 2H), 3.04 (bs, 1H), 2.66−2.41 (m, 4H); *Z* isomer δ 7.10 (t, J = 4.8 Hz, 1H), 7.37−7.25 (m, 5H), 5.80−5.76 (m, 2H), 5.11 (s, 2H), 4.35 (d, J = 1.2 Hz, 2H), 3.04 (bs, 1H), 2.66−2.41 (m, 4H); ^{13}C NMR δ 151.2, 150.3, 137.4, 137.1, 128.4, 128.3, 128.2, 128.0, 127.9, 127.8, 120.0, 119.9, 119.1, 118.6, 96.1, 96.0, 95.2, 94.9, 82.7, 82.3, 79.9, 79.5, 75.9, 75.7, 51.2, 51.0, 28.4, 24.6, 17.5, 16.6; HRMS (EI) calcd for $C_{17}H_{17}NO_2$ (M^+) 267.1259, found 267.1247.

Preparation of (*Z*)-10-Hydroxy-*N*-(diphenylamino)dec-6-ene-4,8-diyn-1-imine (57). To a stirred solution of (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)dec-6-ene-4,8-diynal (**50**)[7c] (0.400 g, 1.45 mmol) in dichloromethane (10 mL) were added 1,1-diphenylhydrazine hydrochloride (0.384 g, 1.74 mmol) and pyridine (0.140 mL, 1.74 mmol). The reaction mixture was allowed to stir at room temperature for 10 min, upon which the aldehyde had been consumed as monitored by TLC. The solvent was removed in vacuo, and the residue was filtered through silica gel using a 3:1 mixture of hexanes/ethyl acetate. The filtrate was evaporated, and the residue was subjected to radial chromatography (98:2 hexanes/ethyl acetate) to afford (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)-*N*-(diphenylamino)dec-6-ene-4,8-diyn-1-imine as a yellow oil (0.610 g, 95%): TLC R_f 0.72 (3:1 hexanes/ethyl acetate); IR (neat) ν 2930, 2247, 2214, 1591, 1495, 1211, 1072 cm^{-1}; ^{1}H NMR δ 7.39−7.31 (m, 4H), 7.15−7.05 (m, 6H), 6.56 (t, J = 4.8 Hz, 1H), 5.76−5.74 (m, 2H), 4.47 (s, 2H), 2.68−2.61 (m, 2H), 2.57−2.48 (m, 2H), 0.90 (s, 9H), 0.13 (s, 6H); ^{13}C NMR δ 144.0, 136.9, 129.7, 124.0, 122.3, 120.0, 118.0, 97.6, 94.8, 82.1, 78.4, 52.3, 31.8, 25.8, 18.3, 17.7, −5.1; HRMS (EI) calcd for $C_{28}H_{34}SiN_2O$ (M^+) 442.2440, found 442.2451.

(*Z*)-10-((*tert*-Butyldimethylsilyl)oxy)-*N*-(diphenylamino)dec-6-ene-4,8-diyn-1-imine (0.550 g, 1.24 mmol) was subjected to desilylation reaction conditions similar to those used for the preparation of **54** using tetra-*n*-butylammonium fluoride (1.0 M solution in THF, 3.70 mL, 3.70 mmol). Purification by radial chromatography (3:1 hexanes/ethyl acetate) gave **57** as a light yellow oil (0.380 g, 93%): TLC R_f 0.18 (3:1 hexanes/ethyl acetate); IR (neat) ν 3393, 2924, 2212, 1591, 1495, 1211, 1092 cm^{-1}; ^{1}H NMR δ 7.39−7.32 (m, 4H), 7.15−7.07 (m, 6H), 6.61 (t, J = 4.8 Hz, 1H), 5.79−5.76 (m, 2H), 4.29 (d, J = 5.1 Hz, 2H), 2.69−2.61 (m, 2H), 2.60−2.49 (m, 3H); ^{13}C NMR δ 144.0. 138.4, 129.6, 124.0, 122.4, 120.3, 117.9, 97.7, 94.6, 82.8, 78.6, 51.3, 31.6, 17.6; HRMS (EI) calcd for $C_{22}H_{20}N_2O$ (M^+) 328.1576, found 328.1582.

Preparation of (*Z*)-10-((*tert*-Butyldimethylsilyl)oxy)-undec-6-ene-4,8-diynal (58). To a stirred solution of (*Z*)-7-chlorohept-6-en-4-yn-1-ol[7c] (1.90 g, 13.1 mmol) and *n*-butylamine (2.20 mL, 22.3 mmol) in anhydrous benzene (25 mL) was added tetrakis(triphenylphosphine)palladium(0) (0.258 g, 0.223 mmol) under nitrogen. After the reaction mixture was stirred at room temperature for 10 min, copper(I) iodide (0.100 g, 0.525 mmol) was added and the resulting mixture was stirred for an additional 10 min. 3-((*tert*-Butyldimethylsilyl)-oxy)-1-butyne (2.90 g, 15.8 mmol) was then added, and the reaction mixture was allowed to stir at 50 °C under nitrogen for 24 h. The solvent was removed *in vacuo* and the residue filtered through silica gel using a 2:1 mixture of hexanes/ethyl acetate. The filtrate was evaporated and the residue subjected to radial chromatography (9:1 hexanes/ethyl acetate) to yield (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)undec-6-ene-4,8-diyn-1-ol as a pale yellow oil (3.04 g, 79%): TLC R_f 0.32 (2:1 hexanes/ethyl acetate); IR (neat) ν 3364, 2953, 2212, 1256, 1099 cm^{-1}; ^{1}H NMR δ 5.74−5.72 (m, 2H), 4.67 (dq, J = 0.6, 6.6 Hz, 1H), 3.77 (t, J = 6.6 Hz, 2H), 2.47 (dt, J = 0.9, 6.6 Hz, 2H), 2.11 (bs, 1H), 1.76 (quintet, J = 6.6 Hz, 2H), 1.43 (d, J = 6.6 Hz, 3H), 0.87 (s, 9H), 0.11 (s, 3H), 0.10 (s, 3H); ^{13}C NMR δ 119.9,

118.3, 98.5, 97.5, 80.8, 78.7, 61.2, 59.6, 31.0, 25.8, 25.3, 18.2, 16.2, −4.6, −5.1; HRMS (EI) calcd for $C_{13}H_{19}SiO_2$ ($M^+ - C_4H_9$) 235.1154, found 235.1148.

Pyridinium chlorochromate (2.48 g, 11.5 mmol) was added to a stirred solution of (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)-undec-6-ene-4,8-diyn-1-ol (2.80 g, 9.60 mmol) in dichloromethane (50 mL). The resulting reaction mixture was allowed to stir at room temperature for 24 h, upon which the alcohol had been consumed as monitored by TLC. The solvent was removed *in vacuo* and the residue filtered through silica gel using a 2:1 mixture of hexanes/ethyl acetate. The filtrate was evaporated and the residue subjected to radial chromatography (95:5 hexanes/ethyl acetate) to afford **58** as a colorless oil (2.15 g, 77%): TLC R_f 0.54 (2:1 hexanes/ethyl acetate); IR (neat) ν 2955, 2216, 1728, 1256, 1099 cm^{-1}; ^1H NMR δ 9.78 (t, J = 0.9 Hz, 1H), 5.74−5.70 (m, 2H), 4.67 (dq, J = 1.2, 6.6 Hz, 1H), 2.69−2.65 (m, 4H), 1.42 (d, J = 6.6 Hz, 3H), 0.87 (s, 9H), 0.11 (s, 3H), 0.10 (s, 3H); ^{13}C NMR δ 200.2, 119.3, 118.8, 99.0, 95.5, 80.5, 78.9, 59.4, 42.4, 25.7, 25.3, 18.2, 13.0, −4.6, −5.0; HRMS (EI) calcd for $C_{13}H_{17}SiO_2$ ($M^+ - C_4H_9$) 233.0998, found 233.0998.

Preparation of Methyl (*E*,*Z*)-12-Hydroxytrideca-2,8-diene-6,10-diynoate (59). Aldehyde **58** (0.450 g, 1.55 mmol)-was subjected to Horner−Emmons reaction conditions similar to those for the preparation of **11** and **52** using trimethyl phosphonoacetate (0.422 g, 2.32 mmol), acetonitrile (10 mL), lithium chloride (0.131 g, 3.10 mmol), and DBU (0.347 mL, 2.32 mmol). Purification afforded methyl (*E*,*Z*)-12-((*tert*-butyldimethylsilyl)oxy)trideca-2,8-diene-6,10-diynoate as a yellow oil (0.492 g, 92%): TLC R_f 0.65 (2:1 hexanes/ethyl acetate); IR (neat) ν 2953, 2214, 1728, 1660, 1257, 1099 cm^{-1}; ^1H NMR δ 6.96 (dt, J = 15.6, 6.6 Hz, 1H), 5.86 (dt, J = 15.6, 1.5 Hz, 1H), 5.74−5.72 (m, 2H), 4.67 (dq, J = 0.6, 6.6 Hz, 1H), 3.69 (s, 3H), 2.54−2.38 (m, 4H), 1.41 (d, J = 6.6 Hz, 3H), 0.86 (s, 9H), 0.11 (s, 3H), 0.10 (s, 3H); ^{13}C NMR δ 166.7, 146.8, 122.0, 119.5, 118.5, 98.9, 96.1, 80.6, 78.9, 59.4, 51.4, 31.3, 25.7, 25.3, 18.7, 18.2, −4.6, −5.0; HRMS (EI) calcd for $C_{20}H_{30}SiO_3$ (M^+) 346.1964, found 346.1963.

Alcohol **59** was prepared like **51** using (*E*,*Z*)-12-((*tert*-butyldimethylsilyl)oxy)trideca-2,8-diene-6,10-diynoate (0.415 g, 1.20 mmol), dichloromethane (10 mL), and boron trifluoride diethyl etherate (0.440 mL, 3.58 mmol) with stirring for 1 h to afford **59** as a pale yellow oil (0.234 g, 84%): TLC R_f 0.19 (2:1 hexanes/ethyl acetate); IR (neat) ν 3430, 2984, 2211, 1722, 1659, 1285 cm^{-1}; ^1H NMR δ 7.06 (dt, J = 15.6, 6.6 Hz, 1H), 5.89 (dt, J = 15.6, 1.5 Hz, 1H), 5.74−5.71 (m, 2H), 4.66 (dq, J = 1.2, 6.6 Hz, 1H), 3.68 (s, 3H), 3.12 (bs, 1H), 2.55−2.48 (m, 2H), 2.45−2.36 (m, 2H), 1.44 (d, J = 6.6 Hz, 3H); ^{13}C NMR δ 167.2, 147.3, 121.8, 119.7, 118.5, 98.6, 96.2, 80.7, 79.2, 58.4, 51.6, 30.9, 24.0, 18.6; HRMS (EI) calcd for $C_{14}H_{16}O_3$ (M^+) 232.1100, found 232.1102.

Preparation of (*Z*)-11-((*tert*-Butyldimethylsilyl)oxy)-undec-7-ene-5,9-diynal (60). *cis*-Dichloroethylene (4.30 mL, 57.5 mmol) was subjected to palladium-catalyzed coupling reaction conditions similar to those used for the preparation of **58** using tetrakis(triphenylphosphine)palladium(0) (0.092 g, 0.780 mmol), copper(I) iodide (0.350 g, 0.184 mmol), *n*-butylamine (7.70 mL, 78.2 mmol), and 5-hexynol (4.53 g, 46.0 mmol). Purification by radial chromatography (5:1 hexanes/ethyl acetate) provided (*Z*)-8-chlorooct-7-en-5-yn-1-ol as a colorless oil (5.46 g, 75%): TLC R_f 0.22 (2:1 hexanes/ethyl acetate); IR (neat) ν 3345, 2942, 2214, 1335, 1059 cm^{-1}; ^1H NMR δ 6.26 (dt, J = 7.5, 0.6 Hz, 1H), 5.80 (dt, J = 7.5, 2.1 Hz, 1H), 3.63 (t, J = 6.3 Hz, 2H), 2.43−2.36 (m, 2H), 1.94 (s, 1H), 1.73−1.55 (m, 4H); ^{13}C NMR δ 126.9, 112.3, 98.8, 74.9, 62.2, 31.6, 24.7, 19.3; HRMS (EI) calcd for $C_8H_{11}OCl$ (M^+) 158.0499, found 158.0490.

(*Z*)-8-Chlorooct-7-en-5-yn-1-ol (2.00 g, 12.6 mmol) was subjected to palladium-catalyzed coupling reaction conditions similar to those described above using tetrakis(triphenylphosphine)palladium(0) (0.248 g, 0.214 mmol), copper(I) iodide (0.096 g, 0.500 mmol), *n*-butylamine (2.10 mL, 21.4 mmol), and 3-((*tert*-butyldimethylsilyl)oxy)propyne (2.57 g, 15.2 mmol). Purification by radial chromatography (5:1 hexanes/ethyl acetate) afforded (*Z*)-11-((*tert*-butyldimethylsilyl)oxy)undec-7-ene-5,9-diyn-1-ol as a pale yellow oil (2.80 g, 76%): TLC R_f 0.35 (2:1 hexanes/ethyl acetate); IR (neat) ν 3356, 2932, 2214, 1256, 1076, 837 cm^{-1}; ^1H NMR δ 5.76−5.73 (m, 2H), 4.47 (d, J = 1.8 Hz, 2H), 3.64 (t, J = 6.3 Hz, 2H), 2.40 (dt, J = 1.8, 6.6 Hz, 2H), 1.89 (s, 1H), 1.77−1.54 (m, 4H), 0.88 (s, 9H), 0.11 (s, 6H); ^{13}C NMR δ 120.4, 117.9, 98.2, 94.5, 82.3, 78.5, 62.3, 52.3, 31.8, 25.8, 24.7, 19.5, 18.3, −5.2; HRMS (EI) calcd for $C_{17}H_{28}SiO_2$ (M^+) 292.1859, found 292.1852.

(*Z*)-11-((*tert*-Butyldimethylsilyl)oxy)undec-7-ene-5,9-diyn-1-ol (1.00 g, 3.42 mmol) was subjected to PCC oxidation reaction conditions similar to those used for the preparation of **58** using pyridinium chlorochromate (1.10 g, 5.10 mmol). Purification by radial chromatography (95:5 hexanes/ethyl acetate) furnished **60** as a pale yellow oil (0.845 g, 85%): TLC R_f 0.58 (2:1 hexanes/ethyl acetate); IR (neat) ν 2932, 2214, 1726, 1256, 1076, 837 cm^{-1}; ^1H NMR δ 9.78 (t, J = 1.5 Hz, 1H), 5.76−5.73 (m, 2H), 4.46 (d, J = 0.9 Hz, 2H), 2.61 (dt, J = 1.5, 7.2 Hz, 2H), 2.44 (dt, J = 0.6, 7.2 Hz, 2H), 1.85 (quintet, J = 7.2 Hz, 2H), 0.87 (s, 9H), 0.10 (s, 6H); ^{13}C NMR δ 201.7, 119.8, 118.3, 96.8, 94.8, 82.1, 79.1, 52.2, 42.6, 25.8, 20.9, 19.1, 18.2, −5.2; HRMS (EI) calcd for $C_{17}H_{26}SiO_2$ (M^+) 290.1702, found 290.1693.

Preparation of (*Z*)-11-Hydroxy-*N*-(diphenylamino)undec-7-ene-5,9-diyn-1-imine (61). Aldehyde **60** (0.350g, 1.20 mmol) was subjected to reaction conditions similar to those for the preparation of **57** using 1,1-diphenylhydrazine hydrochloride (0.318 g, 1.44 mmol) and pyridine (0.116 mL, 1.44 mmol). Purification was accomplished by radial chromatography (98:2 hexanes/ethyl acetate) to afford (*Z*)-10-((*tert*-butyldimethylsilyl)oxy)-*N*-(diphenylamino)undec-7-ene-5,9-diyn-1-imine as a pale yellow oil (0.505 g, 92%): TLC R_f 0.74 (3:1 hexanes/ethyl acetate); IR (neat) ν 2930, 2214, 1591, 1495, 1211, 1074 cm^{-1}; ^1H NMR δ 7.40−7.32 (m, 4H), 7.15−7.05 (m, 6H), 6.53 (t, J = 5.4 Hz, 1H), 5.79−5.75 (m, 2H), 4.48 (d, J = 1.2 Hz, 2H), 2.49−2.37 (m, 4H), 1.79 (quintet, J = 7.2 Hz, 2H), 0.90 (s, 9H), 0.12 (s, 6H); ^{13}C NMR δ 144.1, 138.3, 129.6, 123.9, 122.2, 120.1, 117.9, 98.0, 94.7, 82.2, 78.5, 52.3, 31.7, 25.9, 25.8, 19.4, 18.2, −5.1; HRMS (EI) calcd for $C_{29}H_{36}SiN_2O$ (M^+) 456.2597, found 456.2590.

(*Z*)-10-((*tert*-Butyldimethylsilyl)oxy)-*N*-(diphenylamino)undec-7-ene-5,9-diyn-1-imine (0.500 g, 1.10 mmol) was subjected to desilylation conditions similar to those used for the preparation of **54** using tetra-*n*-butylammonium fluoride (1.0 M solution in THF, 3.30 mL, 3.30 mmol). Purification was achieved by radial chromatography (3:1 hexanes/ethyl acetate) to provide **61** as a pale yellow oil (0.358 g, 95%): TLC R_f 0.19 (3:1 hexanes/ethyl acetate); IR (neat) ν 3387, 2933, 2212, 1591, 1495, 1211, 1092 cm^{-1}; ^1H NMR δ 7.40−7.32 (m, 4H), 7.15−7.05 (m, 6H), 6.55 (t, J = 5.4 Hz, 1H), 5.81−5.77 (m, 2H), 4.38 (dd, J = 6.6, 1.2 Hz, 2H), 2.53−2.42 (m, 5H), 1.76 (quintet, J = 7.2 Hz, 2H); ^{13}C NMR δ 144.1, 139.4, 129.6, 124.0, 122.4, 120.5, 117.9, 98.1, 94.5, 82.8, 78.7, 51.4, 31.4, 25.7, 19.2; HRMS (EI) calcd for $C_{23}H_{22}N_2O$ (M^+) 342.1732, found 342.1744.

General Procedure for the [2,3] Sigmatropic Rearrangement Reaction of the Enediyne Substrates 51−57, 59, and 61. To a stirred solution of the respective enediyne in dichloromethane (≈0.02 M) at −78° C were added triethylamine (2.0 equiv) and chlorodiphenylphosphine (1.5 equiv) *via* syringe. After being stirred at −78 °C under nitrogen for 30 min, the reaction mixture was allowed to warm up to 0 °C and stirred for an additional 30 min. The mixture was then concentrated *in vacuo* at 0 °C, and the residue was dissolved in diethyl ether (60 mL). The solution was washed with 10% aqueous sodium bicarbonate (3 × 50 mL). The combined organic layers were dried over anhydrous magnesium sulfate, filtered, and evaporated *in vacuo* at 0 °C to provide the respective crude enyne allene as a yellow oil.

General Procedure for the Tandem Enyne Allene−Radical Cyclization Reaction of the Enyne Allene Substrates 62−67, 73, 74, and 78. The respective crude enyne allene was dissolved in anhydrous benzene (6.0 mL), and the resulting solution was transferred to a predried high-pressure vial. The reaction mixture was degassed by passing dry nitrogen through the solution for 20 min, and 1,4-CHD (3.00 mL, 31.7 mmol, 3.5 M) was added *via* syringe. The reaction vial was sealed under nitrogen with a nylon screw cap and heated to 37 °C for 12 h, upon which the starting material

had been consumed on the basis of TLC. The reaction mixture was concentrated *in vacuo*, and the residue was filtered through a small amount of silica gel using a 1:4 mixture of hexanes/ethyl acetate. The filtrate was evaporated, and the residue was subjected to radial chromatography to provide the respective 2,3-dihydroindene or 1,2,3,4-tetrahydronaphthalene derivatives.

Preparation of Methyl 2,3-Dihydro-5-(diphenylphosphinyl)-4-methylindene-1-acetate (68). Enyne allene ester **62** was prepared from **51** (0.050 g, 0.23 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.064 mL, 0.46 mmol) and chlorodiphenylphosphine (0.061 mL, 0.34 mmol) in dichloromethane (10 mL). Crude allene **62** was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was achieved by radial chromatography (1:2 hexanes/ethyl acetate) to provide **68** as a pale yellow oil (0.063 g, 68% from **51**): TLC R_f 0.30 (1:4 hexanes/ethyl acetate); IR (neat) ν 2955, 1736, 1190, 1170, 752 cm^{-1}; ^{1}H NMR δ 7.67−7.57 (m, 4H), 7.54−7.38 (m, 6H), 6.90 (dd, J = 7.8, 2.4 Hz, 1H), 6.82 (dd, J = 13.8, 7.8 Hz, 1H), 3.67 (s, 3H), 3.65−3.52 (m, 1H), 2.85 (ddd, J = 16.2, 8.7, 4.8 Hz, 1H), 2.81−2.69 (m, 1H), 2.69 (dd, J = 15.6, 6.0 Hz, 1H), 2.46−2.33 (m, 2H), 2.32 (s, 3H), 1.73 (m, 1H); ^{13}C NMR δ 172.8, 149.8 (d, J_{PC} = 2.6 Hz), 145.0 (d, J_{PC} = 11.3 Hz), 139.0 (d, J_{PC} = 8.8 Hz), 133.9, 132.5 (d, J_{PC} = 14.0 Hz), 131.8 (d, J_{PC} = 9.8 Hz), 131.5 (d, J_{PC} = 2.6 Hz), 129.8, 128.4 (d, J_{PC} = 11.9 Hz), 120.1 (d, J_{PC} = 14.4 Hz), 51.6, 41.6, 39.4, 31.5, 29.9, 18.3 (d, J_{PC} = 5.2 Hz); ^{31}P NMR (121 MHz, $CDCl_3$) d 32.4; HRMS (EI) calcd for $C_{25}H_{25}PO_3$ (M^+) 404.1541, found 404.1549.

Preparation of Methyl α-Methyl-2,3-dihydro-5-(diphenylphosphinyl)-4-methylindene-1-acetate (69a,b). Enyne allene **63** was prepared from **52** (0.080 g, 0.34 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.095 mL, 0.68 mmol) and chlorodiphenylphosphine (0.091 mL, 0.51 mmol) in dichloromethane (18 mL). Crude allene **63** was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was accomplished by radial chromatography (1:2 hexanes/ethyl acetate) to afford **69a**,**b** as a pale yellow oil (0.101 g, 3.5:1 diastereomeric mixture, 70% combined yield from **52**): TLC R_f 0.32 (1:4 hexanes/ethyl acetate); IR (neat) ν 2953, 1732, 1437, 1192, 1170 cm^{-1}; ^{1}H NMR major isomer δ 7.66−7.56 (m, 4H), 7.53−7.38 (m, 6H), 6.91 (dd, J = 7.8, 2.1 Hz, 1H), 6.82 (dd, J = 13.8, 7.8 Hz, 1H), 3.61 (s, 3H), 3.59−3.42 (m, 1H), 2.90−2.62 (m, 3H), 2.31 (s, 3H), 2.29−2.08 (m, 1H), 1.89 (m, 1H), 1.09 (d, J = 7.2 Hz, 3H); minor isomer δ 7.66−7.56 (m, 4H), 7.53−7.38 (m, 6H), 6.91 (dd, J = 7.8, 2.1 Hz, 1H), 6.82 (dd, J = 13.8, 7.8 Hz, 1H), 3.65 (s, 3H), 3.59−3.42 (m, 1H), 2.90−2.62 (m, 3H), 2.31 (s, 3H), 2.29−2.08 (m, 1H), 1.89 (m, 1H), 1.01 (d, J = 7.2 Hz, 3H); ^{13}C NMR major isomer δ 175.9, 148.2 (d, J_{PC} = 2.6 Hz), 145.6 (d, J_{PC} = 10.9 Hz), 138.8 (d, J_{PC} = 8.8 Hz), 133.8, 132.4 (d, J_{PC} = 14.0 Hz), 131.8 (d, J_{PC} = 9.3 Hz), 131.5 (d, J_{PC} = 2.6 Hz), 129.7, 128.4 (d, J_{PC} = 11.9 Hz), 121.6 (d, J_{PC} = 14.0 Hz), 51.5, 47.9, 42.5, 29.9, 29.1, 18.3 (d, J_{PC} = 5.1 Hz), 14.2; minor isomer δ 176.0, 148.9 (d, J_{PC} = 2.6 Hz), 145.5 (d, J_{PC} = 10.9 Hz), 138.9 (d, J_{PC} = 8.8 Hz), 133.9, 132.4 (d, J_{PC} = 14.0 Hz), 131.7 (d, J_{PC} = 9.2 Hz), 131.5 (d, J_{PC} = 2.6 Hz), 129.7, 128.4 (d, J_{PC} = 11.9 Hz), 120.3 (d, J_{PC} = 14.0 Hz), 51.6, 47.3, 42.6, 30.3, 26.8, 18.3 (d, J_{PC} = 5.1 Hz), 12.7; ^{31}P NMR major isomer δ 32.6; minor isomer δ 32.6; HRMS (EI) calcd for $C_{26}H_{27}PO_3$ (M^+) 418.1698, found 418.1695.

Preparation of Methyl α-Methyl-2,3-dihydro-5-(diphenylphosphinyl)-4-methylindene-1-acetate (69a,b). Enyne allene ester **64** was prepared from **53** (0.055 g, 0.24 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.066 mL, 0.47 mmol) and chlorodiphenylphosphine (0.064 mL, 0.36 mmol) in dichloromethane (12 mL). Crude allene **64** was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was achieved by radial chromatography (1:2 hexanes/ethyl acetate) to provide **69a**,**b** as a pale yellow oil (0.066 g, 3.5:1 diastereomeric mixture, 67% combined yield from **53**).

Preparation of 2-[2,3-Dihydro-5-(diphenylphosphinyl)-4-methylindenyl]ethyl Acetate (70). Enyne allene **65** was prepared from **54** (0.100 g, 0.431 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.120 mL, 0.860 mmol) and chlorodiphenylphosphine (0.115 mL, 0.640 mmol) in dichloromethane (20 mL). Crude allene **65** was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was achieved by radial chromatography (1:3 hexanes/ethyl acetate) to provide **70** as a pale yellow oil (0.112 g, 62% from **54**): TLC R_f 0.27 (1:4 hexanes/ethyl acetate); IR (neat) ν 2955, 2220, 1738, 1242 cm^{-1}; ^{1}H NMR δ 7.68−7.57 (m, 4H), 7.55−7.39 (m, 6H), 6.92 (dd, J = 7.8, 2.4 Hz, 1H), 6.82 (dd, J = 13.8, 7.8 Hz, 1H), 4.15 (t, J = 6.9 Hz, 2H), 3.20 (m, 1H), 2.87 (ddd, J = 16.2, 8.7, 4.8 Hz, 1H), 2.80−2.65 (m, 1H), 2.37−2.24 (m, 1H), 2.32 (s, 3H), 2.11 (m, 1H), 2.03 (s, 3H), 1.78−1.64 (m, 2H); ^{13}C NMR δ 171.1, 150.7 (d, J_{PC} = 2.1 Hz), 145.0 (d, J_{PC} = 11.3 Hz), 138.9 (d, J_{PC} = 8.7 Hz), 133.9 (d, J_{PC} = 3.6 Hz), 132.4 (d, J_{PC} = 14.0 Hz), 131.8 (d, J_{PC} = 9.2 Hz), 131.5 (d, J_{PC} = 3.1 Hz), 129.5, 128.4 (d, J_{PC} = 12.4 Hz), 120.2 (d, J_{PC} = 14.4 Hz), 62.8, 42.0, 33.4, 31.2, 30.1, 21.0, 18.4 (d, J_{PC} = 5.2 Hz); ^{31}P NMR δ 32.5; HRMS (EI) calcd for $C_{26}H_{26}PO_3$ (M^+ − H) 417.1620, found 417.1624.

Preparation of 2,3-Dihydro-5-(diphenylphosphinyl)-1-(methoxymethyl)-4-methylindene (71). Enyne allene **66** was prepared from **55** (0.080 g, 0.42 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.117 mL, 0.840 mmol) and chlorodiphenylphosphine (0.113 mL, 0.630 mmol) in dichloromethane (20 mL). The crude allene was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was accomplished by radial chromatography (1:3 hexanes/ethyl acetate) to furnish **71** as a pale yellow oil (0.087 g, 55% from **55**): TLC R_f 0.28 (1:4 hexanes/ethyl acetate); IR (neat) ν 2968, 1437, 1190, 1117, 752 cm^{-1}; ^{1}H NMR δ 7.68−7.57 (m, 4H), 7.54−7.39 (m, 6H), 7.03 (dd, J = 7.8, 2.4 Hz, 1H), 6.82 (dd, J = 13.8, 7.8 Hz, 1H), 3.57−3.35 (m, 3H), 3.34 (s, 3H), 2.93−2.70 (m, 2H), 2.32 (s, 3H), 2.31−2.17 (m, 1H), 1.85 (m, 1H); ^{13}C NMR δ 148.9 (d, J_{PC} = 2.6 Hz), 145.5 (d, J_{PC} = 11.4 Hz), 138.8 (d, J_{PC} = 8.8 Hz), 134.0, 132.4 (d, J_{PC} = 14.0 Hz), 131.8 (d, J_{PC} = 9.8 Hz), 131.5 (d, J_{PC} = 3.1 Hz), 129.7, 128.4 (d, J_{PC} = 11.9 Hz), 121.0 (d, J_{PC} = 14.5 Hz), 76.0, 58.9, 45.6, 30.1, 28.1, 18.4 (d, J_{PC} = 5.2 Hz); ^{31}P NMR δ 32.5; HRMS (EI) calcd for $C_{24}H_{25}PO_2$ (M^+) 376.1592, found 376.1608.

Preparation of Methyl 2,3-Dihydro-5-(diphenylphosphinyl)-4-ethylindene-1-acetate (72). Enyne allene **67** was prepared from **59** (0.060 g, 0.26 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.072 mL, 0.52 mmol) and chlorodiphenylphosphine (0.070 mL, 0.39 mmol) in dichloromethane (13 mL). The crude allene was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was achieved by radial chromatography (1:1 hexanes/ethyl acetate) to afford **72** as a pale yellow oil (0.056 g, 52% from **59**): TLC R_f 0.35 (1:4 hexanes/ethyl acetate); IR (neat) ν 2971, 1736, 1437, 1188 cm^{-1}; ^{1}H NMR δ 7.67−7.58 (m, 4H), 7.54−7.38 (m, 6H), 6.91 (dd, J = 7.8, 2.4 Hz, 1H), 6.84 (dd, J = 13.8, 7.8 Hz, 1H), 3.68 (s, 3H), 3.64−3.51 (m, 1H), 2.98−2.77 (m, 4H), 2.72 (dd, J = 15.6, 5.7 Hz, 1H), 2.43 (dd, J = 15.6, 8.7 Hz, 1H), 2.42−2.32 (m, 1H), 1.72 (m, 1H), 0.87 (t, J = 7.5 Hz, 3H); ^{13}C NMR δ 172.9, 150.4 (d, J_{PC} = 2.1 Hz), 145.4 (d, J_{PC} = 9.2 Hz), 144.8 (d, J_{PC} = 10.9 Hz), 134.4, 132.7 (d, J_{PC} = 14.0 Hz), 131.9 (d, J_{PC} = 9.8 Hz), 131.5 (d, J_{PC} = 2.6 Hz), 129.5, 128.3 (d, J_{PC} = 11.9 Hz), 120.2 (d, J_{PC} = 14.5 Hz), 51.6, 41.4, 39.3, 31.9, 29.4, 25.6 (d, J_{PC} = 5.2 Hz), 13.5; ^{31}P NMR δ 32.3; HRMS (EI) calcd for $C_{26}H_{27}PO_3$ (M^+) 418.1698, found 418.1689.

Preparation of *N*-(phenylmethoxy)-2,3-dihydro-5-(diphenylphosphinyl)-4-methylindene-1-amine (75). Enyne allene **73** was prepared from **56** (0.100 g, 0.370 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.103 mL, 0.740 mmol) and chlorodiphenylphosphine (0.100 mL, 0.560 mmol) in dichloromethane (18 mL). Crude **73** was then subjected to

thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was accomplished by radial chromatography (1:2 hexanes/ethyl acetate) to produce **75** as a pale yellow oil (0.042 g, 25% from **56**): TLC R_f 0.14 (1:4 hexanes/ethyl acetate); IR (neat) ν 2972, 1437, 1190, 752 cm^{-1}; ^{1}H NMR δ 7.67−7.58 (m, 4H), 7.56−7.39 (m, 6H), 7.35−7.25 (m, 5H), 7.19 (dd, J = 7.8, 2.1 Hz, 1H), 6.86 (dd, J = 14.1, 7.8 Hz, 1H), 5.70 (bs, NH), 4.67 (s, 2H), 4.60 (dd, J = 7.8, 5.1 Hz, 1H), 2.93 (ddd, J = 16.5, 8.7, 5.7 Hz, 1H), 2.75 (ddd, J = 16.5, 8.7, 5.4 Hz, 1H), 2.38−2.33 (m, 1H), 2.33 (s, 3H), 2.02 (m, 1H); ^{13}C NMR δ 146.4, 145.6 (d, J_{PC} = 11.3 Hz), 139.3 (d, J_{PC} = 8.8 Hz), 137.6, 133.8 (d, J_{PC} = 4.7 Hz), 132.4 (d, J_{PC} = 14.0 Hz), 131.8 (d, J_{PC} = 9.8 Hz), 131.6 (d, J_{PC} = 3.1 Hz), 129.6, 128.5 (d, J_{PC} = 11.3 Hz), 128.4, 128.3, 127.8, 121.8 (d, J_{PC} = 14.5 Hz), 76.6, 66.0, 29.4, 29.4, 18.2 (d, J_{PC} = 5.2 Hz); ^{31}P NMR δ 32.5; HRMS (EI) calcd for $C_{29}H_{28}NPO_2$ (M^+) 453.1858, found 453.1852.

Preparation of *N*-(Diphenylamino)-2,3-dihydro-5-(diphenylphosphinyl)-4-methylindene-1-amine (76). Enyne allene **74** was prepared from **57** (0.100 g, 0.300 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.063 mL, 0.45 mmol) and chlorodiphenylphosphine (0.065mL, 0.36 mmol) in dichloromethane (15 mL). Crude allene **74** was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was achieved by radial chromatography (1:2 hexanes/ethyl acetate) to furnish **76** as a pale yellow oil (0.090 g, 58% from **57**): TLC R_f 0.17 (1:4 hexanes/ethyl acetate); IR (neat) ν 3378, 2940, 1589, 1495, 1192 cm^{-1}; ^{1}H NMR δ 7.68−7.57 (m, 4H), 7.57−7.39 (m, 6H), 7.30−7.22 (m, 4H), 7.12−6.94 (m, 7H), 6.82 (dd, J = 14.1, 7.8 Hz, 1H), 4.51 (dd, J = 6.6, 3.6 Hz, 1H), 4.17 (bs, 1H), 3.15−3.00 (m, 1H), 2.79 (ddd, J = 15.9, 8.4, 4.5 Hz, 1H), 2.39 (s, 3H), 2.25−1.98 (m, 2H); ^{13}C NMR δ 147.7, 147.2 (d, J_{PC} = 2.6 Hz), 145.9 (d, J_{PC} = 11.3 Hz), 139.3 (d, J_{PC} = 8.3 Hz), 133.8 (d, J_{PC} = 2.6 Hz), 132.5 (d, J_{PC} = 14.0 Hz), 131.8 (d, J_{PC} = 9.8 Hz), 131.6 (d, J_{PC} = 2.6 Hz), 129.5, 129.0, 128.4 (d, J_{PC} = 11.9 Hz), 122.3, 121.4 (d, J_{PC} = 13.9 Hz), 120.3, 62.2, 30.7, 29.6, 18.4 (d, J_{PC} = 4.7 Hz); ^{31}P NMR δ 32.5; HRMS (EI) calcd for $C_{34}H_{31}N_2PO$ (M^+) 514.2174, found 514.2168.

Preparation of *N*-(Diphenylamino)-6-(diphenylphosphinyl)-5-methyl-1,2,3,4-tetrahydronaphthalene-1-amine (79). Enyne allene **78** was prepared from **77** (0.100 g, 0.290 mmol) according to the general procedure for the [2,3] sigmatropic rearrangement reaction using triethylamine (0.061 mL, 0.44 mmol) and chlorodiphenylphosphine (0.063 mL, 0.35 mmol) in dichloromethane (15 mL). Crude allene **78** was then subjected to thermolysis according to the general procedure for the tandem enyne allene−radical cyclization. Purification was acomplished by radial chromatography (1:1 hexanes/ethyl acetate) to afford **79** as a pale yellow oil (0.034 g, 22% from **77**): TLC R_f 0.25 (1:4 hexanes/ethyl acetate); IR (neat) ν 3378, 2944, 1590, 1485, 1192 cm^{-1}; ^{1}H NMR δ 7.65−7.56 (m, 4H), 7.54−7.38 (m, 6H), 7.32−7.10 (m, 8H), 7.03−6.96 (m, 2H), 6.78−6.70 (m, 2H), 3.97 (m, 1H), 2.87−2.76 (m, 1H), 2.53−2.38 (m, 1H), 2.36 (s, 3H), 2.34−2.10 (m, 2H), 1.90−1.80 (m, 1H), 1.54 (m, 1H); ^{13}C NMR δ 148.1, 142.1 (d, J_{PC} = 8.3 Hz), 139.8 (d, J_{PC} = 2.6 Hz), 139.2 (d, J_{PC} = 10.3 Hz), 133.8 (d, J_{PC} = 18.1 Hz), 132.5 (d, J_{PC} = 20.1 Hz), 131.9 (d, J_{PC} = 9.8 Hz), 131.6 (d, J_{PC} = 6.2 Hz), 130.8 (d, J_{PC} = 13.4 Hz), 129.2, 128.5 (d, J_{PC} = 11.9 Hz), 126.3 (d, J_{PC} = 13.4 Hz), 122.5, 120.6, 54.3, 26.9, 25.0, 18.4 (d, J_{PC} = 6.2 Hz), 18.0; ^{31}P NMR δ 32.9; HRMS (EI) calcd for $C_{35}H_{33}N_2PO$ (M^+) 528.2330, found 528.2336.

Preparation of 1-Ethynyl-2-[3-(phenylsulfonyl)-1-propynyl]benzene (81). 3-(2-Ethynylphenyl)-2-propyn-1-ol (**36**) (0.145 g, 0.93 mmol) was dissolved in 4 mL of dichloromethane, and the solution was cooled to 0 °C under nitrogen. To this solution was added triethylamine (0.181 mL, 0.132 g, 1.30 mmol) *via* syringe. Then methanesulfonyl chloride (0.093 mL, 0.138 g, 1.21 mmol) was added slowly *via* syringe and the reaction mixture was stirred for 1 h at room temperature. The solvent was removed *in vacuo* and the residue passed through a short silica gel column with a 1:1 mixture of hexanes/ethyl acetate. Purification of the crude product by radial chromatography with a 90:10 mixture of hexanes/ethyl acetate afforded 0.204 g (94%) of 3-(2-ethynylphenyl)-2-propynyl methanesulfonate as a pale yellow oil: TLC R_f 0.24 (3:1 hexanes/ethyl acetate); IR (neat) ν 3285, 3065, 3028, 2940, 2239, 2110 cm^{-1}; ^{1}H NMR δ 3.18 (3H, s), 3.31 (1H, s), 5.12 (2H, s), 7.31 (2H, m), 7.42−7.47 (1H, m), 7.47−7.53 (1H, m); ^{13}C NMR δ 132.7, 132.3, 129.1, 128.6, 124.9, 124.0, 87.5, 84.6, 81.7, 81.6, 58.4, 39.4; HRMS (EI) calcd for $C_{12}H_{10}O_3S$ (M^+) 234.0351, found 234.0367.

To a solution of thiophenol (0.123 mL, 0.132 g, 1.20 mmol) in 10 mL of THF was added at room temperature a 15.1 M aqueous sodium hydroxide solution (0.080 mL, 0.048 g, 1.20 mmol). Then a solution of 3-(2-ethynylphenyl)-2-propynyl methanesulfonate (0.200 g, 0.85 mmol) in 5 mL of THF was added slowly *via* syringe and the reaction mixture was vigorously stirred for 1 h. The solvent was removed *in vacuo* and the residue passed through a short silica gel column with dichloromethane. Purification of the crude product by radial chromatography with hexanes afforded 0.200 g (94%) of 1-ethynyl-2-[3-(phenylthio)-1-propynyl]benzene as a pale yellow oil: TLC R_f 0.56 (3:1 hexanes/ethyl acetate); IR (neat) ν 3287, 3061, 2957, 2911, 2245, 2108, 1479, 1441 cm^{-1}; ^{1}H NMR δ 3.16 (1H, s), 3.89 (2H, s), 7.20−7.25 (3H, m), 7.27−7.36 (3H, m), 7.43−7.46 (1H, m), 7.50−7.54 (2H, m); ^{13}C NMR δ 135.3, 132.4, 132.1, 130.1, 128.9, 128.4, 127.8, 126.7, 125.9, 124.5, 89.5, 81.9, 81.8, 80.9, 23.6; HRMS (EI) calcd for $C_{17}H_{12}S$ (M^+) 248.0660, found 248.0668.

m-Chloroperbenzoic acid (0.229 g, 1.33 mmol) was dissolved in 10 mL of dichloromethane, and the solution was cooled to 0 °C. To this mixture was added *via* syringe a solution of 1-ethynyl-2-[3-(phenylthio)-1-propynyl]benzene (0.150 g, 0.60 mmol) in 3 mL of dichloromethane, and the reaction mixture was stirred for 1 h at 0 °C. Then the solution was passed through a short Florisil column with dichloromethane. The crude product was purified by radial chromatography with an 80:20 mixture of hexanes/ethyl acetate to afford 0.164 g (97%) of **81** as a pale yellow oil: TLC R_f 0.22 (3:1 hexanes/ethyl acetate); IR (neat) ν 3283, 3063, 2953, 2907, 2230, 2108, 1323, 1138 cm^{-1}; ^{1}H NMR δ 3.17 (1H, s), 4.24 (2H, s), 7.25−7.28 (2H, m), 7.30−7.34 (1H, m), 7.43−7.46 (1H, m), 7.52−7.58 (2H, m), 7.63−7.69 (1H, m), 8.02−8.06 (2H, m); ^{13}C NMR δ 137.8, 134.1, 132.6, 132.3, 129.1, 129.0, 128.7, 128.5, 124.8, 124.6, 85.8, 81.5, 81.4, 80.7, 49.5; HRMS (EI) calcd for $C_{17}H_{12}O_2S$ (M^+) 280.0558, found 280.0579.

Preparation of 2-[(Phenylsulfonyl)methyl]naphthalene (82) *via* Tandem Acetylene Isomerization−Enyne Allene Cyclization of 1-Ethynyl-2-[3-(phenylsulfonyl)-1-propynyl]benzene (81). A stirred solution of 1-ethynyl-2-[3-(phenylsulfonyl)-1-propynyl]benzene (**81**) (0.075 g, 0.27 mmol) in 4.8 mL of anhydrous benzene in a pressure vial was degassed with dry nitrogen for 30 min. Then triethylamine (0.186 mL, 0.135 g, 1.34 mmol) and 1,4-CHD (2.480 mL, 2.101 g, 26.21 mmol) were added *via* syringe and the vial was sealed with a Teflon screw cap. The reaction mixture was heated at 30 °C for 11 h. The volatile components were removed *in vacuo*, and the residue was passed through a short silica gel column with a 1:1 mixture of hexanes/ethyl acetate. Subjecting the crude product to radial chromatography with an 80:20 mixture of hexanes/ethyl acetate yielded 0.051 g (68%) of **82** as a colorless solid: TLC R_f 0.22 (3:1 hexanes/ethyl acetate); IR ν 3052, 2932, 2857, 1377, 1150 cm^{-1}; ^{1}H NMR δ 4.45 (2H, s), 7.18 (1H, dd, J = 8.3, 2.0 Hz), 7.36−7.43 (2H, m), 7.46 (2H, m), 7.51 (1H, s), 7.54−7.60 (1H, m), 7.60−7.63 (2H, m), 7.67−7.74 (2H, m), 7.77−7.81 (1H, m); ^{13}C NMR δ 137.8, 133.7, 133.0, 133.0, 130.5, 128.9, 128.6, 128.3, 127.9, 127.8, 127.6, 126.7, 126.4, 125.5, 63.0; HRMS (EI) calcd for $C_{17}H_{14}O_2S$ (M^+) 282.0744, found 282.0729. Anal. Calcd for $C_{17}H_{14}O_2S$: C, 72.31; H, 5.00; S, 11.36. Found: C, 72.39; H, 5.06; S, 11.44.

Preparation of 5-[2-[3-(Phenylthio)-1-propynyl]phenyl]-4-pentynal (83). 3-(2-Iodophenyl)-2-propyn-1-ol (**8**) (1.001 g, 3.88 mmol) was subjected to coupling conditions similar to those for the preparation of **8** using triethylamine (1.622 mL, 1.178 g, 11.64 mmol), bis(triphenylphosphine)palladium(II) chloride (0.082 g, 0.12 mmol), copper(I) iodide (0.074 g, 0.39 mmol), and 5-((*tert*-butyldimethylsilyl)oxy)-1-pentyne (0.923 g, 4.65 mmol) Purification by radial chromatography with a 90:10 mixture of hexanes/diethyl ether afforded 1.249 g (98%) of 3-[2-5-((*tert*-butyldimethylsilyl)oxy)-1-pentynyl)phenyl]-2-pro-

pyn-1-ol as a pale yellow oil: TLC R_f 0.36 (3:1 hexanes/ethyl acetate); IR (neat) ν 3385 (br), 3063, 2953, 2930, 2859, 2247, 2232 cm^{-1}; ^{1}H NMR δ 0.06 (6H, s), 0.89 (9H, s), 1.84 (2H, q, J = 6.6 Hz), 2.42 (1H, s, br), 2.51 (2H, t, J = 6.8 Hz), 3.84 (2H, t, J = 6.5 Hz), 4.50 (2H, s), 7.16−7.24 (2H, m), 7.34−7.40 (2H, m); ^{13}C NMR δ 131.8, 131.5, 128.0, 127.2, 126.4, 125.1, 94.0, 91.0, 84.2, 79.6, 61.9, 51.4, 31.6, 25.9, 18.3, 15.9, −5.3; HRMS (EI) calcd for $C_{19}H_{25}O_2Si$ ($M^+ - CH_3$) 313.1624, found 313.1619.

This compound was prepared by a mesylation reaction similar to that used for the preparation of **81** using 3-[2-(5-((*tert*-butyldimethylsilyl)oxy)-1-pentynyl)phenyl]-2-propyn-1-ol (0.400 g, 1.22 mmol), dichloromethane (10 mL), triethylamine (0.238 mL, 0.172 g, 1.70 mmol), and methanesulfonyl chloride (0.123 mL, 0.181 g, 1.58 mmol) Purification afforded 0.465 g (94%) of 3-[2-((5-(*tert*-butyldimethylsilyl)oxy)-1-pentynyl)phenyl]-2-propynyl methanesulfonate as a pale yellow oil: TLC R_f 0.38 (3:1 hexanes/ethyl acetate); IR (neat) ν 3063, 3028, 2953, 2932, 2895, 2232, 1366, 1177 cm^{-1}; ^{1}H NMR δ 0.05 (6H, s), 0.89 (9H, s), 1.81 (2H, m), 2.53 (2H, t, J = 7.1 Hz), 3.18 (3H, s), 3.75 (2H, t, J = 6.1 Hz), 5.11 (2H, s), 7.19−7.31 (2H, m), 7.38−7.43 (2H, m); ^{13}C NMR δ 132.2, 132.1, 129.1, 127.3, 127.0, 123.3, 95.0, 88.3, 83.9, 78.9, 61.5, 58.5, 39.2, 31.7, 25.9, 18.3, 16.0, −5.4.

To a solution of thiophenol (0.148 mL, 0.159 g, 1.45 mmol) in 20 mL of THF was added at room temperature a 15.1 M aqueous sodium hydroxide solution (0.096 mL, 0.058 g, 1.45 mmol). Then a solution of 3-[2-(5-((*tert*-butyldimethylsilyl)-oxy)-1-pentynyl)phenyl]-2-propynyl methanesulfonate (0.420 g, 1.03 mmol) in 5 mL of THF was added slowly *via* syringe and the reaction mixture was vigorously stirred for 1 h. The solvent was removed *in vacuo* and the residue passed through a silica gel column with dichloromethane. Purification of the crude product by radial chromatography with hexanes afforded 0.422 g (97%) of 1-[5-((*tert*-butyldimethylsilyl)oxy)-1-pentynyl]-2-[3-(phenylthio)-1-propynyl]benzene as a pale yellow oil: TLC R_f 0.66 (3:1 hexanes/ethyl acetate); IR (neat) ν 3061, 2951, 2930, 2897, 2857, 2230, 1479, 1441 cm^{-1}; ^{1}H NMR δ 0.05 (6H, s), 0.88 (9H, s), 1.78 (2H, q, J = 6.5 Hz), 2.47 (2H, t, J = 7.1 Hz), 3.73 (2H, t, J = 6.1 Hz), 3.88 (2H, s), 7.17 (2H, m), 7.22−7.25 (1H, m), 7.28−7.36 (4H, m), 7.49−7.53 (2H, m); ^{13}C NMR δ 135.5, 132.0, 131.7, 130.1, 128.9, 127.8, 127.1, 126.7, 126.5, 125.2, 94.2, 88.7, 82.5, 79.3, 61.7, 31.8, 25.9, 23.9, 18.3, 16.0, −5.3; HRMS (EI) calcd for $C_{26}H_{32}OSSi$ (M^+) 420.1943, found 420.1962.

To a solution of 1-[5-((*tert*-butyldimethylsilyl)oxy)-1-pentynyl]-2-[3-(phenylthio)-1-propynyl]benzene (0.410 g, 0.97 mmol) were added 6 mL of acetic acid, 2 mL of water, and 2 mL of THF, and the reaction mixture was stirred at room temperature, until no starting material could be detected by TLC (4−7 h). Then THF was removed *in vacuo*, 25 mL of water and 25 mL of dichloromethane were added to the residue, and the organic layer was washed several times with sodium bicarbonate. The aqueous layer was extracted twice with dichloromethane (20 mL each). The organic layers were combined, dried over magnesium sulfate, and concentrated. The residue was subjected to radial chromatography with a 70:30 mixture of hexanes/diethyl ether to afford 0.272 g (91%) of 5-[2-[3-(phenylthio)-1-propynyl]phenyl]-4-pentyn-1-ol as a pale yellow oil: TLC R_f 0.15 (3:1 hexanes/ethyl acetate); IR (neat) ν 3378 (br), 3059, 3022, 2945, 2878, 2228, 1481, 1441 cm^{-1}; ^{1}H NMR δ 1.62 (1H, s), 1.82 (2H, q, J = 6.5 Hz), 2.52 (2H, t, J = 6.7 Hz), 3.82 (2H, t, J = 6.1 Hz), 3.89 (2H, s), 7.18 (2H, m), 7.22−7.25 (1H, m), 7.28−7.36 (4H, m), 7.49−7.53 (2H, m); ^{13}C NMR δ 135.3, 132.0, 131.7, 130.1, 128.9, 127.8, 127.2, 126.8, 126.1, 125.1, 93.5, 88.7, 82.5, 79.8, 61.5, 31.1, 23.8, 16.1; HRMS (EI) calcd for $C_{20}H_{18}OS$ (M^+) 306.1078, found 306.1097.

A dry 25 mL flask under nitrogen was charged with a solution of oxalyl chloride in dichloromethane (2 M) (0.605 mL, 0.153 g, 1.21 mmol) and 15 mL of dichloromethane. This solution was cooled to −78 °C. Then a solution of dimethyl sulfoxide (0.172 mL, 0.189 g, 2.42 mmol) in 3 mL of dichloromethane was slowly added *via* syringe and the mixture was stirred for 15 min. Then a solution of 5-[2-[3-(phenylthio)-1-propynyl]phenyl]-4-pentyn-1-ol (0.285 g, 0.93 mmol) in 5 mL of dichloromethane was slowly added *via* syringe, and the reaction mixture was stirred for an additional 25 min, before triethylamine (0.648 mL, 0.471 g, 4.65 mmol) was added at once *via* syringe. The mixture was stirred for 1 h at −78 °C and then allowed to warm to 0 °C, and 2 mL of a saturated ammonium chloride solution was added. After the mixture was extracted three times with dichloromethane, the organic layers were combined and dried over magnesium sulfate. The crude product was subjected to radial chromatography with a 90:10 mixture of hexanes/ethyl acetate to afford 0.260 g (92%) of **83** as a pale yellow oil: TLC R_f 0.33 (3:1 hexanes/ethyl acetate); IR (neat) ν 3059, 2909, 2827, 2729, 2231, 1725, 1481, 1439 cm^{-1}; ^{1}H NMR δ 2.67 (4H, s), 3.89 (2H, s), 7.16−7.24 (3H, m), 7.27−7.36 (4H, m), 7.48−7.53 (2H, m), 9.77 (1H, s); ^{13}C NMR δ 200.5, 135.4, 131.9, 131.7, 129.9, 128.9, 127.8, 127.4, 126.7, 125.8, 125.3, 91.9, 88.9, 82.3, 80.0, 42.4, 23.7, 12.8; HRMS (EI) calcd for $C_{20}H_{16}OS$ (M^+) 304.0922, found 304.0936.

Preparation of Methyl (*E*)-7-[2-[3-(Phenylsulfonyl)-1-propynyl]phenyl]hept-2-en-6-ynoate (84). Trimethyl phosphonoacetate (0.136 mL, 0.153 g, 0.84 mmol) was dissolved in 4 mL of acetonitrile. To this solution were added under nitrogen lithium chloride (0.047 g, 1.12 mmol) and 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) (0.125 mL, 0.128 g, 0.84 mmol), and the reaction mixture was stirred at room temperature for 15 min. Then a solution of 5-[2-[3-(phenylthio)-1-propynyl]phenyl]-4-pentynal (**83**) (0.170 g, 0.56 mmol) in 2 mL of acetonitrile was added *via* syringe and the reaction stirred for 1 min. The reaction mixture was passed through a short silica gel column with a 1:1 mixture of hexanes/ethyl acetate. Purification of the crude product by radial chromatography with a 97:3 mixture of hexanes/ethyl acetate afforded 0.165 g (82%) of (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-ynoate as a pale yellow oil: TLC R_f 0.42 (3:1 hexanes/ethyl acetate); IR (neat) ν 3059, 3023, 2949, 2911, 2843, 2232, 1723, 1659, 1481, 1439 cm^{-1}; ^{1}H NMR δ 2.42−2.55 (4H, m), 3.71 (3H, s), 3.90 (2H, s), 5.90 (1H, dt, J = 15.6, 1.5 Hz), 7.03 (1H, dt, J = 15.6, 6.6 Hz), 7.16−7.24 (3H, m), 7.27−7.36 (4H, m), 7.48−7.53 (2H, m); ^{13}C NMR δ 166.8, 147.1, 135.5, 131.9, 131.8, 130.0, 128.9, 127.8, 127.4, 126.7, 126.0, 125.3, 121.9, 92.4, 88.9, 82.4, 80.2, 51.4, 31.3, 23.7, 18.5; HRMS (EI) calcd for $C_{23}H_{20}O_2S$ (M^+) 360.1184, found 360.1189.

m-Chloroperbenzoic acid (0.126 g, 0.73 mmol) was dissolved in 10 mL of dichloromethane, and the solution was cooled to 0 °C. To this mixture was added *via* syringe a solution of methyl (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-ynoate (0.120 g, 0.33 mmol), and the reaction was stirred for 1 h at 0 °C. Then the solution was passed through a short Florisil column with dichloromethane. The crude product was purified by radial chromatography with an 80:20 mixture of hexanes/ethyl acetate to afford 0.110 g (84%) of **84** as a pale yellow oil: TLC R_f 0.52 (1:1 hexanes/ethyl acetate); IR (neat) ν 3065, 2953, 2911, 2851, 2255, 1721, 1659, 1325, 1163 cm^{-1}; ^{1}H NMR δ 2.47 (2H, m), 2.55−2.60 (2H, m), 3.72 (3H, s), 4.27 (2H, s), 5.91 (1H, dt, J = 15.6, 1.6 Hz), 7.03 (1H, dt, J = 15.6, 6.6 Hz), 7.15−7.29 (3H, m), 7.36 (1H, m), 7.52−7.58 (2H, m), 7.66 (1H, m), 8.02−8.06 (2H, m); ^{13}C NMR δ 166.8, 147.1, 137.9, 134.0, 132.1, 132.0, 129.0, 129.0, 128.6, 127.4, 126.4, 124.0, 121.9, 93.0, 86.3, 80.2, 79.8, 51.5, 49.5, 31.1, 18.5; HRMS (EI) calcd for $C_{23}H_{20}O_4S$ (M^+) 392.1082, found 392.1101.

Preparation of Methyl (*E*)-7-[2-[3-(Phenylsulfonyl)-1-propynyl]phenyl]-3-methylhept-2-en-6-ynoate (85). 5-[2-[3-(Phenylthio)-1-propynyl]phenyl]-4-pentynal (**83**) (0.150 g, 0.49 mmol) was subjected to Horner−Emmons reaction conditions similar to those used in the preparation of **84** using trimethyl methylphosphonoacetate (0.145 g, 0.74 mmol), acetonitrile (4 mL), lithium chloride (0.042 g, 0.99 mmol), and DBU (0.111 mL, 0.113 g, 0.74 mmol). Purification afforded 0.114 g (62%) of the *E* isomer of methyl (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]-3-methylhept-2-en-6-ynoate (next to 0.039 g [21%] of the corresponding *Z* isomer) as a pale yellow oil: TLC R_f 0.40 (3:1 hexanes/ethyl acetate); IR (neat) ν 3059, 3000, 2950, 2839, 2231, 1717, 1653, 1481, 1437 cm^{-1}; ^{1}H NMR δ 1.86 (3H, d, J = 1.5 Hz), 2.42−2.55 (4H, m), 3.73 (3H, s), 3.89 (2H, s), 6.83 (1H, m), 7.15−7.26 (3H, m), 7.28−7.38 (4H, m), 7.50−7.54 (2H, m); ^{13}C NMR δ 168.4, 140.1, 135.5, 131.9, 131.8, 130.0, 128.9, 128.7, 127.8, 127.3, 126.7, 126.1, 125.3, 93.0, 88.9, 82.4, 79.8, 51.8, 28.1, 23.8, 18.9, 12.6; HRMS (EI) calcd for $C_{24}H_{22}O_2S$ (M^+) 374.1341, found 374.1328.

The sulfone was prepared by an *m*-CPBA oxidation similar to that used for the preparation of **84** using *m*-chloroperbenzoic acid (0.096 g, 0.56 mmol), dichloromethane (10 mL), and methyl (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]-3-methylhept-2-en-6-ynoate (0.095 g, 0.25 mmol) to afford 0.073 g (71%) of **85** as a pale yellow oil: TLC R_f 0.57 (1:2 hexanes/ethyl acetate); IR (neat) ν 3065, 2996, 2951, 2907, 2843, 2255, 1711, 1649, 1325, 1138 cm^{-1}; ^{1}H NMR δ 1.84 (3H, d, J = 1.5 Hz), 2.45 (2H, m), 2.53−2.58 (2H, m), 3.72 (3H, s), 4.24 (2H, s), 6.82 (1H, tq, J = 7.3, 1.5 Hz), 7.15−7.28 (3H, m), 7.34−7.42 (1H, m), 7.51−7.58 (2H, m), 7.65 (1H, m), 8.02−8.07 (2H, m); ^{13}C NMR δ 168.5, 140.2, 137.9, 134.1, 133.7, 132.1, 132.0, 130.2, 129.8, 129.0, 128.8, 128.6, 128.2, 127.4, 126.5, 124.0, 93.6, 86.3, 80.1, 79.4, 51.8, 49.5, 27.8, 18.9, 12.6; HRMS (EI) calcd for $C_{24}H_{22}O_4S$ (M^+) 406.1239, found 406.1243.

Preparation of (*E*)-7-[2-[3-(Phenylsulfonyl)-1-propynyl]phenyl]hept-2-en-6-ynenitrile/(*Z*)-7-[2-(3-(Phenylsulfonyl)-1-propynyl)phenyl]hept-2-en-6-ynenitrile (86). Potassium *tert*-butoxide (0.106 g, 0.95 mmol) was dissolved in 10 mL of THF. To this solution was added diethyl (cyanomethyl)phosphonate (0.163 mL, 0.178 g, 1.01 mmol) under nitrogen, and the reaction mixture was stirred at room temperature for 30 min. Then a solution of 5-[2-[3-(phenylthio)-1-propynyl]phenyl]-4-pentynal (**83**) (0.180 g, 0.59 mmol) in 3 mL of THF was added *via* syringe and the reaction stirred for 1 min. The solvent was removed *in vacuo*, and the residue was passed through a short silica gel column with a 2:1 mixture of ethyl acetate/hexanes. Purification of the crude product by radial chromatography with a 96:4 mixture of hexanes/ethyl acetate afforded 0.147 g (76%) of (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-ynenitrile/(*Z*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-ynenitrile as a pale yellow oil (3:2 mixture of *cis*/*trans* isomers): TLC R_f 0.37 (3:1 hexanes/ethyl acetate); IR (neat) ν 3061, 2951, 2922, 2222, 1624, 1584, 1481, 1441 cm^{-1}; ^{1}H NMR *cis* isomer δ 2.40−2.57 (3H, m), 2.63−2.70 (1H, m), 3.88 (2H, s), 5.36 (1H, dt, J = 11.0, 1.2 Hz), 6.66 (1H, dt, J = 11.0, 7.6 Hz), 7.18−7.25 (3H, m), 7.28−7.38 (4H, m), 7.48−7.53 (2H, m); *trans* isomer δ 2.40−2.57 (3H, m), 2.63−2.70 (1H, m), 3.90 (2H, s), 5.41 (1H, dt, J = 16.4, 1.5 Hz), 6.78 (1H, dt, J = 16.4, 6.6 Hz), 7.18−7.25 (3H, m), 7.28−7.38 (4H, m), 7.48−7.53 (2H, m); ^{13}C NMR *cis* isomer δ 152.9, 135.4, 132.0, 131.8, 129.9, 128.9, 127.9, 127.5, 126.8, 125.7, 125.2, 117.3, 100.6, 91.5, 88.8, 82.4, 80.7, 30.6, 23.8, 18.6; *trans* isomer δ 153.5, 135.4, 132.0, 131.7, 129.9, 128.9, 127.9, 127.6, 126.7, 125.6, 125.2, 115.8, 101.0, 91.3, 88.9, 82.4, 80.8, 32.1, 23.8, 18.1; HRMS (EI) calcd for $C_{22}H_{17}NS$ (M^+) 327.1084, found 360.1083.

The sulfone was prepared by an *m*-CPBA oxidation similar to that used for the preparation of **84** using *m*-chloroperbenzoic acid (0.139 g, 0.81 mmol), dichloromethane (10 mL), (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-ynenitrile, and (*Z*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-ynenitrile (0.120 g, 0.37 mmol). The solution was passed through a short Florisil column with a 1:1 mixture of hexanes/ethyl acetate. The crude product was purified by radial chromatography with an 80:20 mixture of hexanes/ethyl acetate to afford 0.111 g (84%) of **86** as a pale yellow oil (3:2 mixture of *cis*/*trans* isomers): TLC R_f 0.52 (1:1 hexanes/ethyl acetate); IR (neat) ν 3065, 2951, 2909, 2843, 2224, 1634, 1586, 1323, 1163 cm^{-1}; ^{1}H NMR *cis* isomer δ 2.46−2.54 (1H, m), 2.59−2.72 (3H, m), 4.22 (2H, s), 5.40 (1H, dt, J = 11.0, 1.2 Hz), 6.65 (1H, dt, J = 11.0, 7.3 Hz), 7.15−7.28 (3H, m), 7.35−7.39 (1H, m), 7.51−7.57 (2H, m), 7.62−7.68 (1H, m), 8.01−8.05 (2H, m); *trans* isomer δ 2.59−2.72 (4H, m), 4.23 (2H, s), 5.46 (1H, dt, J = 16.4, 1.5 Hz), 6.80 (1H, dt, J = 16.4, 6.6 Hz), 7.15−7.28 (3H, m), 7.35−7.39 (1H, m), 7.51−7.57 (2H, m), 7.62−7.68 (1H, m), 8.01−8.05 (2H, m); ^{13}C NMR *cis* isomer δ 152.8, 137.8, 134.1, 132.1, 132.0, 129.0, 128.8, 128.7, 127.5, 126.1, 123.9, 117.4, 100.7, 92.2, 86.3, 80.1, 80.0, 49.5, 30.6, 18.6; *trans* isomer δ 153.7, 137.8, 134.1, 132.1, 131.9, 129.0, 128.8, 128.7, 127.6, 126.0, 124.0, 115.8, 101.0, 92.1, 86.3, 80.3, 80.0, 49.5, 31.9, 18.2; HRMS (EI) calcd for $C_{22}H_{17}NO_2S$ (M^+) 359.0980, found 359.0955.

Preparation of (*E*)-7-[2-[3-(Phenylsulfonyl)-1-propynyl]phenyl]hept-2-en-6-yn-1-ol (87). Methyl (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-ynoate (0.186 g, 0.52 mmol) was dissolved in 15 mL of dichloromethane, and the solution was cooled to 0 °C. Then a 1 M solution of diisobutylaluminum hydride in *n*-hexane (1.290 mL, 0.183 g, 1.29 mmol) was slowly added *via* syringe and the reaction mixture was stirred for 30 min at 0 °C. Next, 1 mL of a concentrated aqueous potassium fluoride solution was added and the biphasic mixture was stirred for an additional 10 min. After the aqueous layer was extracted several times with dichloromethane, the organic layers were combined and dried over magnesium sulfate. Purification of the crude product by radial chromatography with a 70:30 mixture of hexanes/diethyl ether afforded 0.124 g (72%) of (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-yn-1-ol as a pale yellow oil: TLC R_f 0.32 (2:1 hexanes/ethyl acetate); IR (neat) ν 3385 (br), 3059, 2924, 2868, 2232, 1584, 1481, 1441 cm^{-1}; ^{1}H NMR δ 1.45 (1H, s, br), 2.29−2.36 (2H, m), 2.44−2.49 (2H, m), 3.88 (2H, s), 4.08 (2H, d, br), 5.66−5.85 (2H, m), 7.18 (2H, m), 7.19−7.24 (1H, m), 7.28−7.37 (4H, m), 7.49−7.53 (2H, m); ^{13}C NMR δ 135.4, 132.0, 131.8, 130.9, 130.3, 130.1, 128.9, 127.8, 127.2, 126.8, 126.3, 125.2, 93.6, 88.7, 82.5, 79.7, 63.5, 31.4, 23.9, 19.6; HRMS (EI) calcd for $C_{22}H_{20}OS$ (M^+) 332.1235, found 332.1263.

This compound was prepared by an *m*-CPBA oxidation similar to that used for the preparation of **84** using *m*-chloroperbenzoic acid (0.126 g, 0.73 mmol), dichloromethane (10 mL), and (*E*)-7-[2-[3-(phenylthio)-1-propynyl]phenyl]hept-2-en-6-yn-1-ol (0.110 g, 0.33 mmol). The solution was passed through a short Florisil column with a 3:1 mixture of ethyl acetate/hexanes. The crude product was purified by radial chromatography with a 65:35 mixture of hexanes/ethyl acetate to afford 0.055 g (46%) of **87** as a pale yellow oil: TLC R_f 0.47 (1:2 hexanes/ethyl acetate); IR (neat) ν 3405 (br), 3063, 2953, 2926, 2870, 2243, 1586, 1325, 1138 cm^{-1}; ^{1}H NMR δ 1.74 (1H, s, br), 2.28−2.34 (2H, m), 2.47−2.52 (2H, m), 4.09 (2H, s), 4.23 (2H, s), 5.67 (2H, m), 7.14−7.27 (3H, m), 7.34−7.37 (1H, m), 7.52−7.58 (2H, m), 7.63−7.69 (1H, m), 8.02−8.06 (2H, m); ^{13}C NMR δ 137.8, 134.1, 132.1, 132.0, 130.5, 130.4, 129.0, 129.0, 128.6, 127.3, 126.7, 123.9, 94.3, 86.5, 79.9, 79.3, 63.4, 49.6, 31.2, 19.6; HRMS (EI) calcd for $C_{22}H_{20}O_3S$ (M^+) 364.1133, found 364.1133.

Preparation of *N*-(Phenylmethoxy)-5-[2-[3-(phenylsulfonyl)-1-propynyl]phenyl]pent-4-yn-1-imine (88). To a solution of 5-[2-[3-(phenylthio)-1-propynyl]phenyl]-4-pentynal (**83**) (0.200 g, 0.66 mmol) in 5 mL of dichloromethane were added *O*-benzylhydroxylamine hydrochloride (0.147 g, 0.92 mmol) and pyridine (0.074 mL, 0.073 g, 0.92 mmol), and the reaction mixture was stirred at room temperature for 30 min. Then the heterogeneous mixture was passed through a Florisil column with dichloromethane. Purification of the crude product by radial chromatography with a 90:10 mixture of hexanes/ethyl acetate afforded 0.253 g (94%) of *N*-(phenylmethoxy)-5-[2-[3-(phenylthio)-1-propynyl]phenyl]pent-4-yn-1-imine as a pale yellow oil (1:1 mixture of *syn*/*anti* isomers): TLC R_f 0.52 (2:1 hexanes/ethyl acetate); IR (neat) ν 3063, 3032, 2918, 2875, 2242, 1480, 1439 cm^{-1}; ^{1}H NMR δ 2.43−2.68 (4H, m), 3.86 (1H, s), 3.88 (1H, s), 5.06 (1H, s), 5.11 (1H, s), 6.90 ($^1/_2$H, t, J = 4.9 Hz), 7.17−7.24 (3H, m), 7.27−7.37 (9H, m), 7.48−7.52 (2H, m), 7.64 ($^1/_2$H, t, J = 5.7 Hz); ^{13}C NMR δ 150.4, 149.8, 137.9, 137.5, 135.4, 132.0, 131.9, 131.7, 131.7, 130.1, 130.0, 128.9, 128.3, 128.2, 127.9, 127.8, 127.7, 127.4, 127.4, 126.7, 126.0, 125.4, 125.3, 92.4, 92.2, 89.0, 88.9, 82.4, 82.3, 80.3, 80.3, 75.8, 75.6, 28.8, 25.1, 23.7, 23.7, 17.4, 16.6; HRMS (EI) calcd for $C_{27}H_{23}NOS$ (M^+) 409.1500, found 409.1506.

This compound was prepared by an *m*-CPBA oxidation similar to that used for the preparation of **86** using *m*-chloroperbenzoic acid (0.232 g, 1.34 mmol), dichloromethane (17 mL), and *N*-(phenylmethoxy)-5-[2-[3-(phenylthio)-1-propynyl]-phenyl]pent-4-yn-1-imine (0.250 g, 0.61 mmol) to afford 0.183 g (68%) of **88** as a pale yellow oil (1:1 mixture of *syn*/*anti* isomers): TLC R_f 0.52 (1:1 hexanes/ethyl acetate); IR (neat) ν 3061, 3028, 2940, 2907, 2232, 1325, 1138 cm^{-1}; ^{1}H NMR δ 2.38−2.45 (1H, m), 2.55−2.60 (3H, m), 4.18 (1H, s), 4.22 (1H, s), 5.05 (1H, s), 5.10 (1H, s), 6.82 ($^1/_2$H, t, J = 4.9 Hz), 7.17−7.35 (9H, m), 7.49−7.65 (3H, m), 7.56 ($^1/_2$H, t, J = 5.9 Hz), 7.98−8.03 (2H, m); ^{13}C NMR δ 150.4, 149.7, 137.8, 137.8, 137.4, 134.0, 132.1, 132.1, 131.8, 131.7, 129.0, 128.9, 128.9, 128.6, 128.4, 128.2, 127.9, 127.8, 127.7, 127.4, 127.4, 126.3, 124.1,

124.1, 93.0, 92.7, 86.3, 86.2, 80.3, 80.2, 79.9, 79.9, 75.8, 75.6, 49.4, 49.4, 28.5, 24.9, 17.4, 16.6; HRMS (EI) calcd for $C_{27}H_{23}NO_3S$ (M^+) 441.1399, found 441.1389.

General Procedure for the Tandem Enyne Allene−Radical Cyclization of the Enediyne Sulfones 84−88. A stirred solution of the respective enediyne sulfone (approximately 0.2 mmol) in anhydrous benzene (5.35 mL) in a pressure vial was degassed with dry nitrogen for 30 min. Then triethylamine (5.0 equiv) and 1,4-CHD (2.649 mL, 2.244 g, 28.00 mmol, $c = 3.5$ M) were added *via* syringe and the vial was sealed with a Teflon screw cap. The reaction mixture was heated at 37 °C for 16 h. The volatile components were removed *in vacuo*, and the residue was passed through a short silica gel column with a 1:1 (1:3 for **92**) mixture of hexanes/ethyl acetate. Products **89**−**93** were obtained after the respective crude product was subjected to radial chromatography with an 85:15 (65:35 for **92**) mixture of hexanes/ethyl acetate.

Tandem Enyne Allene−Radical Cyclization of Methyl (*E*)-7-[2-[3-(Phenylsulfonyl)-1-propynyl]phenyl]hept-2-en-6-ynoate (84). The reaction was performed according to the general procedure for the tandem enyne allene−radical cyclization using **84** (0.070 g, 0.18 mmol) and triethylamine (0.124 mL, 0.090 g, 0.89 mmol) to provide 0.0535 g (76%) of methyl 2,3-dihydro-4-[(phenylsulfonyl)methyl]-1*H*-benz[*e*]indene-1-acetate (**89**) as a yellow oil: TLC R_f 0.52 (1:1 hexanes/ethyl acetate); IR (neat) ν 3057, 2947, 1730, 1319, 1152 cm^{-1}; ^1H NMR δ 1.94 (1H, m), 2.16 (1H, m), 2.21 (1H, dd, $J = 15.4$, 11.0 Hz), 2.61−2.70 (3H, m), 3.69 (3H, s), 4.06 (1H, ddd, $J = 11.1$, 8.0, 3.2 Hz), 4.44 (2H, s), 7.37−7.44 (3H, m), 7.50 (1H, m), 7.51 (1H, s), 7.57−7.63 (3H, m), 7.77 (2H, t, $J = 8.5$ Hz); ^{13}C NMR δ 173.0, 141.8, 140.9, 138.1, 133.8, 132.9, 130.7, 129.3, 128.9, 128.9, 128.8, 127.0, 125.4, 123.5, 122.7, 60.8, 51.7, 40.5, 38.3, 30.6, 29.6; HRMS (EI) calcd for $C_{23}H_{22}O_4S$ (M^+) 394.1239, found 394.1244.

Tandem Enyne Allene−Radical Cyclization of Methyl (*E*)-7-[2-[3-(phenylsulfonyl)-1-propynyl]phenyl]-3-methylhept-2-en-6-ynoate (85). The reaction was performed according to the general procedure for the tandem enyne allene−radical cyclization using **85** (0.077 g, 0.19 mmol) and triethylamine (0.132 mL, 0.096 g, 0.95 mmol) to provide 0.060 g (78%) of methyl 2,3-dihydro-α-methyl-4-[(phenylsulfonyl)-methyl]-1*H*-benz[*e*]indene-1-acetate (**90**) as a yellow oil (3.5:1 mixture of diastereomers): TLC R_f 0.57 (1:2 hexanes/ethyl acetate); IR (neat) ν 3063, 2951, 2854, 1727, 1318, 1154 cm^{-1}; ^1H NMR major diastereoisomer d 1.13 (3H, d, $J = 7.1$ Hz), 2.05−2.16 (2H, m), 2.58−2.85 (3H, m), 3.53 (3H, s), 3.88 (1H, m), 4.43 (2H, s), 7.36−7.44 (3H, m), 7.48 (1H, ddd, $J = 8.3$, 6.8, 1.5 Hz), 7.55−7.63 (4H, m), 7.70 (1H, d, $J = 8.1$ Hz), 7.80 (1H, d, $J = 8.4$ Hz); ^1H NMR minor diastereoisomer δ 0.68 (3H, d, $J = 7.1$ Hz), 2.05−2.16 (2H, m), 2.58−2.85 (2H, m), 3.09 (1H, m), 3.68 (3H, s), 4.20 (1H, m), 4.45 (2H, s), 7.36−7.44 (3H, m), 7.51 (1H, s), 7.55 (1H, m), 7.55−7.63 (3H, m), 7.75 (1H, d, $J = 8.1$ Hz), 7.84 (1H, d, $J = 8.4$ Hz); ^{13}C NMR (major diastereoisomer) δ 176.1, 141.9, 141.4, 138.1, 133.7, 132.7, 130.7, 130.6, 128.9, 128.7, 128.7, 126.6, 125.2, 125.0, 122.6, 60.7, 51.7, 47.1, 43.3, 30.3, 29.7, 16.8; HRMS (EI) calcd for $C_{24}H_{24}O_4S$ (M^+) 408.1396, found 408.1387.

Tandem Enyne Allene−Radical Cyclization of (*E*)-7-[2-[3-(Phenylsulfonyl)-1-propynyl]phenyl]hept-2-en-6-ynenitrile/(*Z*)-7-[2-(3-(Phenylsulfonyl)-1-propynyl)phenyl]-hept-2-en-6-ynenitrile (86). The reaction was performed according to the general procedure for the tandem enyne allene−radical cyclization using **86** (0.075 g, 0.21 mmol) and triethylamine (0.145 mL, 0.106 g, 1.04 mmol) to provide 0.055 g (72%) of 2,3-dihydro-4-[(phenylsulfonyl)methyl]-1*H*-benz[*e*]-indene-1-acetonitrile (**91**) as a colorless solid: TLC R_f 0.47 (1:1 hexanes/ethyl acetate); IR (Nujol) ν 3061, 2945, 2872, 2253, 1319, 1154 cm^{-1}; ^1H NMR δ 2.17 (1H, m), 2.26−2.40 (1H, m), 2.34 (1H, dd, $J = 16.9$, 9.7 Hz), 2.72 (1H, dd, $J = 16.9$, 3.7 Hz), 2.77−2.87 (2H, m), 3.99 (1H, m), 4.43 (1H, A of AB q, $J = 13.9$ Hz), 4.45 (1H, B of AB q, $J = 13.9$ Hz), 7.39−7.47 (3H, m), 7.51 (1H, s), 7.54 (1H, m), 7.62 (1H, m), 7.61−7.64 (2H, m), 7.71 (1H, d, $J = 8.8$ Hz), 7.76 (1H, d, $J = 8.1$ Hz); ^{13}C NMR δ 141.3, 139.5, 138.1, 133.9, 133.0, 131.7, 129.2, 129.1, 129.0, 128.7, 127.5, 125.7, 123.0, 122.7, 118.9, 60.7, 40.8, 30.4, 29.8, 22.2; HRMS (EI) calcd for $C_{22}H_{19}NO_2S$ (M^+) 361.1137, found 361.1137.

Tandem Enyne Allene−Radical Cyclization of (*E*)-7-[2-[3-(Phenylsulfonyl)-1-propynyl]phenyl]hept-2-en-6-yn-1-ol (87). The reaction was performed according to the general procedure for the tandem enyne allene−radical cyclization using **87** (0.069 g, 0.19 mmol) and triethylamine (0.132 mL, 0.096 g, 0.95 mmol) to provide 0.047 g (68%) of 2,3-dihydro-4-[(phenylsulfonyl)methyl]-1*H*-benz[*e*]indene-1-ethanol (**92**) as a yellow oil: TLC R_f 0.37 (1:2 hexanes/ethyl acetate); IR (neat) ν 3420 (br), 3061, 2932, 2886, 1308, 1152 cm^{-1}; ^1H NMR δ 1.49 (1H, s, br), 1.59 (1H, m), 1.87−1.98 (2H, m), 2.04−2.17 (1H, m), 2.65 (2H, dd, $J = 9.8$, 4.5 Hz), 3.72 (2H, dd, $J = 7.5$, 5.7 Hz), 3.77 (1H, m), 4.45 (2H, s), 7.36−7.42 (3H, m), 7.45−7.51 (1H, m), 7.47 (1H, s), 7.55−7.61 (3H, m), 7.73 (1H, d, $J = 8.1$ Hz), 7.83 (1H, d, $J = 8.3$ Hz); ^{13}C NMR δ 143.6, 140.6, 138.1, 133.7, 132.9, 130.2, 129.7, 128.9, 128.8, 126.7, 125.3, 124.0, 122.6, 61.6, 60.8, 40.3, 36.9, 30.2, 30.1; HRMS (EI) calcd for $C_{22}H_{22}O_3S$ (M^+) 366.1290, found 366.1312.

Tandem Enyne Allene−Radical Cyclization of *N*-(Phenylmethoxy)-5-[2-[3-(phenylsulfonyl)-1-propynyl]-phenyl]pent-4-yn-1-imine (88). The reaction was performed according to the general procedure for the tandem enyne allene−radical cyclization using **88** (0.081 g, 0.18 mmol) and triethylamine (0.128 mL, 0.093 g, 0.92 mmol) to provide 0.058 g (71%) of 2,3-dihydro-*N*-(phenylmethoxy)-4-[(phenylsulfonyl)-methyl]-1*H*-benz[*e*]inden-1-amine (**93**) as a pale yellow oil: TLC R_f 0.47 (1:1 hexanes/ethyl acetate); IR (neat) ν 3258, 3063, 3032, 2928, 2859, 1317, 1152 cm^{-1}; ^1H NMR δ 2.04−2.17 (1H, m), 2.26−2.33 (1H, m), 2.58−2.66 (1H, m), 2.72−2.83 (1H, m), 4.40 (1H, A of AB q, $J = 14.0$ Hz), 4.44 (1H, B of AB q, $J = 14.0$ Hz), 4.61 (1H, A of AB q, $J = 11.6$ Hz), 4.64 (1H, B of AB q, $J = 11.6$ Hz), 5.00 (1H, d, $J = 6.6$ Hz), 5.45 (1H, s, br), 7.28−7.43 (8H, m), 7.47 (1H, ddd, $J = 8.3$, 6.8, 1.2 Hz), 7.51 (1H, s), 7.54−7.59 (3H, m), 7.71 (1H, d, $J = 8.4$ Hz), 7.88 (1H, d, $J = 8.3$ Hz); ^{13}C NMR δ 143.2, 138.0, 138.0, 136.9, 133.8, 132.8, 132.0, 130.5, 128.9, 128.8, 128.6, 128.5, 128.3, 127.8, 127.1, 125.5, 124.2, 122.7, 65.3, 60.6, 29.8, 29.6; HRMS (EI) calcd for $C_{27}H_{25}NO_3S$ (M^+) 443.1555, found 443.1552.

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Supporting Information Available: NMR spectra of all new compounds (89 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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